SEISMIC PROSPECTION FOR OIL IN POLAND

VOLUME 1

Stanislaw M. Wyrobek

A Thesis Submitted for the Degree of PhD
at the
University of St Andrews

2023

http://hdl.handle.net/10023/27756

SEISMIC EXPLORATION FOR OIL IN POLAND

VOLUME I.

SEISMIC PROSPECTION FOR OIL
IN POLAND

Being a Thesis presented by

STANISŁAW M. WYROBEK, Dipl.Min.Eng., Dipl.Geoph.Eng.,

TO THE UNIVERSITY OF ST ANDREWS

in application for the

DEGREE of PH.D.

CERTIFICATE

I certify that Stanisław M. Wyrobek has spent ten terms at Research Work in the Department of Geology, University of St Andrews, that he has fulfilled the conditions of Ordinance No 16,/St Andrews/, and that he is qualified to submit the accompanying Thesis in application for the degree of Ph.D.

DECLARATION

I hereby declare that the following Thesis is based on the results of investigation carried out by me, that the Thesis is my own composition and that it has not previously been presented for a Higher Degree.

The research was done in years 1941 to 1945 in the Department of Geology, University of St Andrews, based upon the investigations carried out in terrain in Poland during the years 1932 to 1939.

CAREER

I matriculated in the Academy of Mines of Cracow, Poland, in October, 1921 and followed a course in Applied Science until July, 1927. On presentation of a geological Thesis I was awarded the degree of Dipl.Min.Eng. in 1929.

In October, 1936 I matriculated in the University of Strassbourg, France, where I followed a course of Pure and Applied Geophysics. In July, 1937 I was granted the degree of Dipl.Geoph.Eng.

The remaining time from 1931 to 1939, I was employed in geophysical prospection in Poland.

In October, 1941 I commenced research work in the Department of Geology, the University of St Andrews, the results of which are now being submitted as a Ph.D.Thesis.

January, 1945.

GENERAL CONTENTS

Page

INTRODUCTION 1

PART I. REFRACTION PROSPECTING

Detailed Contents of the Part I. 20
CHAPTER I. General Data 21
CHAPTER II. The Refraction Outfit of Mintrop 37
CHAPTER III. Influence of the Explosion 68
CHAPTER IV. Analyses of the Prospecting 93

PART II. REFLECTION METHOD

Detailed Contents of the Part II. 139
CHAPTER V. The 6-Geophone Set of Seiscor 141
CHAPTER VI. The 6-Geophone Set of Heiland 173
CHAPTER VII. The Distribution of Seismic Energy 177
CHAPTER VIII. Reflection Seismogram 223

PART III. SEISMIC EXPLORATION BY REFLECTION METHOD

Detailed Contents of the Part III 0
CHAPTER IX. Some notes on the Geology 1
CHAPTER X. Exploration of the Carpathian Strata 17
CHAPTER XI. Prospecting along the Stryj-Lwow Rd 51
CHAPTER XII. " within the Contact Zone 79
CHAPTER XIII. " in the Kosow Area 87
CHAPTER XIV. " in the Daszawa Area 111
CHAPTER XV. " of Stratigraphic Beds 136

INTRODUCTION

Poland, which in its central and northern parts is an open plain bounded on the south by the Carpathians and on the north by the Baltic Sea, is not an easy terrain for geological exploration unless examined by much deeper boring than has hitherto been attempted. With the exception of the Carpathians, the Saint Cross mountain region north east of Cracow, and a part of Volhynia the older rocks are covered by a monotonous series of Mezozoics and Kenozoics, and these in turn by a series of Diluvial formation, the latter extending in some places to 700 feet in depth. Geologists in their exploration have met many natural exposures in these parts, but they are not sufficient to disclose the structural and lithological conditions of the subsurface.

The partitioners of Poland, up to 1918, did not endeavour to undertake research in these deeper parts, not even on a fraction of the scale done in their own countries, but from time to time one of the foreign firms would begin to bore here and there for commercial purposes without very much systematic planning.

The Oil Industry under Austrian occupation in the east of Poland was partly in the hands of Franco-Austrian capital and partly in the hands of Swedish-American capital and the principal exertion was expended on the exploitation of the better known districts in the Carpathians. Many of the Austrian and Polish geologists contented themselves with the supposition that every convexity of the terrain in the northern fringe of the Carpathians was likely to be a new folding, analogous to that existing in the Boryslaw area. A considerable number of oil refineries - 14 to be precise - were built between 1909 and 1910, to enable the refining of oil, which was to be exploited both in the Boryslaw area and also in the areas where the existence of oil was only suspected.

When the output of petroleum from the Boryslaw area, which in 1909 had reached 2 million metric tons, fell in 1911 to 1 million, some firms undertook borings in new areas which were supposed to yield oil and were met with discouraging results. That condition compelled the Austrian government to close the greater number of the refineries and limit exploitation to the Boryslaw area, to some other wells further in the south-east /Bitkow/, and to several others in the western Carpathians.

In the north-west part of Poland, which was under German occupation geological work was carried out more carefully, but as the Germans were forced to leave Poland in 1918, they took with them almost all their results except those covering Silesia. Even the topographical maps were found to be missing.

The north-east part, occupied by Russians, was the most neglected; in the geological sense there was almost nothing done.

During the Great War, when the tempest of war swept across her territories, Poland was on four occasions a battlefield. From East to West, and from West to East, between 1914 and 1920, the Russian, Austrian, German, Bolshevic, and finally Polish armies fought their way over Polish terrain. That war liberated Poland from her century old bondage, but she emerged from it maimed in almost every department, and therefore it is easy to understand that the geological institutes created at that time had before them a very great task in partly recreating and partly resuming the investigations so much neglected during the past years.

Although the writer has no intention of describing here from a geological point of view, the particular activities of these institutes yet it seems worth mentioning that the Geological Institute of Warsaw was in charge of the Geological Survey of Poland. It was the head office and comprised the Coal, Salt and Ore Departments, with two provisional branches in the Carpathians, one in Boryslaw for the south-east Oil District of

Poland and the second at Jaslo for the south-west part. This division into two Carpathian Geological Surveys was due to the distances between the Oil Regions and to the entirely different geological conditions of oil occurrences in the Eastern and Western areas of southern Poland.

The task which those Institutes had before them, first of all, was to collect all attainable and available materials and to complete them to such an extent as to be able to accomplish the fundamental geological maps first for the Carpathians and their foreland being the most important from a commercial point of view.

The coal-basins of Silesia, of the Cracow, and Dombrowa districts, as well as the salt layers in Wieliczka and Bochnia (East of Cracow), did not present so much difficulty, as they were not touched or damaged by the Great War. On the other hand the terrain on the south-west of Poland, being under Austrian occupation, possessed a well developed geological outpost in the University of Cracow staffed with Polish personnel.

The same was true of the University of Lwow which possessed a separate Petroleum Department, which, however, could not afford to undertake borings independent of industry, which kept its results secret, not allowing them to be published or collected for scientific purposes.

For these reasons, in geological research of the oil-industrial areas, there was a great lack of petrography, maps and samples. The Eastern area, which suffered many different occupations during the war, was in a still worse position than the west. For instance, in the Boryslaw district, where the number of wells was about a thousand, a small percentage of them scarcely possessed passable samples from the borings. The rest were either destroyed or, owing to the careless administration of the Austrians and Russians between 1908 and 1919, few samples were taken from the wells or else many had had a very problematical value. Such conditions did not allow the first geological maps from those districts to be published earlier than in the years 1930-1933.

As has been stated above there was, strictly speaking, no research boring in Poland. When the new wells were sunk, they were sunk in a terrain well enough known before and had for their purpose the increasing of oil production. At this point it is woth while mentioning that from 1907-1924 oil from Poland was continually being sent abroad and the proprietors of the firms in question (chiefly Austrians or French) built for themselves, both before and during the Great War, palaces in Vienna and Trieste. Even after the war, up to 1930, several factories were erected in Austria with profits from Poland's petroleum. In contrast, Boryslaw and Tustanowice, which during that period alone yielded 10 million tons of oil, possessed a few better looking brick houses, while the remainder, several thousand in number, consisted of old wooden or stone bothies either separated from or attached to the oil wells which were scattered through this "industrial" area with its proverbial muddy roads.

Only in 1924, after the inflation and devaluation of the Polish mark, which had reached the billionth figure, was the stabilisation of the new Polish monetary units, "zloty", settled and the stabilisation of the Polish Oil Industry at last began.

By this time this stabilisation had become urgent since during the former period of time up to 1924, the total oil production in Poland had been on a steady decrease and despite the new wells sunk in the oil areas, the output in 1924 was only one third of that in 1909. As a result more than half of the wells in the Boryslaw area alone closed, either because they had been exhausted or were not worth while working.

This steady decline in the production of crude oil caused more attention to be paid to prospecting for new reserves in areas which during many years had not been taken into consideration from the geological point of view.

The first Polish Oil company "Polmin", with the main purpose of refining oil products was established. Another company called "Pioneer" was founded in 1926.

Its capital, half of which was derived from the Government and half from all the oil companies in Poland, was set aside to be used for research and the exploration of all the bitumen layers in the new regions which up to that time were unknown.

Four deep research borings conducted by this company in four different places in the Carpathians, did not yield the results which had been expected, but in fact seriously impaired the stock of the company. The Carpathian terrain was full of surprises and was very difficult to drill. The geological forecasts were said to be good, but, one boring, undertaken in order to prove the truth of the geological assumption, was not sufficient in areas with very variable structures even depths exceeding 6000 feet.

The results obtained in the Rumanian Oil Fields which were always supposed to be an extension of the East Polish Carpathians, gave the Polish geologists reason to expect new oil fields in the flat terrain of the Sub-Carpathian region. There the geological premises were very uncertain and consequently the number of borings necessary for a deep exploration should have been greater. For such a purpose the Company should have had much greater capital than was in its possession, or should have applied other methods of research which, while assuring good results, would at the same time have been much cheaper to apply than the deeper, expensive borings.

During the Great War, by means of small field seismographs, the Allies as well as the Germans located the positions of their respective artillery batteries by using 'sound waves' as well as 'grouned waves' in the same general way as the epicentrum of an earthquake is located by several seismological stations spread over the world. During these tests they realised that when using 'ground waves', the most important factor upon which the distance between the artillery positions and the seismograph depended, was the nature of the ground through which these artificially produced waves passed.

After the War Professor Mintrop from the Seismological Institute in Wroclaw (Breslau) patented a new geophysical method of research. German firms undertook research by this method in Germany and abroad, but greater success was reached in the U.S.A. between 1924 and 1926 in the huge flat regions of Louisiana and Texas; here a great number of Salt domes were located, and, in conjunction with them, new petroleum deposits. In 1926 all these field works and geophysical researches were taken over by the Americans themselves.

In a short time all the bigger Oil Companies in the U.S.A. possessed for this seismic field work, their own staff as well as equipment, which differed in details but kep the same principle, The method used by them was given the name of "the seismic method of refraction" based on the refraction of the elastic waves on the boundaries of two lithologically different geological layers. The lack of sufficient exposures to determine the subsurface structure over large areas also led to the use of several other geophysical methods for location not only of the salt domes, but also for the prospection of the more complicated structures of other rocks.

Besides the above-mentioned, various methods have been those making use of the torsion balance, gravity meter, magneto meter, and also the electric and radioactive methods. A reasonable degree of success has been attained by the use of seismograph, torsion balance, and gravity meter; from 1929 the American Geophysicists applied the second seismic method of reflection based on the reflection of elastic waves, a method eminently suitable for the correlation of bedrocks and for determining the structure in more complicated regions.

For these reasons the seismic method in the U.S.A. is at the present time the most widely used of all geophysical methods. In 1938 the U.S.A. possessed about 300 seismic working field groups, not taking into account several scores of groups carrying on their research by other geophysical methods.

Somewhat different conditions prevailed in Germany itself, where, as in the other countries of Europe Geophysical researches by magnetic and gravimetric methods were carried on sporadically and for some time had not any great industrial significance. But the Nazification of the country in 1933 which broke into every department of Germany's life, as well as the desire to become independent of deliveries of petroleum from abroad, led to such researches being undertaken on a greater and in a Germanic organised scale. It may be of some interest to give a brief account of this organisation. All regions suspected of being productive in oil, inaddition to the well-known fields, were divided into small sections in which Geological Institutes, always numerous in Germany, were carrying on geophysical research on a regional basis. All these elaborated sections were joined together in one united plan by the Geological Survey of Berlin, and being correlated, permitted the advancing of suggestions about subsurface geological structure. Provided with such a plan, the regions, in which the occurrence of oil might be most probable, were marked out and selected for deep drilling.

The companies charged with boring in the regions concerned were, first of all, obliged to undertake detailed geophysical researches before drilling by the gravimetric and seismic methods in order to settle the most favourable spots for any intended well. Those companies had been supported from a special boring fund with 50% of their costs. If successful, they had to refund the borrowed capital, but if unsuccessful the Government had to bear the expenses of risk up to 50%. The results obtained in such a way were, rather significant in a country poor in crude oil such as Germany is and during the period from 1937 - 1939 the output of natural petroleum was doubled, reaching, by the beginning of 1939, thefigure of 600,000 tons per annum. Acting on the geophysical information available they bored for oil, not only in the Hamburg and Hanover areas where oil occurred in conjunction with salt domes, but also on the Northern slopes of the Hartz Mountains with good results. In 1939 Germany possessed 12 seismic field-groups, the majority equipped with the old seismographical type associated with Mintrop and Schewydar and the rest worked by the reflection method.

In Poland, K. Bohdadowicz, Professor of Economic Geology in the Academy of Mines in Cracow, was the first to direct attention to the necessity of Geophysical research by the seismic method and, as one of the members of the Council of Experts in the Pioneer Company, he had these researches introduced into the exploration programme of the Company.

In 1929 and 1930, German specialists from Hanover and Cassel were engaged in this work. The former was engaged by the Pioneer Company to undertake research in south-east Poland, and the latter by the Geological Survey of Warsaw (Salt Department) in the north-west. Both firms applied to their researches the seismic method of refraction using the mechanical seismograpsh designed by Mintrop. The aim of these researches was primarily to find out whether the method, yielded good results in the U.S.A. and Germany, would have any value in its application to the flat and geologically unknown parts of Poland.

In the south-east of Poland this method was applied in exploration for the structures of bedrock (Cretaceous) which underlay the Moicene of the foreland. As far as the suboutcrops of the bedrock on its northern fringe was concerned this investigation yielded good results. The boundaries of these suboutcrops were located in a large area from Kolomyja to Stryj. This exploration, passing through Kalusz, defined the localisation of large deposits of Salt and Potassium in the area. It failed, however, further to the south where the bedrock was at a considerable depth.

Nevertheless, it has been proved that the application of that method for the determination of the occurrence of limestone, salt, and other hard rocks, which happened to be met with in the shallow subsurface of the Carpathian foreland, was fairly positive.

In northern Poland, near Innowroclaw, Barcin and Pakosc, the researches conducted by another German field-group were not very successful. At Innowroclaw there exists a large salt dome exploited by the Salt Monopol, The same was true of the vicinity of Wapno 20 miles away to the West. It was of some interest for the Salt Monopol to locate other salt domes which might be met with on the way between the two places named. The great masses of Diluvial clay, however, absorbed the energy artificially produced by charges of explosives to such an extent, that even charges of 800 lbs did not produce satisfactory impulses on the seismograms; on account of that and of the great expenditure in dynamite and of the damage done to the ground, the investigations had to be dropped, at least, temporarily. It was undertaken again in 1938, by using electromagnetic seismographs.

In 1930 a similar exploration was conducted in the south-west of Poland in the district of Cracow on the prolongation of the well known layers of salt in Wieliczka. It afforded good results, as the salt was only 300-500 feet below the surface.

In 1932, the Geological Survey of Warsaw, began seismic refraction work with its own Polish specialists who, after having finished their studies at the Academy of Mines in Cracow, went to Germany, France and the U.S.A. to study their methods. This exploration had for its purpose not only the location of the bedrock in its deeper parts, but was extended further to the south up to the Boryslaw area, where tests were made in applying the refraction method to the examination of deep oil foldings.

The results of this work encouraged the Geological Survey to carry out prospection in 1933, particularly for the determination of the deep structures near the foot of the Boryslaw and Drohobycz areas. In this year the mechanical type of seismograph was used in Poland in field work for the last time, and the refraction method gave place to the reflection method, which at that time proved to be more successful in the U.S.A.

In 1934, the Pioneer Company organized the "Pioneer Institute of Applied Geophysics", its wholly owned subsidiary, to make seismic, torsion balance, magnetic, and electrical surveys.

The good results obtained from the seismic method of reflection with the reflection outfit in south-east Poland /Stryj, Mikolajow, Daszawa/, added to the fact that a detailed correlation of the limestone in its deepest parts could be successfully carried through, induced the Pioneer Company, in 1935, to provide itself with another seismic set. Possessing two seismic field groups, this company up to 1937 conducted a large number of researches in the region of the Carpathians themselves, and on the flat parts of the foreland, from the Roumanian frontier on the east to Cracow on the west. On the basis of correlation the surface of gypsum bedrock has been mapped over a large territory of the foreland /about 5,000 sq. m/, to elucidate the structural conditions existing there.

Simultaneously, the company had introduced in its exploration programme the magnetic and gravimetric methods for reconnaissance survey of the pro spected areas, and followed the research work by shallow borings undertaken with the help of several light mechanical drills, and also by the newest chemical method of investigation of the samples obtained.

This tot al work in the foreland, partly detailed and partly reconnaissance, yielded as its result a general contour map of the bedrock and disclosed the conditions existing in its overburden. Both had an important value in the determination of the deep structures. The results being checked by deep drillings led to the discovery of large, new gas deposits in the regions of Kosow, Jaroslaw, and others.

The Geophysical Institute of the Pioneer Company, possessed in 1937, one gravimetric, one electric, two seismic and two gravimetric groups in the field.

In 1938, its research programme, sketched in advance by the Pioneer Company in co-operation with the Mining Dept. of the Ministry of Industry, was, for the time being, accomplished, and was to be followed only by drillings.

The collaborators of that institute founded a new company called "Geotechnika Exploration Co. " whose aim first of all, was seismic and electric prospectings for the benefit of the salt and oil companies in Poland.

This new company carefully followed prospecting in the U.S.A. where at that time there were already about 300 field seismic groups at work, and provided itself with the latest seismic model of the Heiland Research Corporation composed of 18 geophones suitable, not only for detailed research over complicated areas by the reflection method, but also for refraction work, the latter being necessary for certain problems.

During the 16 months of its existence up to Sept. 1939 this geophysical unit, under the management of Dr. Z. Mitera, my brother K. Wyrobek and myself, carried out a series of detailed seismic prospections in the Carpathians investigating there several interesting tectonic structures with much better results than those obtained formerly by the previous sets. Besides it explored in the foreland, in the Vistula plain and also in Pomerania, using the reflection method for deep structures down to 6,000 feet and detailed refraction work for the shallow structures and especially for the location of salt layers. This period of seismic work resulted in the location of new salt domes in north-west Poland, new salt deposits in the regions of Debica and Pilzno /south-west Poland/, in the determination of further boundaries of Potassium layers in the Kalusz and Holyn areas /south-east Poland/ and in the location of a new and large deep fold in the vicinity of Stryj, south-east Poland, undoubtedly similar to that existing in Boryslaw. Here, in July 1939, a deep well was sunk, entirely on geophysical information. In north-west Poland /Kujawy/ another well was to be sunk, to settle, if, and in what amount, the occurrence of oil might be expected in the vicinity of newly discovered salt domes.

To complete the general picture of geophysical exploration in Poland, it seems worthy of mention that, besides this seismic programme of researches carried out by the Pioneer and Geotechnica Companies from 1934 to 1939, the Geological Survey of Warsaw established within its borders a Geophysical Section, equipped with seven magnetic and two gravimetric groups, the apparatus being mounted on cars. The primary net of gravity points established since 1925 by the Institute of Weights and Measures of Warsaw, had, by the help of the aforementioned gravity meters, been greatly filled in with new points. The magnetic and gravimetric investigations had by 1939 covered one-third of the flat region of Poland. The large geophysical programme arranged for the duration of severals years to come, was to provide the Geological Survey with a general map of magnetic and gravity anomalies over the whole of Poland, for further detailed prospection where necessary by gravity meters and seismograph.

The war interrupted all these plans. Instruments, maps and results of the Geological Survey were either destroyed or taken by the Germans. The descriptive and field material of the Geotechnica Co. collected thoroughly during the ten years of seismic prospecting and especially during the last 16 months of exploration, was destroyed in Lwow by enemy action, together with the laboratory and library, while the field seismic equipment was taken [redacted].

Beginning this paper in December 1941, the writer was aware of the difficulties in collecting the necessary documentary data which would enable him to re-establish the results previously obtained in order to discuss them in the light of the present information concerning seismic prospection, but hoped before finishing, to return to Poland to collect the scattered remnants of his activity and so complete the missing data.

Owing to the unexpected fortunes of war, the only material available was that published either by Dr. Mitera or the writer himself before the war, and occasionally found here or there in the libraries of Great Britain, if it was not evacuated. The rest as far as the descriptive side is concerned, is necessarily based on the writer's memory.

The paper consists of three parts: The first part deals in general with seismic prospection concerning refraction work in Poland, which owing to an almost lack of publications is mainly descriptive.

The second and third parts deal with the reflection survey. The instruments used, and the field methods applied, the theory of the distribution of seismic energy, with its practical application and results, are discussed in the second part.

The third part gives the description and analyses of the results of the prospection in the Carpathians and in the Foreland, based on the documentary data available. In some areas of the Foreland, the results of the reflection surveys appeared to be unreliable. The writer points out the possible importance of these areas from the point of view of oil accumulations, and shows the way in which the reflection method could be applied to the structural problems in zones where the reflections were unsatisfactory for correlation, and where true dips could not be determined by the dip-shooting method alone.

PART I.

REFRACTION METHOD

Instruments and prospection.

CONTENTS

PART I.

CHAPTER Page

I. - General data 21
- Synopsis of the seismic prospection 24
- Seismic apparatuses used 34

II. THE SEISMIC REFRACTION OUTFIT OF MINTROP-SCHWEYDAR

- A single receiving station 37
  - The seismograph 38
  - Some theoretical considerations 39
  - Register instrument 45
  - Oscillograph 46
  - Wireless station 46
- The work at a receiving station 47
- The seismogram 48
- A shot station 50
- Shot-hole drilling 51
- Explosive 53
- Other equipment 57
- Transport 58
- Refraction linear traverses 59
- Organization of the field party in 1932/33 62
- Efficiency and cost 65
- Advantages and disadvantages of the equipment 66
- References to chapter II 67

III. THE INFLUENCE OF THE EXPLOSION ON THE ROCKS. THE ELASTICITY OF THE ROCKS. THE SEISMIC WAVES.

- The physical phenomena occurring in the ground when an explosion takes place 68
- Some points on the theory of seismic waves 80
- Waves encountered in seismic prospection 86
- References to chapter III 92

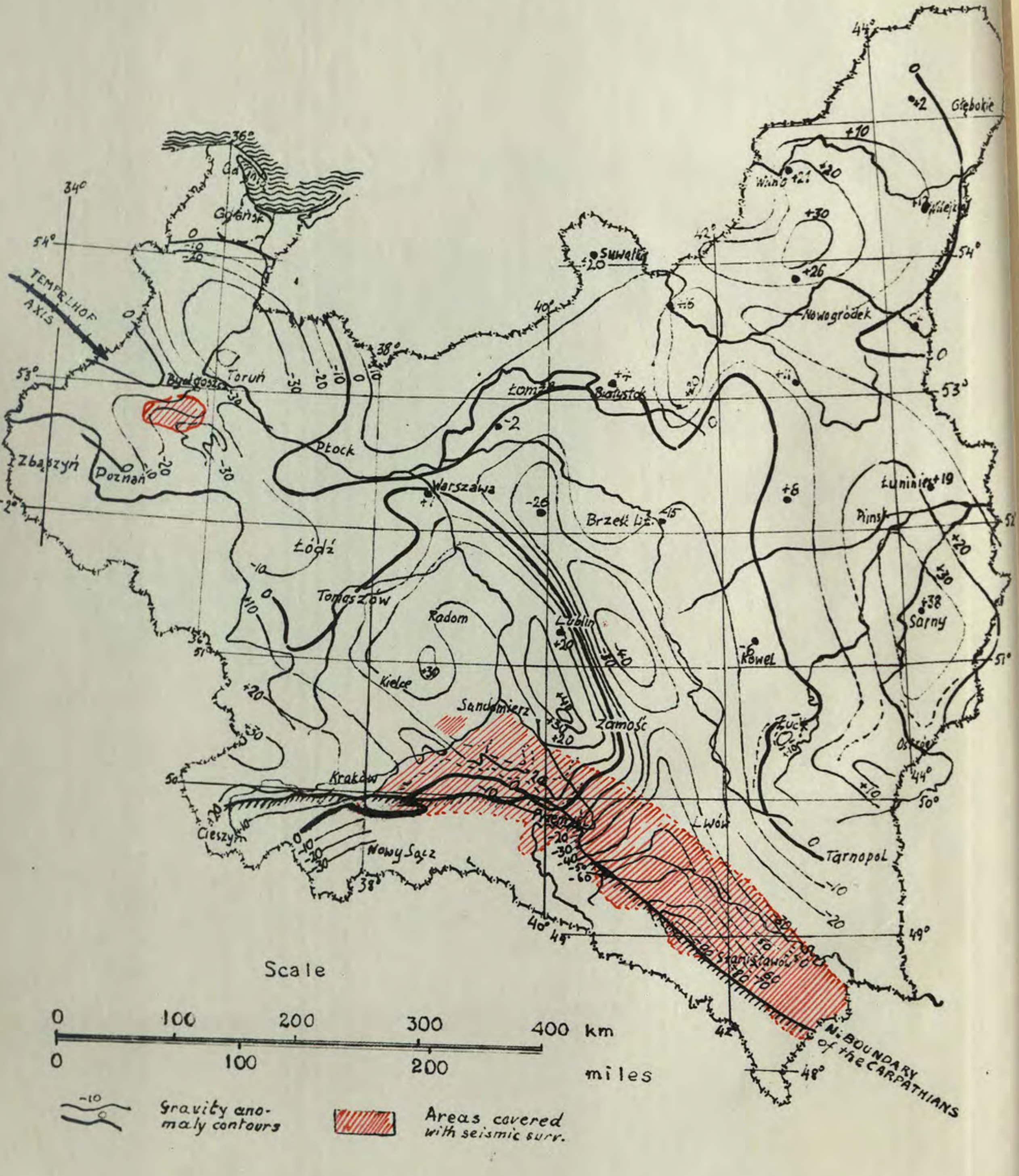
CHAPTER Page

IV. REFRACTION PROSPECTING IN POLAND

- General 93
- Brief geological description 94
- Refraction prospecting of 1929 and 1930 98
- Refraction prospecting conducted by the Geological Survey of Warsaw in 1932 101
- The refraction prospecting in the region west of the river Stryj 106
- Refraction prospecting of 1933 111
- General remarks regarding the survey of 1932 and 1933 119
- Refraction prospectings carried out sporadically from 1934 to 1939 with the use of the reflection set 122
- Examples of the refraction survey conducted with the 6-geophone set of Seiscor 124
- Examples of the refraction survey carried out with the 12-geophone set of Heiland 128
- Inferences regarding the refraction method 132
- Limitations of refraction prospecting 134
- References to chapter IV 138

PART I contains 42 figures in the text.

Fig. I-1.


TEMPELHOF AXIS
Gdańsk
Bydgoszcz
Toruń
Płock
Zbąszyń
Poznań
Łódź
Tomaszów
Warszawa
Łomża
Białystok
Suwałki
Wilno
Wilejka
Głębokie
Nowogródek
Brzeć L.
Łuniniec
Pińsk
Sarny
Kowel
Łuck
Lublin
Radom
Kielce
Sandomierz
Zamość
Kraków
Cieszyn
Nowy Sącz
Lwów
Tarnopol
Stanisławów
N. BOUNDARY of the CARPATHIANS
Scale
0 100 200 300 400 km
0 100 200 miles
Gravity anomaly contours
Areas covered with seismic surv.
34°
36°
38°
40°
42°
44°
48°
49°
50°
51°
52°
53°
54°

CHAPTER I.

1. General Data

The sketch-map of Poland /Fig. I-1/ shows in general the areas covered by seismic prospecting carried out from 1932 onwards; the seismic researches undertaken by the German companies in 1929 and 1930, are excluded on account of the lack of adequate data; besides, they happened to coincide in a great measure with the work conducted at a later date.

The sum- total of these researches may be divided into three periods, each distinguished by the method and apparatus employed during prospecting.

The 1st. Period:

Researches carried out exclusively by the seismic method of refraction. These took place during the summer of 1929 and 1930 and were conducted by two German companies, Askania and Seismos, with their personnel, and during 1932 to 1933 by the Polish personnel of the Geological Survey in Warsaw with the help of Mintrop-Schweydar instruments. These researches had in general, a reconnaissance value. (Nos. 0 - 5 table p.24)

The 2nd. Period:

The 2nd. Period:

Researches carried out exclusively by the seismic method of reflection using two American reflection sets made by Seiscor, Tulsa, Oklahoma and Heiland, Golden Colorado.

These researches were undertaken by the Geophysical Institute of the Pioneer Company in Lwow from 1934 - 1937. They had either a reconnaissance or detailed character; in the first case they were based on the correlation of the reflections from the deep limestone bedrock underlying the Miocene basin of the Foreland, in the second case the 'correlation' method was successful only in the northern parts of the Foreland, whereas the southern parts of this Foreland and Carpathian structures were investigated by the so-called 'dip-shooting' method. At the end of these investigations in 1937, the Seiscor set was also used in refraction work, being applied to the detailed prospecting of the potassium layers near Kalusz. (Nos. 6 - 35).

The 3rd. Period:

This covers the researches carried out by both the seismic methods of refraction and of reflection, using a 12-18 geophone set of the Heiland Corporation model of 1938; they were conducted by the Geotechnika Company.

The prospection of this period had a distinctly detailed character. Correlation, dip-shooting and/or the combined method were applied both to the deep and shallow structures particularly to the deep foldings of the Carpathians, the salt domes of north-west Poland and the shallow irregular layers of salt and potassium with their accompanying limestone bedrock in southern Poland. These researches carried on unceasingly from May of 1938 till August of 1939 were interrupted by the outbreak of the war in 1939. (Nos. 36 - 51).

A detailed chronological synopsis of all seismic researches undertaken in Poland is shown in the following table where, besides the names of places concerned and the methods used, the object and the duration of any field work are shown.

---

2. SYNOPSIS OF THE COMPLETE SEISMIC PROSPECTING IN POLAND

a) Conducted by as shown.

No.	Year	Place	Method Applied	Apparatus used	Conducted by	Object and Purpose.	Duration Weeks.
0	1929 1930	Stanislawow, Kalusz, Stryj Kujawy, Wapno, Cracow County.	Refrac. general detailed and fan shooting	Mintrop	Seismos Askania	Foreland structures. Outcrops of Limestone & potassium. Salt domes.	25
1	1932	Daszawa - gas fields	Refrac. general	Mintrop Schweydar	Geological Survey in Warsaw	Shallow and deep gas structures	4
2	"	Area of:- Lisiatycze, Mikolajow, Wownia, Opary, Medenice, Letnia, Gaje, Drohobycz.	Refrac. general	"	"	Foreland structures. Outcrops of Limestone. Seismic character of explored area.	12
3	1933	Area of:- Rychcice, Dobrowlany-Drohobycz, Modrycz, Truskawiec-Tustanowice.	Refrac. general or detailed	"	"	Sub-Carpthian structures down to 1500 feet.	20

No.	Year	Place	Method Applied	Apparatus used	Conducted by	Object and Purpose	Duration Weeks.
4	1934	Modrycz - (a deep research well 1700 m)	Refrac.	Mintrop Schweydar	Pioneer Expl.Co.	Determination of the average wave velocity of the area.	$\frac{1}{2}$
b) Conducted entirely by Pioneer Expl. Co.							
5	1934	Rachin (a deep research well 1435m)	Refrac.	Mintrop Schweydar		Determination of the average wave velocity of the area.	$\frac{1}{2}$
6	"	Nahujowice	Reflec. detailed correl.	Seiscor		Deep folding	2
7	"	Daszawa	"	"		Deep and shallow subsurface	5
8	"	Orow - (a deep research well 2400 m)	"	"		Determination of the position of Menilite shales	$\frac{1}{2}$

&

No.	Year	Place	Method Applied	Apparatus used	Object or purpose	Duration Weeks
9	1934	Truskawiec (a deep research well 2400 m)	Reflec. detailed correl. & dip shooting	Seiscor	Deep folding	1
10	"	Profile Stryj-Mikolajow	Reflec. detailed correl.	"	Deep bedrock	5
11	"	Region North of Stryj to Zydaczow, Zurawno	Reflec. correl.	"	Deep bedrock	20
12	1935	Uhersko - (a deep research well 1170 m)	Refrac.& reflec.	"	Determination of the average wave velocity	½
13	"	Region N.W.of Stryj, Bilcze Wolica, Medenice, Letnia.	Reflec. correl.	"	Deep bedrock	10
14	"	Wownia - (adeep research well 1140 m)	Refrac.& reflec.	"	Determination of the average wave velocity.	½

No.	Year	Place	Method Applied	Apparatus used	Object or purpose	Duration Weeks
15	1935	Wownia area	Reflec. detail-correl	Seiscor	Location of a deep Horst.	2
16.	"	Area NE andN. of Drobobycz,Medenice Komarno,Rudki, Sambor Sadowa Wisznia,Mosciska.	Reflec. general correl	"	Deep bedrock on its southern boundaries	38
17	"	Markowa	Reflec. dip-shooting & correl	"	Deep folding.	1
18	"	Tustanowice	Reflec. dip - shooting	Heiland	Deep folding	4
19	"	Bitkow	Reflec detailed dip-shoot	"	Deep folding	3
20	"	Perehinsko-Niebytow	"	"	Deep and shallow foldings	4
21	"	Mosciska-Krakowiec	Reflec. general correl	"	Deep bedrock	6

No.	Year	Place	Method Applied	Apparatus used	Object or purpose	Duration Weeks
22	1936	Uhersko, Dobrowlany, Wownia, Komarno, Rudki.	Reflec. detailed correl & dip - shoot.	Seiscor	South boundaries of deep bedrock	8
23	"	Sanok	Reflec. detailed dip-shoot	"	Shallow Carpathian structures.	½
24.	"	Min. Kwiatkowski - a deep well. Boryslaw.	Reflec.	"	Location of the Menilite shales	½
25	"	Lwow	Reflec. refrac.	"	Shallow Limestone	½
26	"	Kosow	Reflec. detailed correl	"	Deep bedrock	8
27	"	Perehinsko-Niebylow	Reflec. detailed dip-shoot	"	Deep and shallow foldings.	5

No.	Year	Place	Method Applied	Apparatus used	Object or purpose	Duration weeks
28	1936	Region of:- Lubaczow, Oleszyce, Jaroslaw Lezajsk, Przemysl, Lancut, Rzeszow Kolbuszowa, Debica Mejlec, Tarnow, Zabno.	Reflec. correl. reconnaisance	Seiscor	Deep bedrock	15
29	1937	Kalusz-Holyn	Refrac. detailed	"	Outcrops of potassium	6
30	"	Medyka and Przemysl	"	"	Shallow foreland structures.	6½
31	"	Region of:- Lancut, Sokolow, Przeworsk Sieniawa, Jaroslaw.	Reflec. detailed correl	Heiland	Location of deep harst of the bedrock	12
32	"	Ustrzyki, Czarna, Nowy Zagorz Komansza.	Reflec. reconnaisance	Seiscor	Deep and shallow structures in the Central Depression	10

No.	Year	Place	Method Applied	Apparatus used	Object and purpose	Duration Weeks
33	1937	Kosow - a deep research well 1450 m)	Reflec. detailed correl	Seiscor	Determination of the average wave velocity	1
34	"	Kolomyja - Ottynia Stanislawow - Kalusz.	Reflec. general correl	"	Deep bedrock	10
35	"	Dolina	Refrac. Reflec. detailed	"	Shallow salt structures in connection with oil.	2

c) Conducted entirely by Geotechnica Expl. Co.

No.	Year	Place	For. Coy.	Method Applied	Apparatus used	Object & Purpose	Duration Weeks
36	1938	Pakosc-Barcin	P.T.G.	Refrac. detailed	Heiland Model 1938	Large Salt dome	4
37	"	Pieranie	"	Refrac. detailed	"	Small Salt dome	½
38	"	Area: Kalusz - Holyn -	T.E.S.P.	Refrac. detailed	"	Location of potassium layers.	12
39	"	Stebnik	"	"	"	" " "	½
40	"	Tutanowice-Modrycz Debrawa a deep well.	Matopolska	Reflec. detailed dip-shoot	"	Deep folding; deep & shallow structures. Determination of the average wave velocity.	6
41	"	Area: Mielec-Tarnobrzeg, Kolbuszowa, Majdan.	P.I.G.	Reflec. detailed correl	"	Deep bedrock	5

No.	Year	Place	For. Coy.	Method Applied	Apparatus used	Object and Purpose	Duration Weeks
42	1938	Bochnia	P.I.G.	Refrac. detailed	Heiland Model 1938	Irregular salt structure.	2
43	"	Brzesko	"	"	"	Carpathian shallow structure.	1
44	1938	Pacanow, Stopnica, Solec	"	Refrac. detailed reflec.	"	Shallow structures of Limestone.	2
45	"	Czarna	Polmin	Reflec. detailed	"	Shallow structure in the gas field.	1
46	1939	Debica-Pilzno-	Solvay	Refrac. detailed	Heiland	Irregular salt structures.	4
47	"	Daszawa-Babice	Gazolina	Reflec. detailed	"	Deep bedrock in the gas area.	6
48	"	Bitkow	Galicja	"	"	Deep folding.	2

No.	Year	Place	For. Coy.	Method Applied	Apparatus used	Object and Puspose	Duration Weeks.
49	1939	Lubience	Galicja Polmin	Reflec. detailed dip-shooting	Heiland	Location of a new deep folding.	10
50	"	Barcin-Pakosc	P.I.G.	Refrac. Detailed Reflec. detailed.	"	Salt dome	5
51	"	Kruszwica, Radziejow	"	Reflec. det. Refrac. fan		Shallow and deep Limestone structures.	5

3. Seismic Apparatus

As mentioned previously there were three types of instruments used in seismic prospection in Poland.

A. The seismic set of the Mintrop-Schweydar mechanical seismograph model of 1928, composed of three seismograph stations destined purely for refraction purposes.

B1. The seismic set of the Seiscor (Seismograph Service Corporation, Tulsa, Oklahoma) 1934 model, composed of 6 electro magnetic seismographs destined purely for reflection purposes.

B2. The seismic set of the Heiland (Heiland Research Corporation, Golden, Colorado) 1933 model, composed of 6 electro magnetic seismographs, destined purely for reflection purposes.

C. The seismic set of the Heiland (as above) 1938 model composed of 12-18 electro magnetic seismographs adapted both for reflection and refraction work.

Seismic instruments record the travel-time of elastic waves from the shot-point to the seismograph.

Each seismic set, as a whole, consists of the following elements:-

(a) Seismographs, also called geophones or detectors in the reflection sets, are the receivers of the ground motion, which, being very small, is amplified by mechanical optical or electrical means and recorded by the second instrument called:-

(b) The Register Instrument in the Mintrop set, or amplifier filter recorder system in the reflection sets.

(c) With the help of these two instruments one is able to register at the receiving station the arrival of waves originated at the shot point. It is also necessary to register the instant of the beginning of the waves, the so called "shot instant" which is produced by the detonation of the explosive in a distant shot-hole and is transformed electrically to the oscillographs in the receiving station and recorded by the register-instrument.

(d) The timing systems. These instruments time the time space between the shot-instant and the response of the seismographs.

(e) In addition each seismic set is completed by the auxiliary field-equipment consisting of telephone or wireless station, shot equipment and finally drill and surveying equipments.

CHAPTER II.

THE SEISMIC REFRACTION-OUTFIT OF MINTROP-SCHWEYDAR

The completed set of this type of seismic instrument (used by the Geological Survey of Warsaw during the years 1932 and 1933, and by the German Companies in 1929 and 1930 in Poland) consisted of three single receiving stations and one shot-station. Larger outfits having more than three receiving stations were at that time not used on account of transport difficulties and the problem of proper co-ordination of all observers spread throughout the explored lines.

I. A single Receiving station consisted of:-

(a) One mechanical seismograph.

(b) One register instrument with timing system.

(c) One oscillograph.

(d) One wireless set.

(e) Auxiliary equipment, such as a tent of double canvas; a box with chemicals for developing the seismograms, small hand-tools, a torch with a red light, a spade, a mallet and signalling flags.

Each station was manned by one observer, and one assistant.

CHAPTER II.

THE SEISMIC REFRACTION-OUTFIT OF MINTROP-SCHWEYDAR

The completed set of this type of seismic instrument (used by the Geological Survey of Warsaw during the years 1932 and 1933, and by the German Companies in 1929 and 1930 in Poland) consisted of three single receiving stations and one shot-station. Larger outfits having more than three receiving stations were at that time not used on account of transport difficulties and the problem of proper co-ordination of all observers spread throughout the explored lines.

I. A single Receiving station consisted of:-

(a) One mechanical seismograph.
(b) One register instrument with timing system.
(c) One oscillograph.
(d) One wireless set.
(e) Auxiliary equipment, such as a tent of double canvas; a box with chemicals for developing the seismograms, small hand-tools, a torch with a red light, a spade, a mallet and signalling flags.

Each station was manned by one observer, and one assistant.

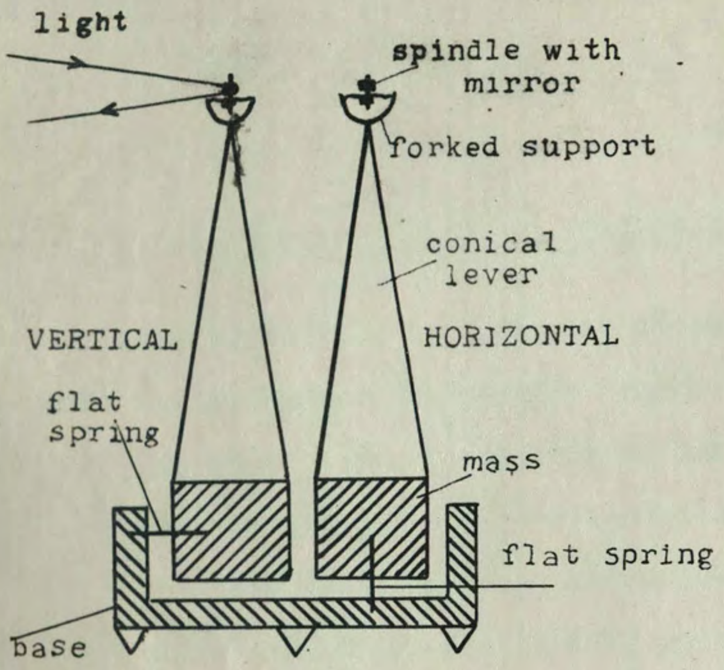


Fig. II-1.

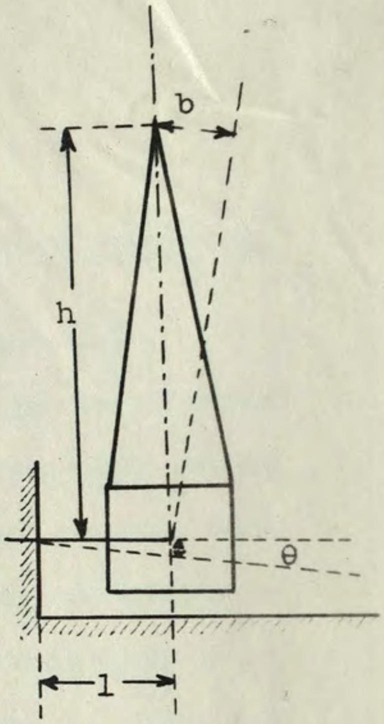


Fig. II-2.

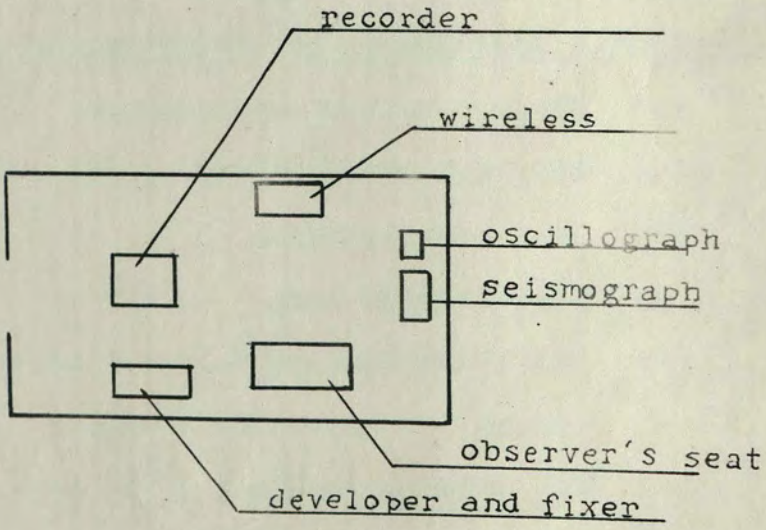


Fig. II-3.

(a) The Mintrop-Schweydar mechanical seismograph.

This mechanical detector (Fig.II-1) consisted of two separate elements mounted on one base. The purpose of one of these elements was to measure the vertical component of the ground motion and the other the horizontal. Each was made up of a heavy steel mass, of about 4 lbs., in the vertical unit attached to a flat horizontal spring and in the horizontal seismograph supported by a vertical spring. On each mass, a light conical aluminium lever, about 2 ft. high, magnified the motion of the block. Each cone carried at the top a forked support with a hair-thread, wrapped round a small vertical spindle the seats of which were in the corpus of the instrument. On any occurring motion of the ground, the blocks responded and the spindle slightly rotated. A beam of light sent from the recording-instrument passing through a flat lens was reflected in the mirrors attached to the spindles and recorded on the moving photographic paper, which was one meter away from the mirrors, giving the enlarged motions of the ground. The whole instrument being covered by a metal case had the shape of a truncated pyramid with a rectangular base, which had three short conical legs so as to be well placed on the ground, and screws for arresting the masses when not in use. At the top of the instruments there were screws for adjusting the mirrors to the spot and a small circular spirit-level for levelling the seismograph when in work.

Some theoretical considerations.

The idea of the application of the seismograph to the investigation of the elastic properties of the subsurface grew out of its more general application for studying the interior of the earth when registering the shocks produced by earthquakes.

The large seismographs, erected for this purpose at the seismological stations spread throughout the world, record three component parts of the ground motion, two horizontal and one vertical. The resultant of the two horizontal components indicates the direction of the hypocentrum whereas the total resultant gives the total magnitude of the shock and its angle of emergency.

Thus, the first small seismographs which were adapted to field-prospecting were constructed on the same principle; since the direction of the hypocentrum, (i.e. the shot-point) was known in advance, the measurements included, besides the vertical component, only one of the horizontal components of the ground motion to give the resultant of the shock and the angle of emergency.

The horizontal component, however, is very weak in comparison with the vertical one, and this fact proves that much more energy arrives at the seismograph in the vertical direction than in the horizontal. When the shot point was very near (150 yards), the amplitude of the vertical motion recorded extended beyond the edges of the record, whereas the amplitude of the horizontal motion of the ground was scarcely measurable. When the shot-point was very far from the receiving-station, the energy necessary to move the horizontal seismograph to a measurable amplitude had to be incommensurably greater than that for the vertical seismograph.

Because of all these facts the horizontal seismograph had been neglected, especially since the angle of emergency, to which Mintrop and Reich attached certain importance in practice, turned out to be of no practical significance in seismic prospection.

The general theory of the vertical seismograph is reduced to the theory of a simple vertical pendulum, the mass of which supported by a rod or spring has its oscillations critically damped. The general equation of the motion, the same for all damped seismographs, assuming the forced oscillations, is as follows:-

$$\theta'' + 2.k.\theta' + n^2.\theta = X''/l$$

where: θ = angular displacement of the mass

θ' = " velocity of the rod

θ'' = " acceleration of the rod

X = periodic displacement of the support due to ground movement,

X'' = its acceleration,

k = coefficient of damping,

l = the length of the ideal or "simple equivalent" pendulum which would have the same "free period" as the actual seismograph,

$n = \sqrt{g : l}$, is the natural angular frequency of the seismograph, or the number of oscillations in 2π sec, so that with f as frequency and T as period $n = 2\pi f = 2\pi : T$,

G. W. Walter (Ref:II - 1) gives the solution of this equation as:

$$\theta = \frac{p^2 \cdot X_0 \cdot \sin(pt - \eta)}{l \cdot \sqrt{(n^2 - p^2)^2 + 4k^2 \cdot p^2}}$$

where : $X = X_0 \cdot \sin pt$, is a single periodic displacement,

p = the angular ground frequency,

$\tan \eta = 2kp : (n^2 - p^2)$

Writing the recorded displacement as $A = L.\theta$, he gives the magnification of the seismograph, i.e., the ratio $A : X$, as

$$\frac{L\,p^2}{l \cdot \sqrt{(n^2 - p^2)^2 + 4 . k^2 . p^2}}$$

This magnification, as can be seen, is proportional to L, i. e., to the mechanical magnification of the seismograph and depends more on the frequency-range of the ground motion than on that of the apparatus. The higher the frequency, that is the quicker the motion of the ground, the greater is the recorded amplitude.

The natural ground frequency $f' = p/2\pi$, most commonly met with in seismic prospecting, is 10 - 60 cycles per second, the lower figures concerning refraction waves, the higher figures reflection waves. In the mechanical seismographs, as in the case of Mintrop, the frequency of the moving system, n , is higher than that of the ground, p , and the seismograph must be damped. Its being undamped, it may, under any tremor of the ground, fall into free oscillations which are highly undesirable on the records.

The seismograph should be critically damped, i.e. being moved from its zero position, should slowly return to it.

Making k as high as n , the magnification is

$$L.p^2 / l. (n^2 + p^2)$$

Making k too high, we kill not only the free oscillations of the seismograph but also the recorded amplitude.

With the electric seismographs, (see page 143 - 150), used in reflection prospecting, where the ground frequency is in the range of 25-60, the moving system could be so adjusted, that it would have a natural frequency in the frequency range of ground movement, and thus $n = p$. In this case, the seismographs are described as being tuned and the formula of magnification may simplify into $L.p / l.2k$;

The factors upon which the magnification of the seismograph depends are then n, k, l, L.

As aforementioned, n was made higher than p, /about 15 in the apparatus used/, k so high as to make the seismograph critically damped, l should be as small as possible, and L as high as possible. For simplifying the calculation of L , suppose that l (actually the length of the "simple equivalent" pendulum which would have the same "free period" as the actual seismograph) is equal to the distance of the centre of gravity of the mass from the point of attachment of the spring to the support. In the vertical seismograph mentioned, the magnification L , was composed of the machanical and optical magnification. The angular displacement of the mass being θ (Fig.II-2) the top of the aluminium cone will have a displacement say "b"; if the height of the cone is h, then

$$\theta : b = l : h, \text{ hence } b = \theta . H / l$$

In consequence of the cone displacement the mirror attached is turned through a small angle [the equivalent of "b" / and a reflected ray of light is turned through twice that angle giving a displacement of the light spot equal to A / the recorded amplitude/ at a distance D, the latter being equal to the focal length of the concave mirror. Thus

$$b : r = A : 2D$$

where r is the radius of the mirror spindle. Hence

$$A = b\ 2D / r = \theta .\ h.2D / l.r$$

and the over-all magnification /mechanical and optical/

$$L = A : \theta = h.2D / l.r$$

Assuming the following values /approx/ for the apparatus used $h = 0{,}60$ m , $D = 1{,}00$ m, $r = 0.001$ m, $l = 0.06$ m, one obtains $L = 20{,}000$. In actual practice, this magnification was about 15,000. The first Mintrop seismographs had a magnification of 2500.

From the above it is evident, that even ground movements with amplitude down to 10^{-6}, can be detected by sensitive seismographs.

Because of its sensitiveness the behaviour of a field-seismograph depended on the type of ground upon which it was placed. The setting-up on peaty ground was not to be recommended. Nor was it advisable to place it on any kind of ground in the vicinity of roads with heavy traffic, with telegraph poles or in the neighborhood of cottages (inside which any movements can be detected at a distance of 300 feet') or scattered trees. It was also inadvisable to record during a wind if its speed exceeded 6 m/sec.

The damping of the Mintrop seismograph was done by the small spade attached to the cone, which moved in a pipe filled with glycerine. This glycerine oil had to be removed during the experiment whenever the station was picked up. If the observer forgot to put it in at the next station, he could not quieten the seismograph movements, caused by outside disturbances with the result that the first impulse of the ground-motion could not be properly and clearly recorded. If he forgot to pour out the glycerine oil then it would stain the apparatus should it overturn. In the later types of Mintrop Seismograph, of which one was tested in Poland, the damping was done by the small piston attached to the moving system which moved in the closed cylinders filled with oil.

The seismograph was placed in a special iron-wood case during transport.

(b) Register Instrument.

It had the shape of a box (1 ft. x 1 ft. x $\frac{3}{4}$ ft) placed on a tripod. The register box contained :- a watch mechanism with mechanical interrupter of the light as a timing system, and electric lamp lit by a car battery, and motor-spring camera with a roll of photographic paper. The motor-spring turned the roll of paper, which passed through the front of the register box into the upper camera. In front of the box was a slit with an oblong lens through which were reflected the beams coming from the mirrors of the seismograph and the oscillograph. These beams were recorded on the travelling film.

During transport the register instrument was placed in a case similar to that of the seismographs.

(c) Oscillograph.

This was a small instrument consisting of a concave mirror placed in the electro-magnetic field. The whole, covered by a metal box the size of the head of the seismograph, was supported on a steel leg and placed beside the seismograph at the same height. The oscillograph was connected by an amplifier with the wireless station and reacted at the shot-instant sent by the shot-station. For transport it was placed together with the register-instrument in the same case.

(d) Wireless Station.

In use there was a military radio-set with a wave-length of about 40 m. Thiswas only a receiver set for receiving orders from the shot-station and for conveying the shot-instant to the oscillograph.

2. The Setting-up and the work done at the Receiving Station.

The assistant put up the tent and the aerial, while the observer unpacked the cases with instruments and placed the seismograph and oscillograph on a level away from the walls of the tent. (Fig II - 3) At a distance of about 3 feet from the seismograph, the register instrument was placed on its tripod. The distance was settled by the focal-length of the mirror. The wireless set and the box with the developer, fixer and water were then placed near at hand. When the electric lamp in the register instrument was lit, a beam of this light reflected by the mirrors of the seismograph and oscillograph was diverted(by the observer) with the aid of auxiliary screws to the register instrument. The lens before the slit focussed the reflected beams on to the photographic paper in the shape of two bright points. The arresting screw of the seismograph being released the corresponding light-spots oscillated, and with a stronger movement of the ground, such as digging, knocking or kicking, might move away from the recorder. The light-spot of the oscillograph also oscillated when the wireless was put on and the electric current was interrupted by the shot-station. Having checked the amount of photographic paper and having wound up the spring mechanism in the register-instrument,

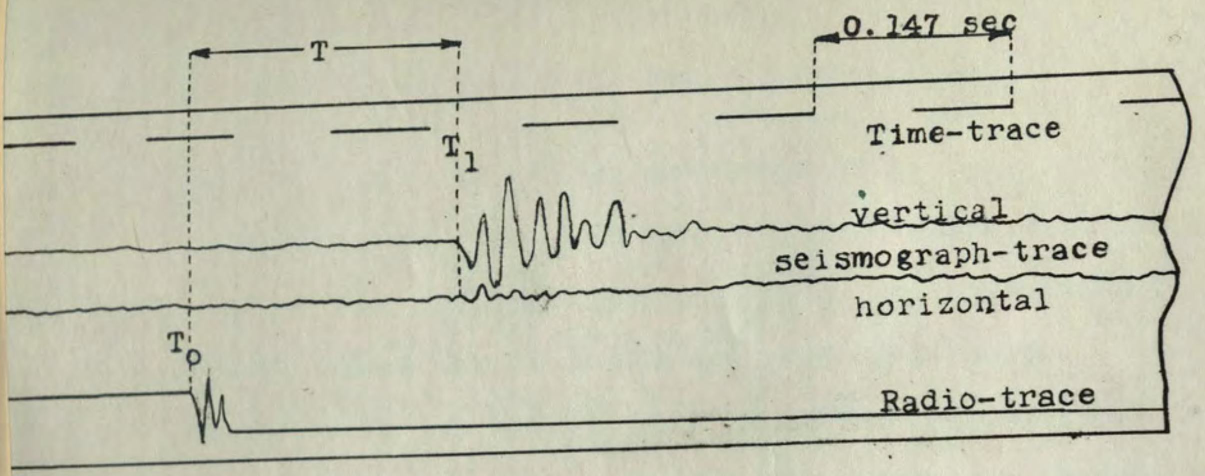


Fig. II-4.

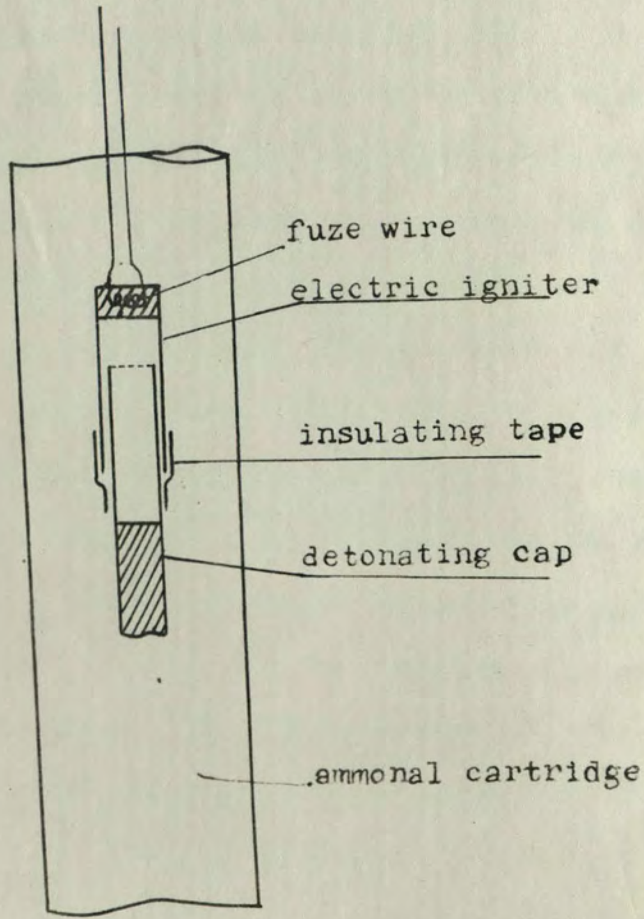


Fig. II-5.

the observer ordered the assistant to close the tent properly and convey to the shot-station, with the aid of signalling-flags, that his station was ready. At the right moment the signal was sent by wireless from the shot-station to the oberver who put the mechanism of the recorder into motion within one to two seconds. The film being cut off and developed, the observer reported to the station the quality of the record and, according to the orders received by wireless he stayed at his place or picking up his station moved to the next position.

3. The Seismogram.

A record obtained at the above-described receiving-station is shown in Fig. II-4. It was about 2" wide, and the length varied from 2' to 3'. The light-spots were usually so arranged that:-

(a) The uppermost interrupted trace was the time-trace. The interval between one end of the dash and the end of the next dash corresponded to 0,147 sec. It was marked by the mechanical interrupter contained in the register-box.

(b) The second trace, called the seismograph trace corresponded to the movements of the vertical seismograph.

(c) The third trace was that corresponding to the horizontal seismograph not used in further prospecting.

(d) The lower trace called the *radio-trace*, was made by the light-spot of the oscillograph-mirror. The two seismograph-traces showed the arriving waves produced artificially at the shot-point. POINT T_1 indicated the time of the first arrival at the seismograph; point T_0 indicated the instance of the explosion sent by wireless. The *difference of time* $T_1 - T_0 = T$ is the actual value of each seismogram, expressing the time taken by the seismic wave to cover the distance from the shot-point to the receiving station.

The seismogram was supposed to be good if both points T_0 and T_1 were clearly readable. As the horizontal seismograph - and thus the corresponding light-point - was normally not in use, the usual appearance of the seismogram used in the field-work with the Mintrop-type of apparatus included only one seismograph-trace from the vertical detector. The distance from the shot-point to the receiving station which usually was surveyed by means of a tape, could easily be measured also by the sound of the explosion, detected by the seismograph and registered on the same record which for that purpose required to be sufficiently long. This way of surveying was often used in prospecting especially in the case of the fan-shooting method, or on very long profiles up to 5 km. If the time of arrival of the sound-wave, recorded on the seismogram is T_2 , then

$$(T_2 - T_0) \cdot V \text{ sound} = D$$

where T_0 = The shot-instant

D = The distance to be measured

V = The velocity of sound, which in normal conditions would have a value of 330 m/sec.

Necessary corrections included the velocity of the wind according to its direction. The alternative way was as follows:-

When shooting a line, two successive receiving stations, the distance between which was surveyed, registered the sound wave. From the records it was easy to compute the actual velocity of sound, and then the distances of the stations from the shot-point.

4. Shot-station.

According to requirements, a shot-point (i.e. a drilled hole loaded with explosive) was fixed at a distance of from 200 to 2000 m. from the nearest receiving station.

The essential equipment of the shot-station consisted of a field broadcasting set of a range of 10 miles /40 m. wave length/, supplied with microphone and telegraphic arrangements, a shot instant indicator and a blasting machine.

5. Shot-hole drilling.

In the first refraction researches carried out on a great scale in the U. S. A. on deserted terrains, directly speaking there were no shot-holes in use.

During those prospectings it was necessary to produce so great a tremor of the ground as to make the first recorded impulse readable. The lines were very long, up to a distance of 10 miles and great quantities of explosives were required. The explosive, naturally, gives the best result when it is concentrated at one point and properly tamped. For charges from 400 to 2,000 lbs, as were used in the U. S. A., a corresponding shot-hole should have been fairly deep and of large diameter and, even then, the concentration of the charge would not have been sufficient; besides being placed in different layers along the hole, its effect would not have been satisfactory. To speed up the operation, the explosive was placed in cases piled on top of one another directly at the surface. Often rectangular pits, several feet deep, were made to decrease the effect of the direct air wave as well as to place the material on beds which had greater seismic velocity.

In Poland a similar method of loading was used by the German companies during their prospecting; the total amount of explosive and damage to the cultivation of the ground were usually high, but small in comparison with the total cost of the exploration. From the time, when Polish personnel was introduced, this ratio became smaller, and it turned out to be very economical to reduce the quantities of explosives and thereby diminish the cost of damage, especially since the researches were becoming more detailed and each seismic line was provided with more than two shot-points. There was- however, a limit to the decreasing of charges used in the researches with regard to the type of apparatus used and its sensitiveness. On one occasion in the north of Poland, during the German prospection in 1929, a charge of about 1000 lbs was placed in a pond. The recorded effect was indefinable, and the compensation claimed by the proprietor for the complete extermination of the fish amounted to £500. Better results were obtained in 1939, in the same place using electromagnetic seismographs /of Heiland 1938/ and a charge of 15 lbs placed in a shallow shot-hole. The damage to cultivation was negligible.

With reference to the above, using the Mintrop-Schweydar outfit, the explosive was placed in a drilled hole, and well tamped.

The hole was 20 to 40 feet deep and

4 to 15 in. in diameter. This was drilled by means of a three legged support and a small tackling tended by a screw of 3 - 4 men. Thismethod of drilling, primitive as it was, turned out to be the most suitable, particularly since most of the prospected areas, was covered with soft layers such as clay, peat, or concise block sand. The hole was not protected by pipes and therefore the drill equipment was limited to very simple tools such as spiral augers of 4" and 6" in diameter, or a winged bore of 15" in diameter, some spanners and simple tackling. This equipment could be transported with sufficient speed on a cart drawn by two horses.

The maximum output per day of such a drilling outfit was 6 - 12 holes, each 15 - 25 feet deep.

6. Explosive.

For the greater part, Ammonnal Gel. /nr. 3 and 5/ was used. It belongs to the "amatol" group of explosives, the strength of which is 30 - 40% of blasting gelatine. This was issued in the original trade packages as cartridges of 100 gr. in weight, wrapped in wax-paper. Ten cartridges were packed in thin cardboard boxes weighing 1 kg., 25 of which were enclosed in a wooden box. Being very safe both in use and transport this explosive was suitable for field work. Safety was the only advantage of this explosive, because, being a powder rendered it very hygroscopic and when wet it would not detonate. Moreover, being weaker than dynamite it was necessary to use at least 30% more than would have been required of dynamite to achieve the same result. During the years 1929 - 1933, Dynamite No. 1. was alone used in Poland. This freezes at a temp: of 54°F / 8°C/, then becoming very dangerous to use. Seismic researches were carried out not only in summer but also in autumn and winter. In the mornings even during summer, the temp. very often fell below 54°F, thus enforcing the use of ammonal which did not possess these inconveniences.

Holes of 4 - 6 in. in diameter were loaded with ammonal cartridges which were tied in packets with string and pushed into the hole by a tamping-rammer. In reconnaissance work the charges went up to 100 lbs. In a shot-hole 6" in diameter, 15 cartridges had a height of about 7 in. so that the whole charge of 100 lbs. exceeded a height of 15 feet. Thus in a hole 50 feet deep the charge could have about 15 feet of strong tamping composed of sand or clay.

In some parts of the exploration areas to decrease the height of a charge and thereby concentrate it more effectively, a winged bore, 15 in. in diameter was used. In such holes the ammonal could be placed in its cardboard boxes, which to a certain extent protected it against humidity in damp or even wet holes. A charge of 100 lbs had thus a height of about 10 feet, assuring thereby sufficient space left for tamping.

At the beginning of the survey, to detonate the explosive a No. 8 detonating cap with electric igniter was used. They were either both in the same tube or in separate metal tubes. Fig. II - 5, shows the igniter charge. A detonating cap, on the open part of which was an electric igniter, was protected against humidity at the point of junction by insulating tape. The whole was placed in an ammonal cartridge, the ends of which were protected by this tape. An igniter charge prepared in this way was placed in the middle of the explosive. During the loading of the upper half of the explosive as well as during the tamping, care had to be taken regarding the wires emerging from the electric igniter at the surface of the hole.

When a charge was longer than 10 feet it was beneficial to use two detonating charges prepared as above in order to secure a regular and simultaneous detonation of the whole charge. The detonating caps were connected in parallel so that, in the event of the interruption of one of the wires in one circuit, the detonation was secured by the other. Since the explosive used was very hygroscopic, damp holes were loaded only at the last moment and the charge could stay in them no longer than half an hour.

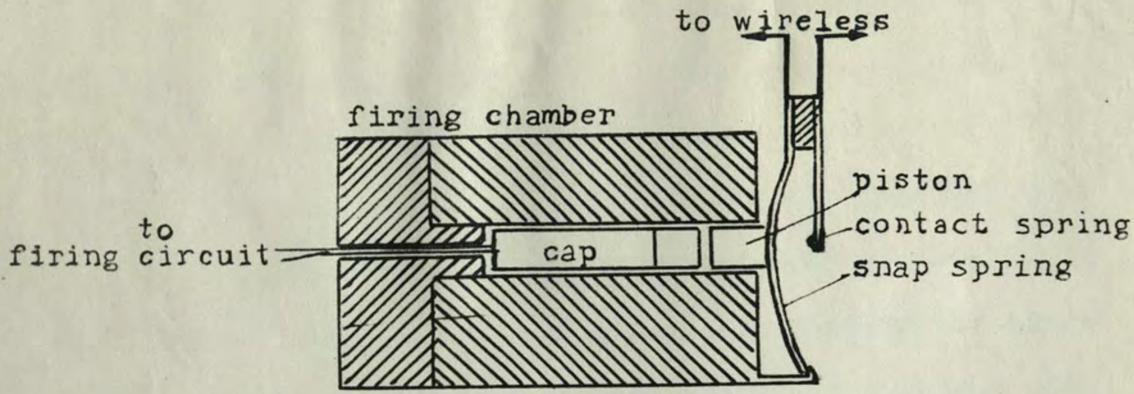


Fig. II-6a.

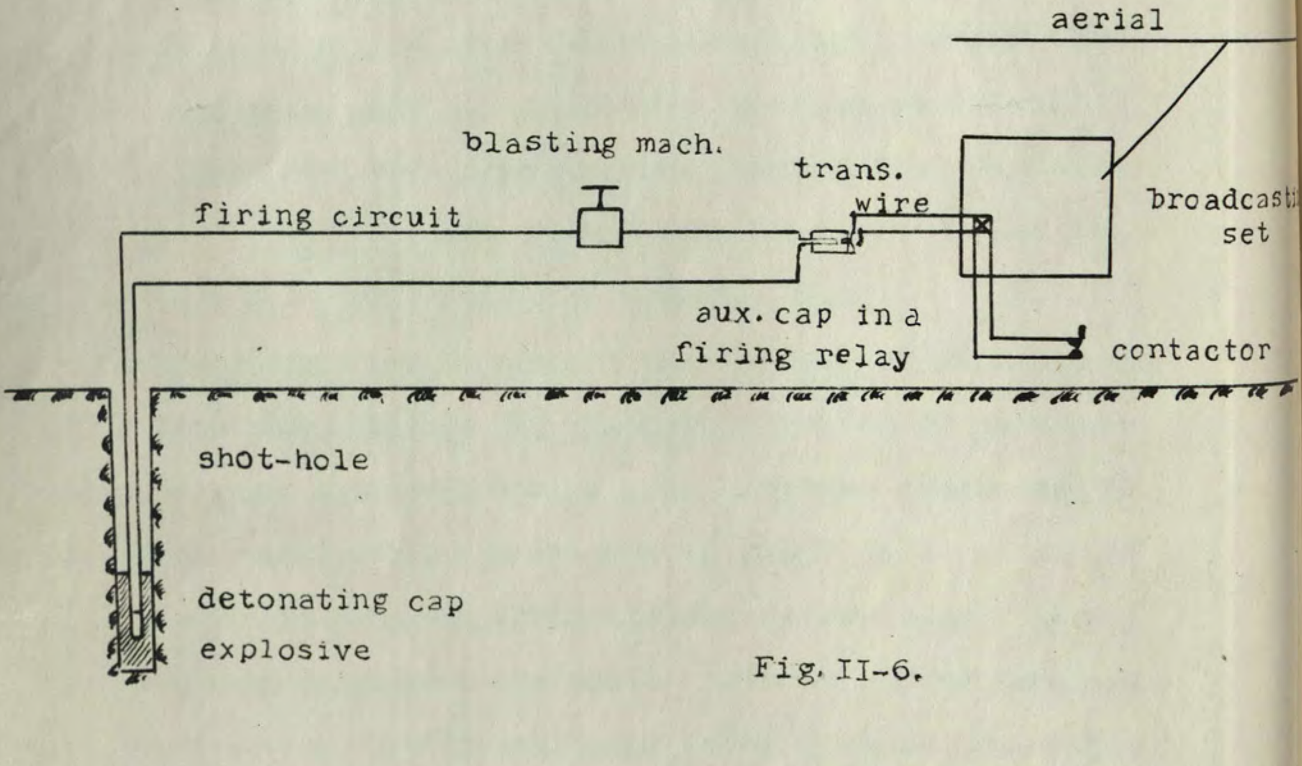


Fig. II-6.

After that time it had to be detonated or taken to the surface. Once wet it had no value as an explosive.

During the first year of prospecting /1932/ an ordinary mining electric igniter was applied. It was the cause of certain errors on account of the delayed fusing. This fact introduced a time difference between the shot-instant sent electrically to the receiving stations and the actual explosion of the detonating cap. This delay varied from 0,004 to 0.04 sec. Until special caps were introduced into seismic prospection /1934/, more complicated means had to be applied to secure a right time-break on the records. One method was to wrap the transmission wire around the charge.

The way of transferring the shot-instant from thecharge to the receiving station was as follows:- A blasting machine and an additional electric igniter with detonating cap, arranged in a firing relay, were put in series in the firing circuit of the main igniter in the hole. /Fig. II - 6/. The blast of the additional cap pushed the snap spring /Fig. II -6a/, closing the second circuit which was connected by wireless with the oscillograph at the receiving station. The effect was similar to that produced by the interruption of the electric current at the shot-station by a telegraphic key this method was used for testing the oscillographs at the receiving stations.

As has been mentioned above the method of wrapping the transmission wire around the charge was applied in order to secure the right shot-instant. The explosion of the charge broke the transmission wire, the shot-instant being thereby recorded. In this way the type of the igniter did not matter, but the loading of a charge with four wires was very inconvenient.

The shot-station was manned by an observer and a shooter with his assistant. The setting up of the shot-station took several minutes. Once the station was set up, its observer sent out the signals calling the receiving station. During this time the shooter with his assistant controlled the hole prepared in advance (its depth and diameter, as well as the dampness of the bottom) and according to the orders prepared the charge, and loaded it at the moment indicated by the observer.

7. Other Equipment.

The surveying equipment consisted of a theodolit, a measuring tape 50 m. long, needles, perches, and pegs with the numbers of the stations. The surveying was conducted by a surveyor and one or two helpers.

The lines were measured directly and very seldom by sound. When the terrain was not flat, the individual station-sites were levelled with regard to the shot-point. Elevation of the shot-points was taken from the maps.

Besides this equipment the field group was provided with drawing and calculation equipment, and with a magazine containing spare parts and stores of material used in field work such as wires, recording papers, batteries etc.

8. Transport.

In the south-east of Poland, where field work was carried out across woods and fields, the transport of the seismic equipment was mainly done by horse and cart. As a rule each receiving station possessed its own cart; the shot-station had usually two carts, the other being for the explosives. In the case of small charges, as the explosive was quite safe, it was carried with the other equipment of the shot-station.

The seismic equipment usually being left in the field, the seismic observers were brought to the spot bya lorry and car. A thrid car was reserved for the party-chief and the surveyor. Thus the transport consisted of from 5 to 6 carts and three cars. Under more favourable conditions when working along roads or tracks all the receiving-stations could be carried by lorry, the shot-station keeping its carts for the explosive. When the receiving stations remained fixed, the shot-station was then carried by the car. The drill equipment was independent regarding its transport.

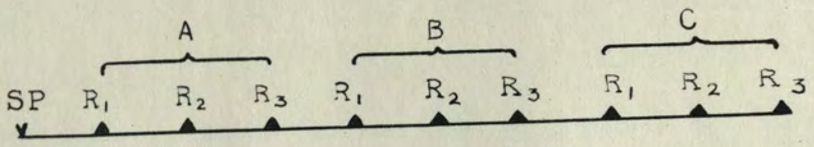


Fig. II-7.

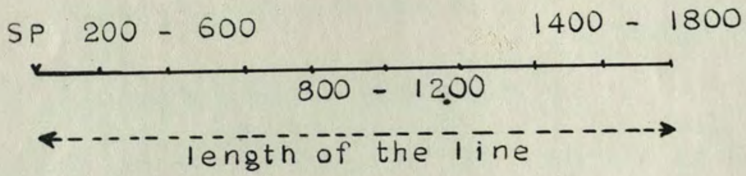


Fig. II-8.

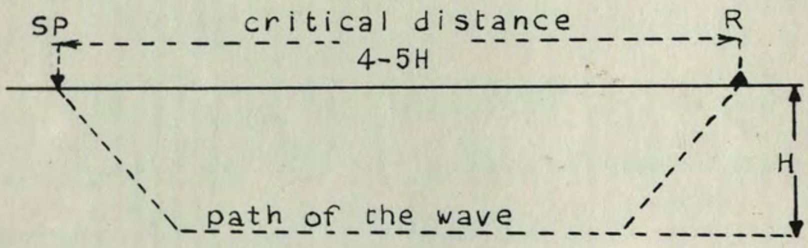


Fig. II-9.

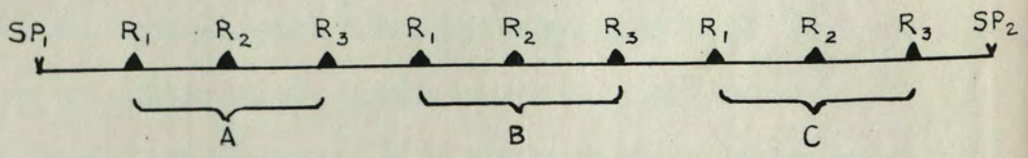


Fig. II-10.

9. Refraction linear traverses.

The detailed and reconnaissance refraction explorations during the years of 1932 and 1933 was done along straight lines called the "refraction traverses or refraction lines." According to the nature of the work, 1 to 5 shot-points and usually 9 sites for the receiving stations were placed along each traverse. A "shot-point" was the name given to a site where 1 to 3 shot-holes, at a distance of about 20 m. from each other, were drilled perpendicularly to the direction of the traverse.

a/ Reconnaissance work was done mainly by one way-shooting lines. Explosions produced at the shot-point S /Fig.II-7/, were recorded along one direction by three stations /R_1 R_2 R_3/ simultaneously, the last-named being moved in turn from the "seismograph spread" A to B and C for successive shots. By the "seismograph spread" is to be understood the length of the traverse occupied by the three stations for one shot. From such a traverse usually 9 seismograms were obtained.

The interval between the stations was 200 or 300 m, and for the reconnaissance line even 400m, the interval between the spreads being correspondingly the same as between the stations. The length of the refraction lines - that is to say - the distance from the shot-point to the last station, depended on the length of the spreads. For the interval of 200 m. between the two receiving stations the spreads were 200-600, 800-1200, 1400-1800 m. (Fig. II-8), whereas for the interval of 400m. the spreads were 400-1200, 1600-2400, 2800-3600m. and the length of the lines 1800 m. or 3600 m. respectively.

Some theoretical considerations concerning the refraction and travel-time of the seismic waves through the subsurface is given in the next chapter, practical observations and remarks being the subject of this below. It is known that the longer the refraction traverse, the deeper is the penetration of the seismic waves and the deeper the layers that can be investigated. As practice shows, and as it follows from theory, to receive a refracted wave from a bed at a depth say H, the length of a refraction line must be longer than 4-5H, that is to say a receiving station R at a distance 4-5H from the shot-point S would record the refracted wave which had reached the layer at a depth H /Fig.II-9/. This distance is usually known as the "critical distance".

From a single one-way line only the values of the apparent velocities of the seismic waves could be obtained and these were adequate for the calculation of the depth in the case of horizontal beds.

b. To investigate the dip of the beds as well as to determine more precisely their depth single two-way shooting lines were used. /Fig.II-10/. This line consisted of two shot-points situated at both ends of the

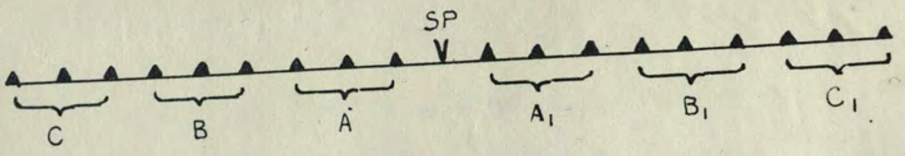


Fig. II-11.

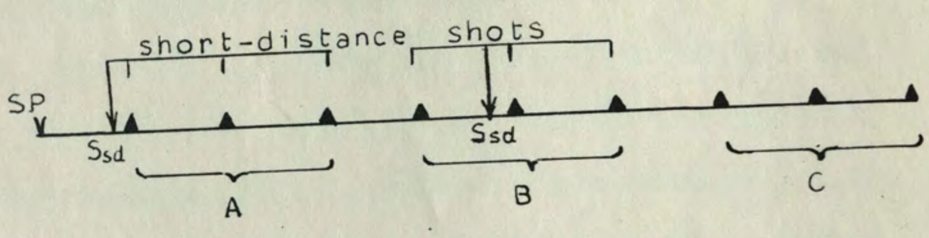
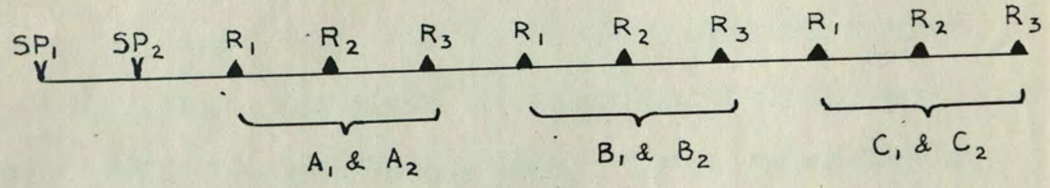


Fig. II-12.

Fig. II-13.



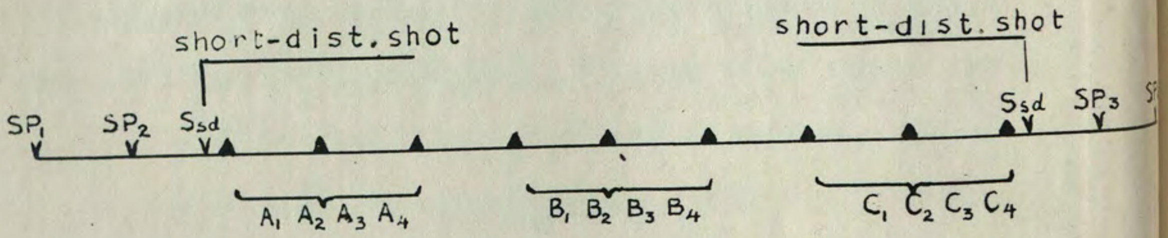


Fig. II-14.

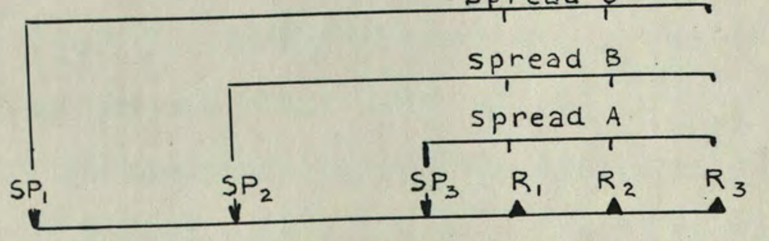


Fig. II-15.

line, the receiving stationsbeing moved, as before, from A to B and C. At each spread the stations recorded shots fired at S_1 and S_2.

During reconnaissance work two-way shooting lines as shown in Fig.II-11 were applied; the shots fired from a shot-point S were recorded in two directions by the receiving stations moved from spreads A,B;C on one side of the shot-point to the spreads C_1 ,B_1 ,A_1, on the other side. This kind of lines accelerated the covering of areas under investigation and gave a general idea of the dip and depth of the sub-surface beds.

To determine the velocity of the surface beds, short-distances shots were fired from a shot-point 50 m. away from the nearest receiving station. They supplied data from a depth of 10 to 15 m. which were important for topographical corrections. Such a shot was usually fired on each line from a shot-point S_{sd} /Fig.II-12/ i.e. between S_1 and the nearest station or between the stations; a shot from the latter position, recorded in two directions ,gave the necessary parameters to determine the mean value of the surface velocity and the depth of the weathering zone.

c. More detailed traverses had their receiving stations placed at a distance of 100-200 m. from each other and a double number of shot-points at each end of the line. A double one-way shooting line (Fig.II-13/ had two shot-points, the interval between them being 200-400m. This line supplied at least 18 seismograms. A double two-way shooting line (Fig.II-14) had two shot-points at each end of the line with the same interval between them as mentioned before and supplied 36 seismograms. An additional record was received from S.P. S_{sd} situated as shown in the figure.

d. If there was a lack of sufficient space for a long line a less accurate shooting was applied; the receiving stations remaining on a chosen spread, the shot-point was moved away from S_1 to S_2 and S_3 (Fig.II-15). The same could be done at both ends of the spread mentioned.

10. Organisation of the seismograph field party in 1932/33.

Personnel	Duties	Equipment
Party Chief.	General charge of all operations as: contact with the geologists of the areas under investigation: control of the location of lines: their direction and length; control of the charges according to the result: control of the calculation and interpretation of records: preparation of the programme for each day	One car.

Personnel	Duties	Equipment
	according to previous result or demand, etc.	
One secretary.	Administration of the field party: indemnification for damage done: arrangement with landowner for permission to enter, etc.	The party Chief's car.
Three observers: instrument operators: with three assistants.	General charge of the receiving stations and their instruments: developing of the records and their proper drying and description. For help in the field work each had an assistant.	Three receiving stations. One lorry
One operator of the shot-station.	General charge of the shot station and co-operation with the shooter and observers.	One cart or a lorry. Shot station equipment.
One shooter and one assistant.	Preparing the charges: Loading of shot-holes: firing the shots: care of the explosives:	

Personnel	Duties	Equipment
	Transport of the explosives from the factory to the field magazines.	
One surveyor and two helpers.	Shooting - lines Survey .	Compass. Theodolite Rods. Tape.
One driller and three assistants.	Drilling of the shot-holes according to the instructions from the surveyor or party chief.	Drill equipment. One cart.
One computer.	Calculations and interpretationsof records concurrently with operations: co-operation with the party chief: drawings, etc.	Calculation and drawing equipment.

Considered as a whole, the refraction-field party consisted of, a party chief, a surveyor, a computer seven mechanics, seven assistants, two drivers, altogether 19 men.

Normal transport: One car and one lorry, and often five carts with horses.

11. Efficiency and Costs.

With such a field party as detailed above and considering the average conditions of transport /partly by motor and partly by horse/, the average efficiency was one to two refraction lines per day, reckoning eight to ten hours of work per day. The combined double line secured from four shot-points in both directions was easily accomplished in ten hours.

With single or double two-way traverses it was useful, from the point of view of efficiency to shoot each spread from all shot-points on the same day. Very often there were eliminated in this way certain errors which could not be controlled and which were due largely to the natural conditions of the work, not to the process itself.

The cost of the maintenance of the field party, including supplies, explosives, indemnities due to the damage done by shooting and passing through fields or meadows, did not involve more than 30,000 zł /£1,500/ monthly. This sum did not include the cost of the depreciation of equipment or the cost of the maintenance of the central office in Warsaw.

The cost of maintenance of a German field party in 1929 and 1930, consisting of one party chief and three observers with three assistants, approached £4,000 permonth, and this did not include explosives, indemnities and the wages of the remaining Polish technical personnel and labour.

12. Advantages and disadvantages.

The instruments used were too heavy for easy transport. Each seismograph station was independently manned by two skilled men, and where transport was difficult a cart was required. The apparatus itself, besides being too delicate for field work, was troublesome in setting-up. The hair-thread of the seismograph mirror was too sensitive to the variations in temperature. The humidity of the air, and damping was very inconvenient. The latter was mechanical and constant in its effect. The record would very often be rendered useless as a result of a stronger wind or a careless movement of the observer or of someone else further afield. Consequently work was often impossible in woods and villages.

The use of a radio-set for communication had the advantage of removing the spreading-out of long telephonic cables but also had the disadvantage of being dependent on weather conditions. During the dry, sunny days of summer the electric discharges of the atmosphere spoiled the real value of the seismogram by interference with the shot-instant and very often made work impossible.

Faulty winding-up of the spring mechanism of the register instrument or inaccurate placing of the photographic band in its camera, would stop the film when the mechanism was put into operation during reception.

Accurate collaboration of all three observers and accurate adjustments of all three receiving stations formed the essential part of the efficient working of the field party.

An advantage of some value, lay in the fact, that this instrument, being mechanical in its design, was not influenced by the high power conductors. In some industrial areas when prospecting was being carried out with electromagnetic outfits this influence could be very annoying.

It might be added here that, in the U.S.A. before the introduction of the reflection method of prospecting, the mechanical seismograph was replaced by an electric or electromagnetic detector-seismograph. These detectors were spread on the ground and their work was recorded by one register instrument manned by one observer; it removed most of the disadvantages mentioned above.

In Poland, after 1933, the mechanical set was replaced by electromagnetic sets for both reflection and refraction work.

REFERENCES: II

Ref. 1. / to page 41/ G.W. Walter "Modern Seismology". pp. 4 - 5.

CHAPTER III.

THE INFLUENCE OF THE EXPLOSION ON THE SURROUNDING ROCKS.

THE ELASTICITY OF THE ROCKS.

THE SEISMIC WAVES.

The physical phenomena occurring in the ground when a discharge of explosive takes place.

The rocks forming the surface of the earth's crust have many and varied properties, upon the recognition of which all geophysical methods are based: thus the magnetic properties of rocks, due to the occurrence in most rocks of small quantities of Fe_3O_4, form the basis of the magnetic method of prospection, while the density of rocks and their mass distribution beneath the surface are the basis of all gravimetric methods; electric methods are based on the electrical anisotropy of the rock-formations and on their behaviour under the influence of electrical forces; finally, the elastic properties of rocks form the basis of seismic methods of geophysical exploration.

The elastic properties of rocks (apart from laboratory experiments) can be investigated by their reaction to any shock, natural or artificial. The natural tremors of the ground and the phenomena involved (earthquakes, microseismic movements, mountain movements) are the subject which constitute the science of seismology. The observation of artificial tremors generated by the explosion of dynamite charges and the subsequent behaviour and distribution of such tremors in the ground, are the object of seismic prospecting investigations.

Of the more common rocks which occur in the earth's crust, limestone,salt, sandstone, and igneous rocks are the most elastic.

Some effects and phenomena occurring in a limestone rock after an artificial explosion has taken place, are the subject of the present paragraph. The following observations are based on an experiment carried out personally by the writer in 1928 in a limestone quarry at Plaza (nr.Cracow) in connection with the study of the torpedoing of oil-wells with the object of increasing oil production.

The experiment was undertaken at the request of J. Naturski who was then the general manager of the Mining Exploration Co.,in Cracow, and with whom the writer collaborated in the work of torpedoing the oil wells. When J. Naturski was killed in 1936, during one of the experiments, the writer continued his work with special reference to seismic prospection. The torpedoing of a well supplied him with the possibility of determining the average velocity of

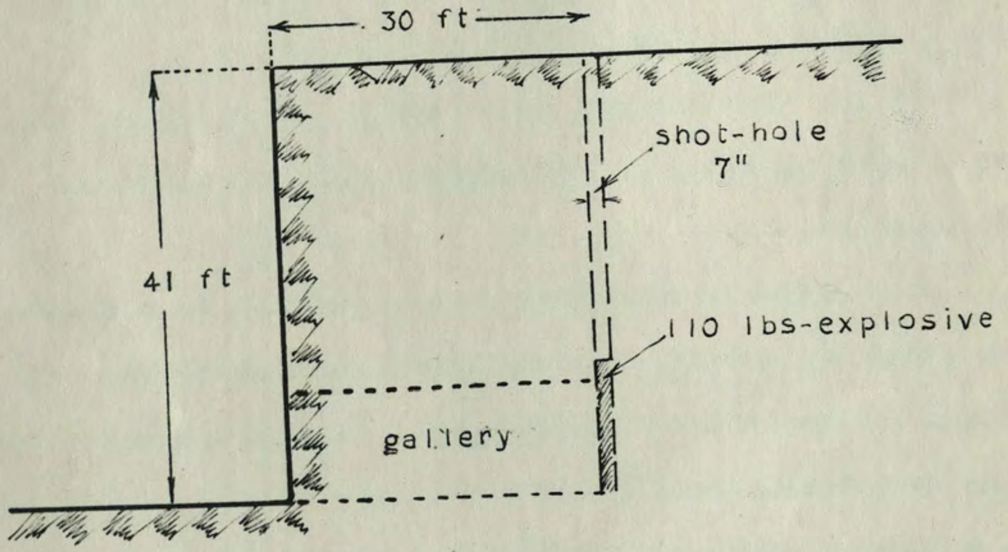


Fig. III-1.

the seismic waves in the rock occurring in the well and this velocity was of great value for the purposes of further prospecting. The description of the experiment is mainly reproduced from the writer's memory since it was impossible to find in this country any copy of the Polish papers in which it was originally published (Przemysl Naftowy, Przeglad Gorniczo Hutniczy 1929). A small sketch found inaa French paper (Ref: III-I) permitted the writer to reproduce (Fig.III-2) given below.

The height of the limestone quarry, in which the experiment took place, was about 41 ft. (Fig.III-I). A Shot-hole, 7" in diameter, was drilled vertically 30 ft. back from the face, this distance being chosen so as to eliminate all danger of destroying the limestone face by the dynamite charge used (110 lbs. loaded to ¼ of the height of the shot-hole.)

To minimise the crushing effect of the explosive on the rock and also to avoid contamination by the tamping material after the explosion, the charge was not tamped. After the shock all crevices produced on the vertical limestone face as well as on its upper surface were surveyed. Later at the base of the limestone face a horizontal gallery was constructed right up to the point of the explosion in order to observe the direct effect of the explosion.

The effects were as follows:- (Fig.III-2).

1) The 7" diameter hole assumed at its lowest part

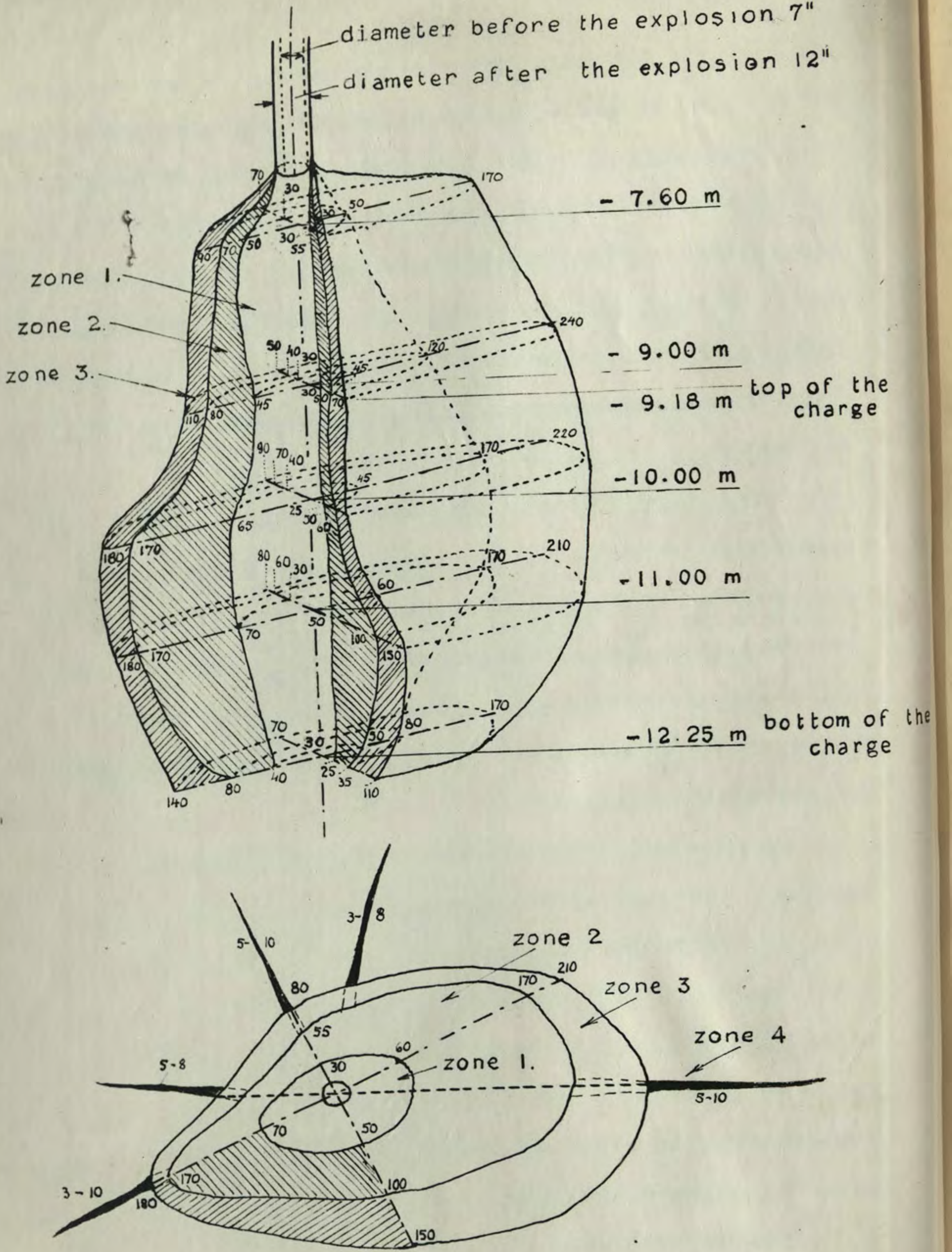

diameter before the explosion 7"
diameter after the explosion 12"
- 7.60 m
- 9.00 m
- 9.18 m
top of the charge
-10.00 m
-11.00 m
-12.25 m
bottom of the charge
zone 1.
zone 2.
zone 3.
zone 4
170
240
220
210
170
140
80
40
25
35
110
180
170
110
80
90
70
50
30
55
45
65
60
100
150
3-8
5-10
5-8
3-10

Fig. III-2.

the shape of an ellipsoid, the height of which was about 16 ft. with tranverse dimensions that did not exceed 4 ft. at its widest part. The limestone facing of this ellipsoid was baked like brick from one to several inches deep.

2) Beyond this burnt-out limestone was a zone easily removed by scratching with a pick, leaving a cavity in the shape of an irregular ellipsoid about 11 ft. wide in its largest section. This was the zone of immediate physical effect upon the rock and the material in it had the consistency of a "soft aggregate" of more or less noticeable grains.

3) The next part of the limestone, within a radius of from 3 to 9 ft. in its largest section, could no longer be removed by scratching only and consisted of material which, when removed by pickwork, split into pieces ranging in size from a pea to a nut or even larger. After the removal of this shattered part of the rock the cavity formed an irregular ellipsoid shaped like a barrel, about 8 to 14 ft. in its largest section and about 18 ft. in height.

4) Beyond a radius of 8 ft. in a direction transverse to the limestone face and beyond a radius of 14 ft. parallel to the limestone face, the rock was more compact but was full of vertical and oblique crevices and cracks, which, reaching the limestone face and surface, could be observed in vertical and horizontal sections. This condition spread over a radius of 90 ft. around the shot-hole, beyond which the crevices changed into small cracks and were not noticeable.

According to the size of the grains of rock which were observed one may deduce a certain grouping of the effects which, though a little artificial, may give some picture of the influence of the explosion on the rock:

The detonation of the explosive produces the chemical change of its components into a small volume of gas of very high pressure and temperature. This large amount of released energy is converted into heat and mechanical energy. In addition to pushing the material away from the centre, the effect of this released energy, upon immediate contact with the exploding charge, is to produce certain chemical changes in the rock. The part so affected can be called the zone of the chemical effect of the charge (zone 1 in Fig.III-2).

The particles of the rock farther away are mostly submitted to the shock impulse which, being greater than the ultimate strength of the rock, causes reciprocal shifting of these particles which results in the pulverized and incoherent consistency of the material. This part can be called the zone of crushing effect (zone 2 in the figure).

In the third zone the rather larger particles are moved bodily while the individual grains of which they are composed retain their cohesion and return after the shock to their original relative positions. This zone can be called the zone of shattering of shuttling effect (zone 3 in the figure) and one should note that within it most of the material retains its original cohesion.

In the fourth zone the released force of the explosive causes only partial deformation along the directions where the resistance of the rock is low, forming crevices and cracks. This may be called the zone of cracking effect, where the attacking force more or less approaches the elastic limits of the rock.

Beyond this sphere, the behaviour of the rock is completely elastic and it may be assumed that all the particles, in the physical meaning of the word, being displaced by the mechanical force from their original positions, return to them, after being balanced to and fro, and the explosion does not leave any permanent sign of its influence. In this zone the compression and shear forces do not exceed the limit of the elasticity of the material. This region may be therefore called the zone of elasticity or the zone of seismic waves.

The inner diameter of this last zone is then the locus of all points where the attacking force is equal to the elastic limits of the rock. For any given charge and conditions of firing, this diameter varies for the same rock and its size probably affects the amount of energy converted into seismic waves, as well as the length and other characteristics of the waves produced.

From Fig.III-2, it is evident, that the effects described above are not confined to the rock material within the height of the charge, but:

a) they spread towards the surface where the zones mentioned (1.2.and 3) can be observed at a distance of 5 ft. above the charge,

b) they spread below the bottom of the charge to a distance of 2 ft. both a. and b. causing the height of the zones discussed to be about 7 ft. greater than the height of the charge; furthermore

c) the diameter of the shot-hole, being originally 7", was enlarged to 12", its effect reaching almost to the surface.

It is also evident, that the zones discussed have their largest dimensions at half the height of the charge, and are not symmetrical with regard to the axis of the hole. In general the effect is greater towards the vertical face of the limestone quarry, i.e. towards the open side of the rock, than towards the solid body, but is larger towards right and left, which might be attributed to the smaller resistance of the limestone bed in these directions.

In another experiment carried out in the same quarry, a charge of the same size and under the same conditions was thoroughly tamped with sand and thick mud. The limestone face was shattered to such an extent that it was impossible to approach the very point of explosion without removing the whole rock.

Similar phenomena, but on a smaller scale, can be obseved in any less elastic rock. Explosive discharged in a clay-hole will produce a zone of crushing effects (zone 2) several times greater than in the case of limestone, whereas the next zone of shattering effects will be very small, and the zone of cracking effects (zone 4) may not exist. The last zone, of seismic waves, will also be small, since the elasticity of caly is smaller than that of limestone.

In the work of seismic prospecting the same shot-hole may be used several times. The effect of each successive charge on the rock will vary with the state of the rock after each explosion, and this state, as has been shown above, depends on the type of rock and on the tamping conditions of the charge used.

It would be of importance for seismic prospection to know the value of exploding force which is converted into seismic waves. However, very little has been done in this direction since it is very difficult to elaborate any formulae which would deal with all possible losses to which the exploding force of dynamite or any other explosive is submitted before it is converted into the part useful for seismic prospection. Most of the considerations, therefore, must be based upon the experiments in the laboratory and direct field observations. Some of the writer's own observations are given below.

The experiments carried through in laboratories for the examination of the strength of explosives show that there is a considerable difference between the so-called "explosive strength" and the "total energy content" in the explosive. The figures given below illustrate this fact clearly (Ref:III-2).

Explosive	Explosive Strength kgm./ kg.	Total Energy Content kgm.per.kg	Maximum Pressure lbs.sq.in.
Blackpowder	29,000	283,000	65,000
Trinitrotoluene	83,000	405,000	690,000
Nitroglycerine	121,000	479,000	1,200,000
100% Blasting Gel.	126,000	536,000	1,000,000
60% Dynamite	93,000	346,000	716,000
30% Ammonal Gel.	68,000	334,000	490,000

The explosives most frequently used in the prospection described were 60% dynamite and 30% Ammonal Gel. The expansion ratio of dynamite i.e. the ratio of the total energy content in dynamite and its explosive strength is 346,000: 93,000 = 3,5: whereas the expansion ratio of Blackpowder is equal to about 9. Some German experiments showed that Blackpowder would have a lower expansion ratio when thoroughly pressed in a tight steel container with thick walls. It is well evident then that when the expansion ratio decreases the explosive acts more strongly, and the work done by it will be greater. Practically the only useful work of an explosive is done during the early stages of expansion. Therefore, great attention must be paid to the compactness of the material. This is practically achieved by correct tamping. Furthermore, as has been shown, the elasticity of the rock embodying the charge is of great importance. It is known that the exploding force of a dynamite charge spreads with a velocity of 5000-7000 m/sec. If this charge is detonated in a rock in which the seismic waves spread with the same velocity the exploding force loses little of its value, especially when the space between the charge and the walls of the hole is reduced to a minimum by a careful tamping with correct material. In this case the tremor will be well observed round the shot-point. The effects of the explosion of the same charge placed in dry sand or dry clay, even if well tamped, may hardly be felt around the immediate vicinity of the shot-point.

In seismic prospection the proportion of the available explosive strength which is converted into useful seismic energy depends very much on these two factors, i.e. tamping and the type of rock. These factors are controlled in the first instance by the party chief, and then by the drillers and shooter. A shot-hole should almost always be drilled down to the rock which contains at least water(in the case of loose sand and dry clay) or whose wave velocity is over

1500 m/sec. As practice further shows it is better to have a shot-hole in compact clays or shales rather than in a dry sand or hard rock. The latter fact may be explained by considering the zones described before. In a hard rock, such as limestone or sandstone, the second zone is very small, and the third zone at each successive shot becomes more and more crushed into a pulp. This pulp and other pieces of loose rock form a kind of natural barrier for the explosive force to spread away towards the harder and compact parts of the rock. In a soft rock the crashed zone and so the displacement of the particles is rather large under the push of the first charge, but each successive charge increases the volume of the empty space in the hole only a small amount These successive charges also press the loose particles into the face of the soft rock thus cementing the face, which, after a certain number of charges, will not be pushed any further from the centre but will convey the shocks well into the solid rock.

The compactness of the charge in a shot-hole increases when the hole is filled with water. After several explosions, the shot-holes, drilled in hard rock, will not retain the water, but it will run away through the cracks and crevices made by the previous charges. In soft ground, after a few charges have been exploded, a cave is made at the bottom of the shot-hole, without crevices, and the facings are covered with smashed pulp of shattered rock. Nevertheless the hole at the bottom, being much larger, causes the compactness of the charge, even when tamped with water, to be smaller, which of course decreases the useful strength of the explosive.

In field work, it is therefore, essential that one shot-hole should not be used for more than two or three shots. The first charges should be very small and a smaller charge should not follow a greater one, unless the hole is deepened to a new stratum. If more than three shots are required from one shot-hole and if the ground is soft and easy to drill it is better to prepare two or three shot-holes in order to obtain suitable results.

All the above-mentioned considerations have their value rather for reflection shooting than for refraction shooting. For the latter as a rule, great charges were employed (from 50 to 150 lbs.) , and to ensure the success of the field work, it was necessary to have several shot-holes ready in advance, as the shot-hole, once used, is normally out of use for the next shot. In reflection shooting the charges were small (from a few ounces to a few pounds) and here the compactness of the material and the state of the rock in which the explosion took place, played an important role in obtaining good results on the seismograms.

Some points on the theory of seismic waves.

The theory of elasticity states that in any material there exist two principal vibrations of each particle removed from its original position by a shock. These two vibrations of each particle round its original position pass from one particle to another forming two waves:

1) Longitudinal (compressional), or primary wave (P), where the vibrations of the particle of the medium are parallel to the direction of propagation.

2) Transversal (shear), or secondary waves (S), where the vibrations of the particle of the medium are perpendicular to the direction of propagation.

These waves are called essential or "body waves" as they are transmitted through the body of the material. In reality these movements are more complicated. In any primary wave there is always a little of transverse movement and vice-versa.

The velocity of these waves depends on the elasticity and density of the material and is expressed by the formulae:

$$V = \sqrt{\frac{\text{Elasticity}}{\text{density}}}$$

It is evident then that the velocity of the waves is proportional to the square root of the elasticity and inversely proportional to the square root of the density. It might then be expected that heavy rocks (of great density) would

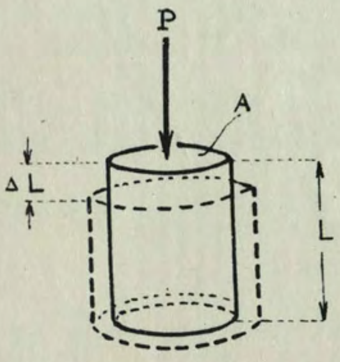


Fig.III-3.

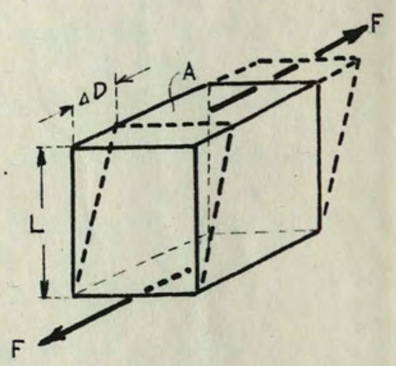


Fig. III-4.

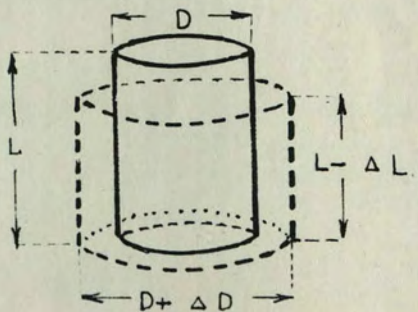


Fig. III-5.

have low wave velocity. However, the elasticity varies over a much wider range than the density and hard rocks have much higher velocities than loose rocks.

The elastic properties of a homogeneous isotropic medium are defined by one of the three pairs of the elastic constants. These pairs are:-

1) Young's modulus "E" and Poisson's ratio "σ"

2) Bulk modulus "K" and shear modulus "n"

3) Lame's constants "λ" and "μ"

These elastic constants can be expressed in a short summary as follows:- (Ref:III- 3 and 4).

a) "E", "K", and "n" are the measures of the stress-strain relations :

Constant	Stress	Strain	Ratio	Remarks
Young's Modulus "E"	Tension or compression per unit area P : A	Elongation or shortening per unit length ΔL : L	$E=\frac{D:A}{\Delta L:L}$ Dynes,/sq.cm	P — force $\perp$ to the area A fig.III.3
Bulk Modulus "K"	Hydrostatic pressure per unit area P : A	Change of volume per unit vol: ΔV : V	$K=\frac{P:A}{\Delta V:V}$ Dynes/sq.cm	
Rigidity or shear modulus "n"	Simple tang. shear per unit area F : A	Displacement in the line of force per unit length $\perp$ to the line of force. ΔD : L	$n=\frac{F:A}{\Delta D:L}$ Dynes/sq.cm	F-force tang. to the area A fig.III.4

b) σ - is a measure of geometric change of shape (fig.III-5)

$$\frac{\Delta D \ : \ D}{\Delta L \ : \ L}$$

where D - diameter
L - length } of the particle

The value of σ is limited to the range of 0 to 1/2.

c) Lame's constants are also very convenient in the theory of elasticity, "λ" corresponding to the "E" and "μ" corresponding to the "n"

There exists a list of the interrelations among these constants, (see ref: III-3). The one important for the following gives the relation between "K", "n" and "σ"

$$n = K \, \frac{3 \, (1 - 2\sigma)}{2 \, (1 + \sigma)}$$

"V_p", the velocity of the longitudinal wave and "V_s", the velocity of the transversal wave through a material are related to the density, D, and to the elastic constants of the material in the formulae:-

$$V_p = \sqrt{\frac{K + \frac{4}{3} n}{D}} \ ; \qquad V_s = \sqrt{\frac{n}{D}}$$

Taking the ratio of V_p and V_s and expressing "n" by "K" and " ", one obtains:-

$$V_p : V_s = \sqrt{(K + \tfrac{4}{3} n) : n} = \sqrt{(1 - \sigma) : (\tfrac{1}{2} - \sigma)}$$

For the special case of $\sigma = 0,25$, which is commonly applied one has:

$$V_p : V_s = \sqrt{3} = 1,73$$

Since " " is always positive, the ratio of V_p and V_s is always greater than 1, and therefore the primary wave has always a greater velocity than the secondary wave. In other words the primary waves are always the first recorded on the seismograms. Hence their name "Primary".

Besides the "body waves" (primary and secondary), two other waves occur at a free boundary of a medium. These waves have their amplitudes decreasing with the depth and their occurrence is therefore confined to a zone near the surface. In field-practice they are called "the waves of the surface." They are also called "Rayleigh waves" (R) and Love waves (L), the first of which occur at the free surface of an elastic body, the second being propagated in a surface layer having elastic properties different from those of an underlying elastic body. The latter are more commonly met with in practice and are also called "ground rolls" of large amplitude and low frequency. Their speed is still smaller than that of the secondary waves.

All these waves can easily be recorded and their speed calculated from the seismograms. A typical example is given by L. D. Leet, (Ref:III-5) who, after having carried through some seismic experiments upon the granite and norite in the area of Rockport and Sudbuy in America, determines the velocities and the elastic constants of these rocks and compares them with those calculated from laboratory experi-

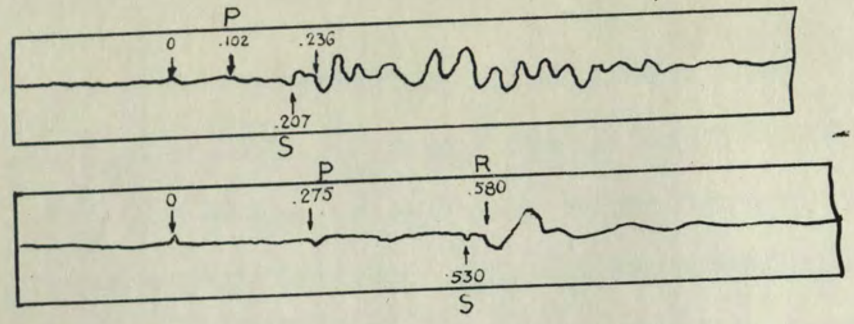


Fig. III-6.

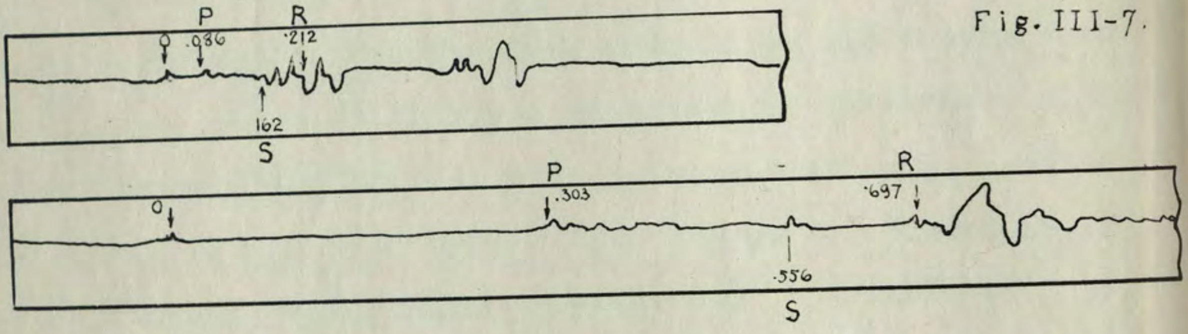


Fig. III-7.

Fig. III-8.

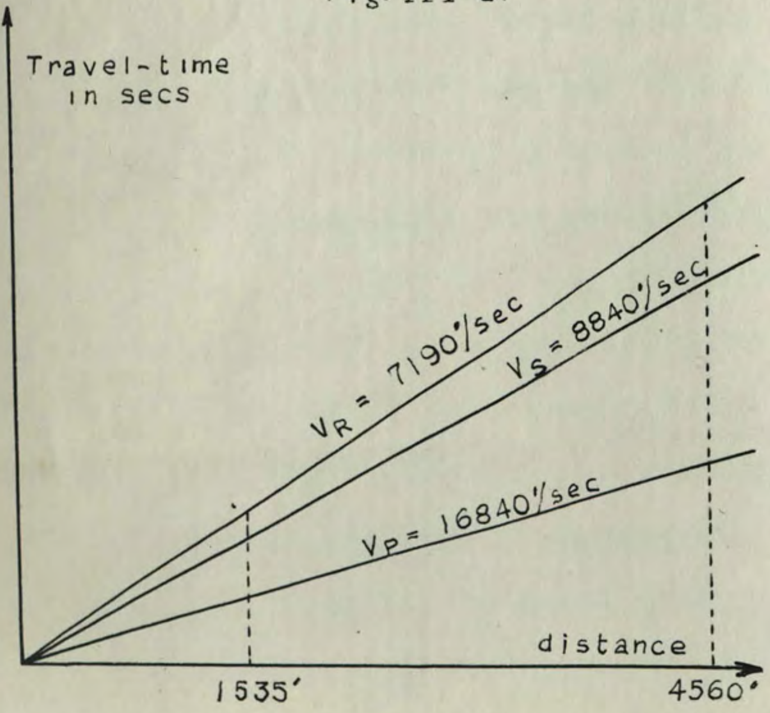
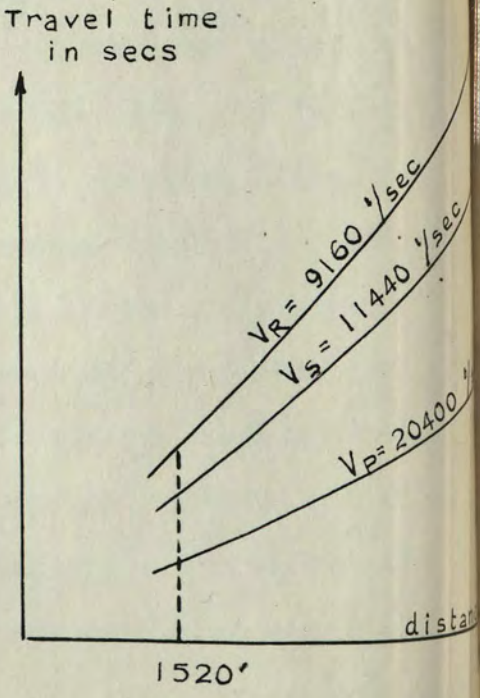


Fig. III-9.



ments. From various seismograms two have been selected and are shown in figs III-6 and 7 for "granite" and two for "norite". The apparatus used in these experiments was of the mechanical type (Mintrop). The seismograms chosen for granite were for a distance of 1535' and 4560' from the shot point to the receiver, and the seismograms for the norite for distances of 1520' and 5590'. On the seismograms one can read the impulses of three waves: Primary, Secondary and Rayleighs. Tracing the co-ordinate system where the abscissae represent the distance in feet and the ordinates the time in seconds, one obtains three travel time-lines, (fig.III-8,9) which give the velocities of corresponding waves.

They are as follows:-

	Granite	Norite
V_p	16840'/ sec	20400'/ sec
V_s	8840'/ sec	11440'/ sec
V_r	7190'/sec	9160'/ sec

The ratio of these velocities are :-

	Granite	Norite
$V_p : V_s$	1,9	1,783
$V_r : V_s$	0,813	0,801

The elastic constants calculated from these figures seem to be higher than those obtained in the laboratories. The values of the elastic constants calculated for great

pressures (from 2,000 - 10,000 atm.) in the laboratories (Adams and Williamson) are not far distant from the values computed from the experiments performed in the terrain. Apparently, the compactness and cementation under the influence of pressure and geologic time cause an increased amount of hardening of the rocks which results in an increase of the elasticity and a consequent increase of the wave velocity. It is also the cause of the fact that in the same rock, the wave velocity increases with depth. Usually the deeper rocks possess higher velocity than those overlying them. If it were not for this fact, refraction prospecting which depends on these orders could not possibly be carried out. It may occur that a bed of lower velocity is embedded in beds of higher velocities. It cannot be detected by refraction waves and its thickness, obtained by other means (drilling) must be added to the depth of the underlying bed. If the thickness is considerable and varies within a large range, the depth computations are very uncertain unless the average velocity from the surface down to the bed prospected is known.

In the following only the primary waves will be considered since they have a higher velocity than other waves and arrive at the receiver first. The others are of theoretical value in prospection as they appear during the disturbances caused by the Primary waves. They are, however,

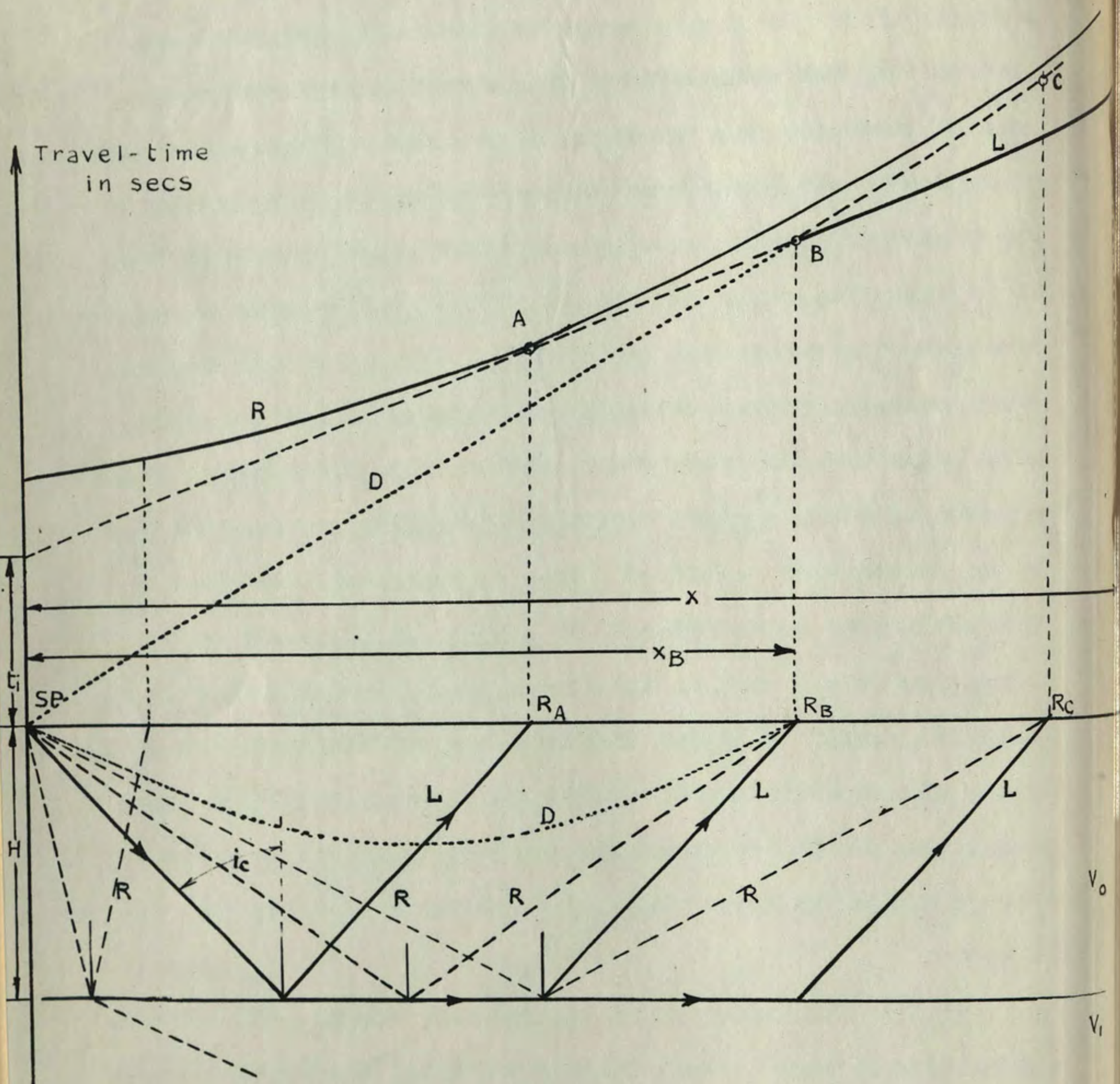

Travel-time
in secs
C
L
B
A
R
D
X
x_B
t_i
SP
R_A
R_B
R_C
L
L
L
D
i_c
H
R
R
R
R
V_0
V_1

Fig. III-10.

of great value in the seismological observations caused by the distant tremors of the ground (earthquakes). They are registered more distinctly on such seismograms because at great distances as dealt with in seismology, the space, of time between the Primary waves and the others is long enough to allow the clear registration of the latter.

Waves encountered in seismic prospection.

Consider an explosion at shot-point S. (Fig.III-10) A spherical wave initiated by it, spreads out uniformly in a homogeneous, isotropic medium, with a velocity V_o (for the Primary waves). Let this medium be in contact with an underlying second medium where the velocity of the longitudinal wave is $V_1 \quad V_o$.

The involved waves will be as follows:

1) The sound-wave or air-wave. This is a longitudinal wave spreading out in a gaseous medium with an average velocity of 330 m/sec (about 1000' per sec). In seismic prospecting this wave is of some value for the determining of the distances between the shot-point and receiver, described in Chapter II page 50 . Being of the lowest speed, the air-wave may be recorded at the end of the seismograms obtained in refraction shooting. In reflection shooting, where the distances are short, usually measured with the tape, this wave is of no special value and rather distrubs the recording of

reflected waves.

2) At the boundary of the two medium, air and ground, one has to deal with the waves of Love and Rayleigh. They are a combination of longitudinal and transverse waves which are of no value to prospection but cause the surface disturbances observed on the seismograms. These surface distrubances are also called "Ground Rolls". Being of lower speed than the next type of waves, they appear after the first impulse is recorded. Being of lower frequency, their presence is made visible upon the seismograms as low vibrations of rather a great amplitude. They may last for a long time and are very undesirable especially in reflection shooting, disturbing as they do the recording of the reflected waves, which are superimposed upon them. One can avoid them by making the seismographs insensible to low frequences. The frequency of these waves is of a range from 10 - 15 cycles per second.

3) The direct wave. This wave travels directly from the shot-point S to the receiver. It travels through the surface (upper) medium with the velocity V_o and gives the first impulses (the first arrivals) on the seismograms until the critical distance R_b is reached at which the actual refracted wave comes first. When the time of travel of the refracted wave becomes shorter than that of the direct wave the latter may produce second impulses, the impulses of the refracted wave being the first to appear.

The corresponding travel-time line of the direct wave in the co-ordinate system is shown by the line "D".

4) That part of the wave which enters deep into the upper medium, strikes the contact surface between the medium V_0 and V_1, at different angles of incidence. The behavior of this wave at this interface is similar to that of the Light-wave. It will be thus partially refracted into the lower medium, partially reflected back into the upper medium, and one part will slide along the contact of these two media. The seismic waves represented by their rays would be ruled by the same principles as the light rays:-

a) So their refractions into the lower medium would take place according to Snell's law

$$\sin i : \sin r = V_0 : V_1$$

where "i" is the angle of incidence

"r" is the angle of refraction

when "r" is equal to 90°, $\sin r = 1$, and $\sin i_c = V_0 : V_1$. This angle "i_c" is described as the critical angle of incidence, at which the wave, striking the interface, besides being completely reflected, behaves according to the Huygens Principle, which states that each point on an advancing wave front may be considered as a new source of spherical waves. Thus the waves striking the interface at the critical angle becomes the source of new spherical waves and wavelets which are diffracted back to the surface at the sm same critical angle i_c. The energy transmitted in this way is very small and the processis not evident from simple geometric considerations. The problem has been considered in detail by M.M$_u$skat (Ref:III-6) who stated that the assumed refraction paths are minimal time paths in the sense of Fermal's principle (the ray reaching a given point from a given source has reached that point by a "minimum time" path between the source and the point) and it has been proved geometrically that they are necessarily real, since they are the only type of paths that can give the observed linear time distance curves or time-travel-lines.

These waves are usually called <u>refraction waves</u> and are the basis of the seismic method of refraction prospecting.

The distance from the shot-point, beginning from which the refraction wave is detected as the first arrival, is called the critical distance and is expressed by the formulae:

$$X_b = 2\,h.\sqrt{(V_1 - V_o) : (V_1 + V_o)}$$

At this distance the refraction wave and the direct wave have the same time of travel (Point of interception "B" of the lines "D" and "L"). The paths of this refraction wave are shown on the figure in solid green and its corresponding travel-time line in the co-ordinate system is represented by the line "L".

From the figure it can be seen that the original wave, striking the contact surface at the angle "i_c" after being refracted at 90°, produces along the contact surface the disturbances which are the sources of new waves, the latter returning back to the surface at the same critical angle. Beginning thus from the point "R_a" at the surface, one is able to observe these waves on seismograms as the second impulses, the first impulses being those of the direct waves. At the point "R_b" the travel-time of the refraction-wave and that of the direct wave are equal. Beginning from this point on the surface, the first arrivals will be those of the refraction-wave, whereas the direct wave will be observed as the second arrival. In practice the intercept point corresponding to the position of receiver at R_b is found from the diagram, by tracing the line "D" and "L", both of which correspond to the first impulses recorded on the seismograms.

b) The waves which strike the contact surface at the angle equal or greater than ~~that of~~ the critical angle, are subjected to total reflection and their impulses traced upon the corresponding distances give the travel time-curve from point "A" upwards. In practice this curve only goes up to point "C", where the direct wave merges into the total reflected wave.

c) The waves striking the contact surface at angles smaller than that of the critical angle will be partially reflected back to the surface and partially refracted, penetrating into the lower medium at the refraction angle lower than 90°. The reflected part of these waves recorded on reflection seismograms gives the first part of the time - travel curve from 0 to the point "A". These waves and their travel-time curve are the basis of the reflection method of prospection, where the depth of the reflected bed can easily be determined by the formulae:-

$$h = \frac{1}{2}\sqrt{V_o^2 \cdot t^2 - x^2}$$

where "x" is the distance of the receiver, and "t" the corresponding time of the reflected impulse recorded on the seismogram. This formulae in algebraic expression represents a hyperbola of which the equation is:

$$V_o^2 t^2 - x^2 = (2h)^2 \qquad \text{or}, \left[\frac{V_o}{2h}\right]^2 t^2 - \left[\frac{1}{2h}\right]^2 x^2 = 1$$

The two axes of hyperbola are accordingly equal :

$$\frac{V_o}{2h} \quad \text{and} \quad \frac{1}{2h}$$

differentiating this equation one obtains:

$$h = \frac{x}{2}\sqrt{\frac{V_1 - V_o}{V_1 + V_o}}$$

Thus the travel-time line for the direct wave "D" is an asymptote to the travel-time curve of the reflected wave, "R" whereas the travel-time line for the refraction-wave

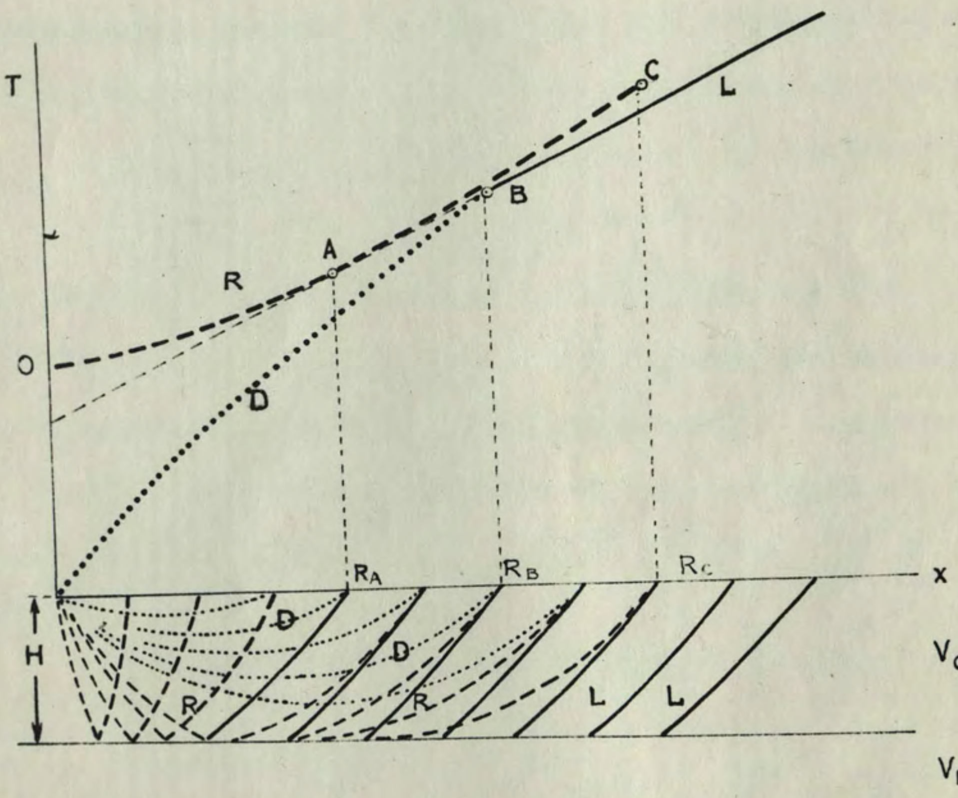


Fig. III-11.

"L" is the tangent to the travel-time curve "R" at the point "A", (the beginning of the refraction wave.)

4) The waves refracted into the lower medium behave in the same way as do the original waves in the upper medium i.e. they are the sources of the direct, refraction and reflection waves at the contact with the third medium of velocity V_2.

In nature, there does not exist a homogeneous, isotropic medium. Even the wave velocity of the same medium increases with depth. The thick deposits of clay or sand, covering the plain of north POLAND are of similar lithology but have a higher wave velocity in their depth a than near the surface. Therefore the path of the seismic rays is not straight as in theory. The velocity "V_o " may change in depth in a linear way or in other more complicated ways. Considering the linear case $V = V_o + ah$ where V_o is the surface wave velocity of the upper medium; "h" the depth considered; "a" a constant co-efficient; then the path of direct, refraction and reflection waves as well as their travel-time curves will be represented as shown in the figure III-11.

In practice, however, it is easier to calculate the depth with the former formulae, especially since the errors made in this way are of a range of 1 -5% .

REFERENCES

Ref: III - 1. J. Naturski, "Augmentation de la puissance des puits a petrole a l' aide du torpillage" Revue de l 'Industrie Mineral 1937. Part 1. p.207.

Ref: III - 2. H.Nash & J.Martin "Significance of Some Fundamental Properties of Explosives with Special Reference to Geophysical Prospecting." Geophysics 1936. Vol. I. No. 2 p. 239.

Ref: III - 3. L.Nettleton, "Geophysical Prospecting for Oil". 1940, p. 235.

Ref: III - 4. B.Gutenberg. "Physics of the Earth, Vol. VII.

Ref: III - 5. L.D.Leet, "Velocity Waves", Physics 4. 1933.

Ref: III - 6. M.Muskat, "The Theory of Refraction Shooting". Physics, Vol.4, Nr.1. pp. 14 - 28. January 1933.

CHAPTER IV.

REFRACTION PROSPECTING IN POLAND.

The surveys carried out in Poland by the refraction method of prospecting can be grouped as follows:-

I. a) Refraction prospecting carried out by the German Companies (Piepmayer Co. of Kassel and the Seismos Co. of Hanover) in 1929 and 1930, with the Mintrop type of seismographs, specially constructed for refraction only.

I. b) Refraction prospecting carried out by the Geological Survey of Warsaw in 1932 and 1933 with its own staff, using the mechanical seismographs of the Mintrop and Schweydar type, constructed for refraction only.

II. a) Refraction prospecting as a detailed work carried out by the Pioneer Co. of Lwow (Geophysical Institute) parallel with the main reflection survey which was done during the years 1934 to 1937, with its own staff, using the 6 - geophone reflection set of Seiscor, Tulsa, model 1934, which could be adjusted correspondingly for refraction work.

II. b.) Detailed refraction prospecting carried out by the Geotechnika Expl. Co., Ltd., of Lwow, parrallel with the reflection work of 1938 and 1939, using the 12 - geophone refraction - reflection set of the Heiland Corpor: Colorado, 1938 model.

The seismic prospecting conducted with the mechanical type of seismographs (point I) can be considered as reconnaissance work in the Carpathian Foreland. The small number of receivers namely three, working simultaneously, the low sensitiveness of the apparatus used thus resulting in the too high expenditure of explosive, and the method as yet inadequately developed as a whole, handicapped the application of these sets to more detailed refraction problems.

The researches headed II. were conducted with the reflection sets of Seiscor or Heiland. The detailed work was very much favoured by the number of receivers (geophones) working simultaneously (6 or 12) with one recording van manned by one observer only; moreover, the higher sensitiveness of the apparatus reduced the quantity of explosive used. The reflection seismographs required only small changes in their mass and suspension, when used for refraction.

Brief geological description.

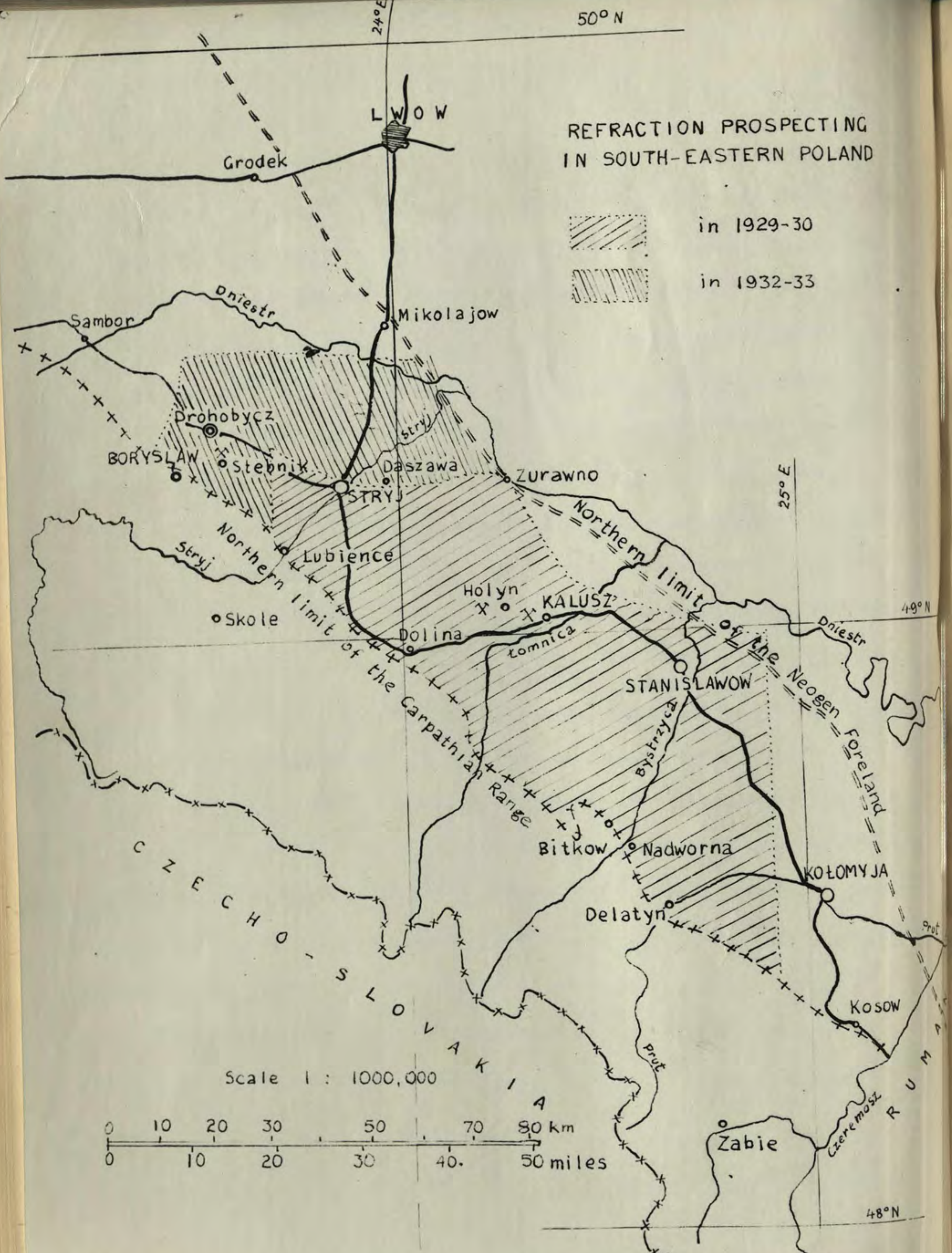

REFRACTION PROSPECTING
IN SOUTH-EASTERN POLAND
▨ in 1929-30
▥ in 1932-33
50° N
24° E
25° E
49° N
48° N
LWOW
Grodek
Mikolajow
Sambor
Dniestr
Drohobycz
BORYSLAW
Stebnik
Stryj
Daszawa
STRYJ
Zurawno
Northern limit of the Neogen Foreland
Lubience
Stryj
Northern limit of the Carpathian Range
Skole
Holyn
KALUSZ
Dolina
Łomnica
STANISLAWOW
Dniestr
Bystrzyca
Bitkow
Nadworna
KOŁOMYJA
Delatyn
Prut
Kosow
Prut
CZECHO-SLOVAKIA
Zabie
Czeremosz
RUMA
Scale 1 : 1000,000
0 10 20 30 50 70 80 km
0 10 20 30 40. 50 miles

Fig. IV-1.

All present oil and gas fields in Poland are situated in southern Poland, in the areas adjacent to or included in the Carpathian Mountain system. These areas form a belt about 30 miles wide and 300 miles long, from the Roumanian frontier in the east to Tarnow in the west. From physiographical and structural points of view the belt considered can be divided into three zones . (Fig.IV - 1):

1) The Carpathian Mountain Range in the south.
2) The Foreland or Sub-Carpathian province in the middle.
3) The Podolian Plateau, in the north.

Oil fields are located along the northern edge of the Carpathian Range. The biggest among them are :- Boryslaw-Tustanowice, Rypne and Bitkow. Natural gas fields are found in the Foreland area at Daszawa, Opary, Kosow, and it also contains rich deposits of salt and potassium near Kałusz, Hotyn and Stebnik.

Genetically, the relationship of these three zones is as follows:-

The first zone, represents a complicated system of folds, in many cases broken or overturned, and major overthrusts extending over large areas. Most of the rocks in this zone are of the Tertiary and Upper Cretaceous age. In the north the rocks of this zone overthrust the Salt Formation of the second zone.

The second zone, constitutes a large Sub-Carpathian

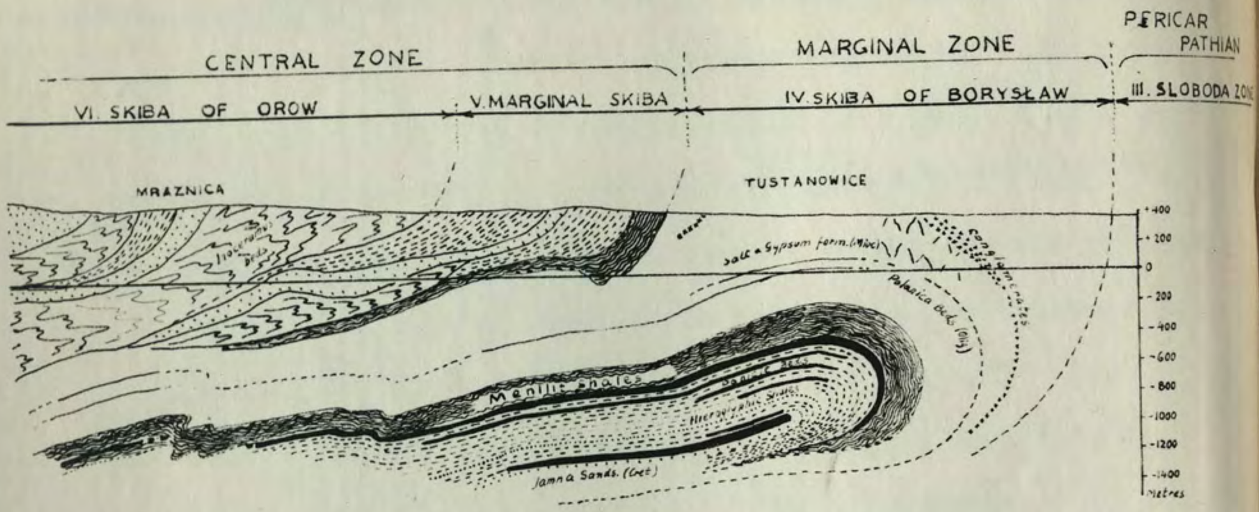


Fig.IV.-2. Geologic section through Carpathian Folds of Borysław after K.Tołwiński.

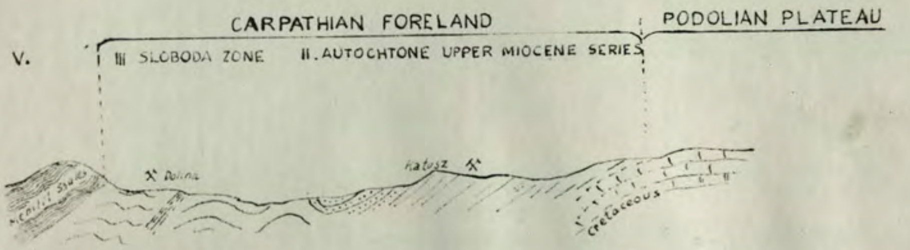


Fig.IV.-3. Geologic section through Carpathian Foreland near Dolina and Kałusz, after Teisseyre.

depression between the orographically exposed Carpathian Range and the rigid Podolian Plateau. This zone, called the Carpathian Foreland, is composed of a formation largely Miocene in age. The southern boundaries of this zone adjacent to the Carpathians are more intensively folded and represent an older salt formation of the Lower Miocene age.

The third zone, forms a rigid and unfolded framework of Cretaceous rocks which has partly determined the strike of the folds in the Foreland and in the Carpathians.

This situation may be illustrated by two geological sections : one through the Carpathian fold of Boryslaw (Fig. IV - 2) and the other through the Carpathian Foreland near Dolina and Kalusz. (Fig.IV-3).

The stratigraphy and structure of the Carpathian Range shown in the first figure, are characterised by sediments ranging in age from the Lower Cretaceous to the Lower Miocene, developed in the Flysch facies i.e. alternating shales and sandstones indicating a near-shore diastrophic deposition during continuous orogenic movements. The old Flysch geosyncline was not folded into a regular anticline, but, due to orogenic forces of great intensity and of a predominantly horizontal direction, the folds were released from the substratum and subsequently overthrust upon one another (Polish "Skiba", French "Nappe", German "Deckfalte"). Thus the Boryslaw deep element is overthrust on the Pericarpathian or Sloboda zone, and the Central Zone (Marginal and Orow Skibas) is overthrust on the marginal zone. Geophysical methods of prospecting up to 1938, with the exception of a few favourable locations, seemed of limited value to exploration work in this area. This was due to the very complicated structural forms of the folds and flexures which prevail in the Carpathian Mountain system. Therefore here exploration had to be guided by the usual geological methods.

Quite different conditions are encountered in the second zone shown in the second figure. The north east part of this zone consists, at the surface, largely of upper Miocene (Helvetian-Tortonian) sediments which are composed of plastic clays, sand or clayish sandstones and are slightly folded. In this part is the Daszawa gas-field. The foldings of this part are intensified towards the south east until they assume a diapiric character, similar to the Pericarpathian saliferous folds of Campina and others in Roumania. Here we have the rock-salt and potassium-salt beds (Stebnik, Kalusz). The more gentle structural forms of the Miocene sediments in this zone, especially in its northern part, made it more favourable for seismic prospection. Moreover, this province was little known because of the lack of natural exposure. Being covered with a thick mantle of Alluvial and Diluvial deposits geological exploration at the surface was limited and thus opened a broad field for the application of various geophysical methods to reveal the subsurface geological conditions and the structural forms which might be interesting from the point of view of oil and gas reservoirs.

The third zone, the Podolian Plateau on the north east boundaries of the Foreland, emerges to the surface from the Precarpathian sediments of the Foreland, mostly by big step-faulting. It consists of hard rocks of the Cretaceous age (Limestone and Anhydrite). This zone was not of great interest in seismic prospection, and some prospecting done in this zone had rather an informative character.

Geological and geophysical characteristics of the areas given above are mentioned in greater detail in Chapter IX.

1.a) Refraction prospecting of 1929 and 1930.

The seismic refraction prospecting applied for the first time in 1929 and carried out by the German Companies in 1930 had for its purpose:-

1. To locate and determine the extension of new salt deposits (potassium beds) in the eastern part of the Carpathian Foreland.

2. To locate the southern boundaries of the sub-outcrops of the Podolian Plateau in the area investigated.

3. To outline the structure of the deep strata.

The programme of the above investigations was

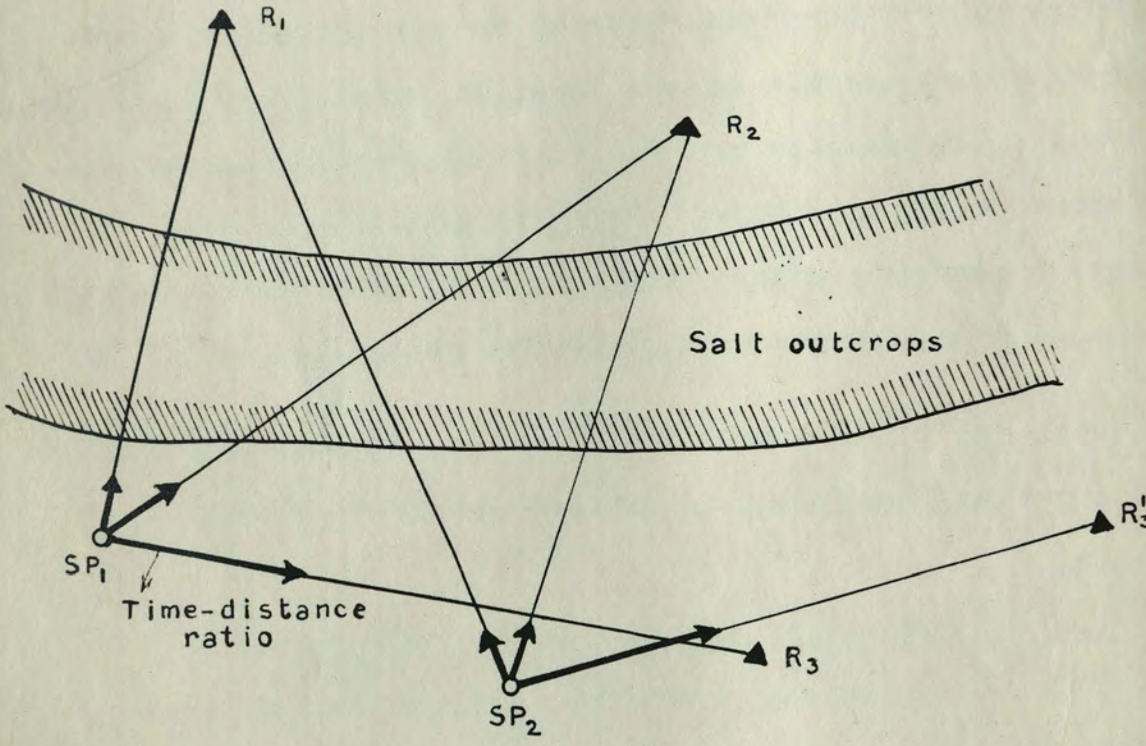


Fig. IV.-4.

established by the Pionier Co. in co-operation with the Mining Department of the Ministry of Industry.

The total area covered by this work of refraction reconnaissance, is shown in fig. IV - 1 in red shading.

Since the writer did not participate personally in this prospecting, he is unable to give the details concerning the field work. In general, it was carried out by two seismic-field-parties, each consisting of three receiver stations with the Mintrop type of seismograph. The investigations were conducted along refraction shooting lines 4 - 6 km. in length. The distance of the receivers varied from 300 - 400 metres. The lines were mainly shot in one direction along communication tracks. The explosive (Ammonit Nr.5.) was placed on the ground in shallow "dugouts", and the expenditure of the explosive as well as the damage done to the terrain were therefore high.

In the area of Kaluzs and Holyn, and thus in the area where salt and potassium deposits were prospected, a "fan-shooting" method of investigation was applied, developed by the Germans in their exploration work in Texas and Louisiana Gulf Coast in shooting for salt domes. The object of this work in Poland was to locate and roughly define the shallow salt and potassium beds.

The way of carrying out a "fan-shooting" is shown in fig. IV-4. The shot point is located at "S" and the corresponding receiver stations at "R_1", "R_2", "R_3", are spread in a fan at almost equal distances from the shot-point.

The potassium and salt beds in the Kalusz and Holyn area seemed to be of irregular forms lying near the surface. A survey carried out in 1937-38, partly by drilling and partly by the seismic method, proved that these beds very greatly in dip, and outcrop at the surface sometimes almost vertically. (See refraction work given below under II.a.,b.)

The prospecting of 1929-30, however, executed in that area, could not deal with the problems of dip or depth, but only with problems of determining in a reconnaissance way, the occurrence of the beds mentioned.

Considering a line of "fan-shooting" passing through a salt bed and another line passing through the normal sequence of sediments (as shown in fig. IV-4) one finds out from time-distance relations which line passes through the salt, since the wave-velocity in the salt is much greater than that in the adjacent sediments. The time-distance ratio for the line passing through the salt will be much smaller than for the line passing through the sediments. When the salt beds are present near the surface at a depth of 100 - 150 feet, as was the case with the potassium beds in the Kalusz area, there was no significant error made in their location by single fan-shooting.

The results of the whole investigation carried out by the Germans over a large area of 3,000 sq. kilometres were not entirely satisfactory. On the strength of this work, suboutcrops of the Podolian Plateau were established and new salt deposits were located within the area explored. In a great measure the problems were favoured by the fact of the shallow occurrence of limestone and salt beds. Problems such as these are normally the easiest for the refraction method of prospecting. This method failed, however, to outline the deep structures in the part of the Foreland investigated. One well sunk in Rachin in 1933 on the strength of the "refraction structure" revealed quite different conditions from those indicated by the refraction method.

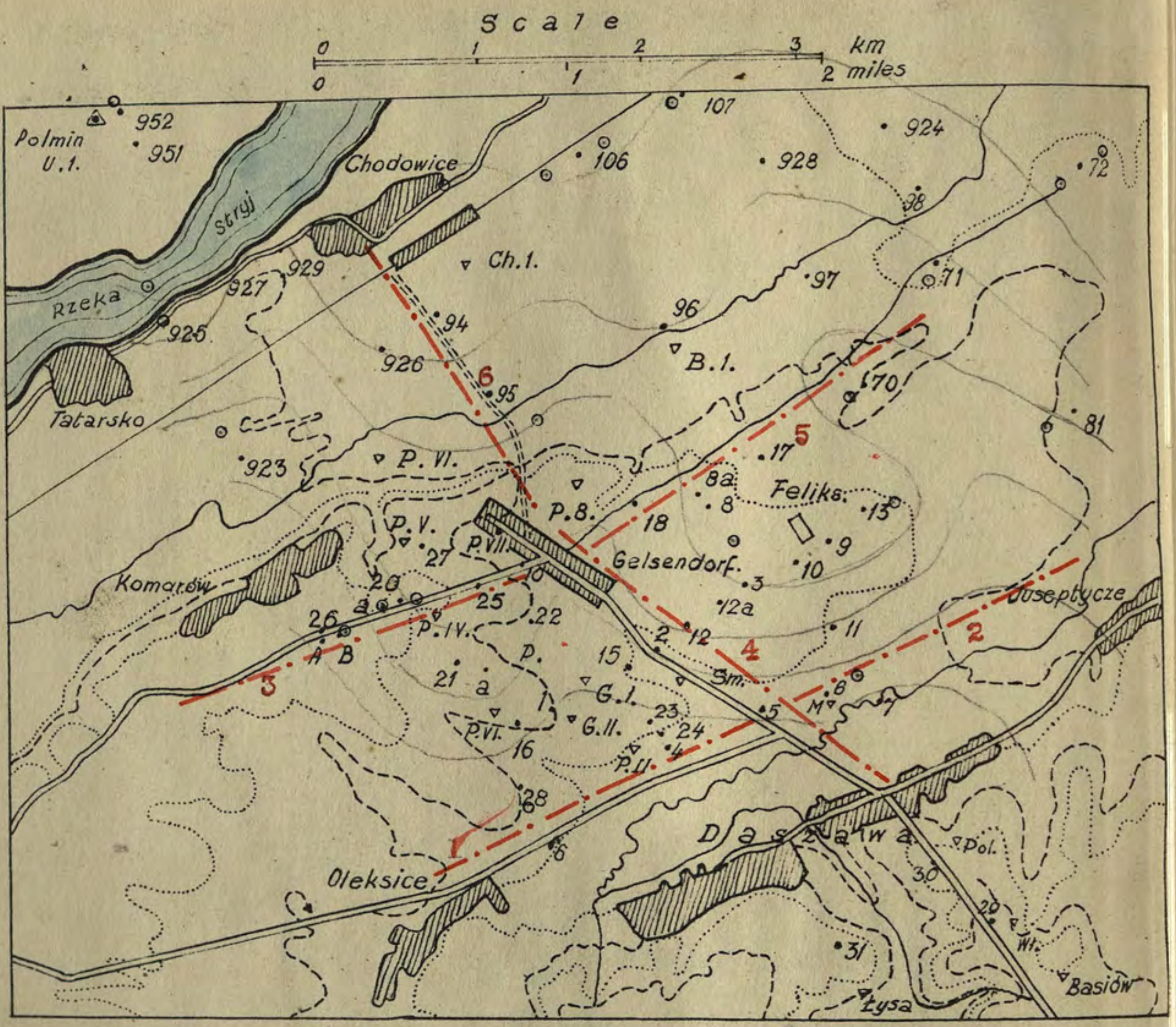
I. b. Refraction prospecting conducted by the Geological Survey of Warsaw in 1932.

The seismograph and its use in field-work has been given in Chapter II.

The Survey began at the Daszawa gas-field in 1932, after a year's pause in 1931, during which preparations were made to equip the Geological Survey with its own staff and seismic outfit.

It was aforementioned, that in the previous years the investigations of deep stuctures in the Foreland area did not yield any satisfactory results, therefore, the investigations of 1932, had for their purpose, first of all, the determining of the possibility of the application of the refraction method for the location of deep or shallow structures in the Foreland area. The cause of the failure of this method in 1930, may have been due to the too great distances between the receiving stations, and therefore the structure which in general might consist of small elements could easily be missed. To "catch" these elements, which might occur, the spreads were made shorter and double traverses, as well as two-way traverses, were applied.

It seems worth while mentioning that the problem of the structural conditions of the Daszawa gas-field had for a long time been fairly important to local geology; all the geologists concerned, have endeavoured to lay down different theories as to the origin. One tried to find out the structural factor which generated the accumulation of such an abundance of "dry gas" (CH_4) under high pressure in a terrain which is more than 10 miles away from the nearest Carpathian foldings. What were the geological conditions in the subsurface which favoured the accumulation of gas and whether these conditions could be followed or found in any other place of the Foreland, formed the basis of the problem presented to the seismic survey. Therefore the



Seismic prospecting at Daszawa.

Fig. IV - 5.

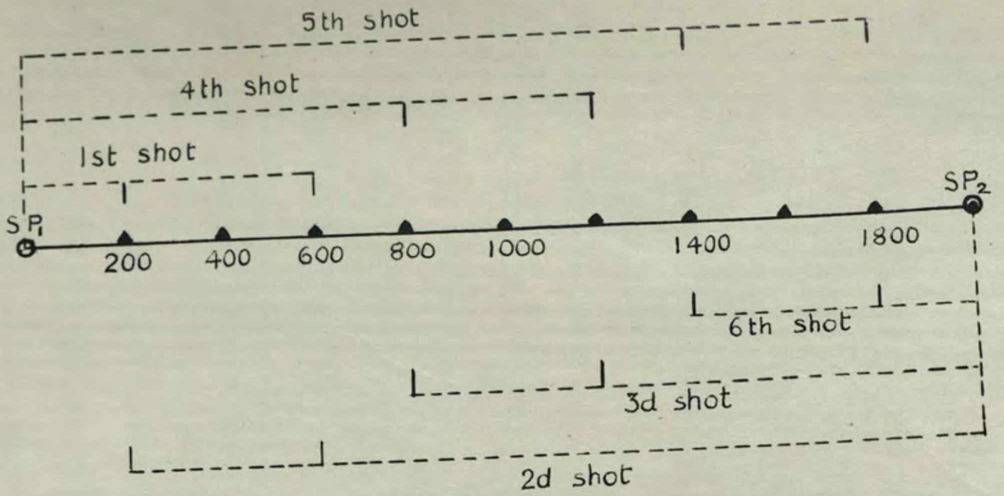
seismic experiments carried out at Daszawa, had for their first object to determine the velocities of the layers possessing gas and tie on the observations to the existing gas wells, and secondly, by exploring the Daszawa subsurface to follow and locate analogical seismic conditions in other places of the Foreland.

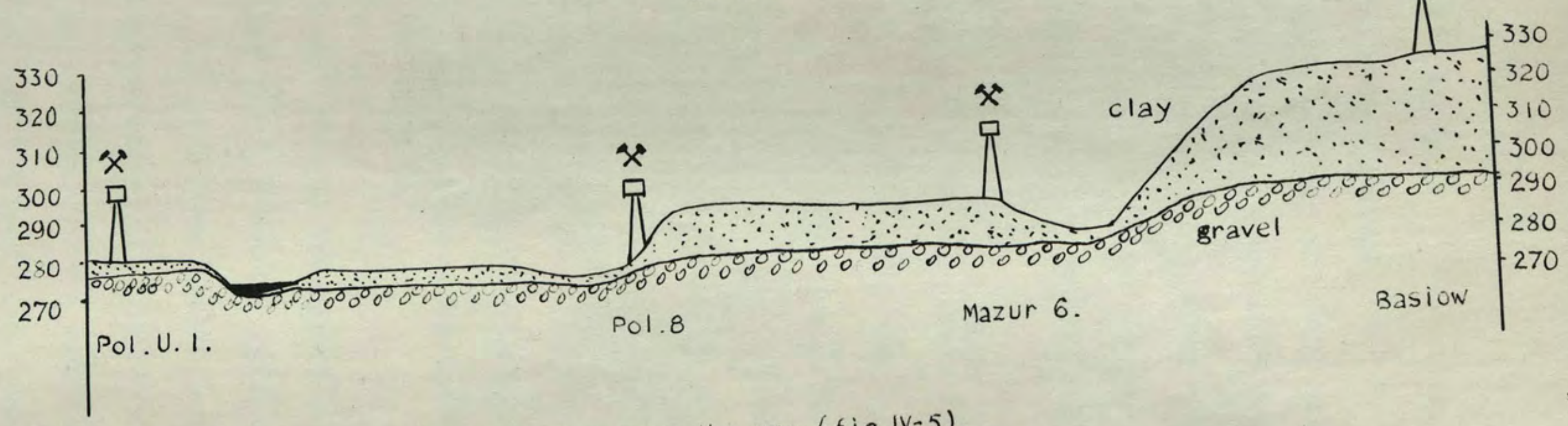
As has been shown during the prospecting, this problem was not an easy one, if not beyond the power of the refraction method; the detailed reflection survey of 1934, 1935, and 1939 (see Chapter XIV) threw more light on the structural conditions of the Daszawa gas reservoir.

The refraction exploration of Daszawa involved the shooting of several lines through the gas wells parallel and perpendicular to the Carpathians (Fig. IV-5). These were single two-way traverses usually with three spreads: 200-600, 800-1200, and 1400-1800 m, the shot-points being placed 200-300 m. from the nearest receiving station (Fig. IV-6).

The range of depth for these lines was about 450 m. Practically, however, the depth of penetration was only about 300 m. thus reaching the first and shallowest gas series of the Miocene water-gravels. The wave velocities obtained were as follows - (Ref: IV - 1), the surface velocity i.e. that of the Alluvial and Diluvial deposits V_o = 600-800 m/sec; V_1 = 1700-1800 m/sec which

Fig. IV-6.





Section A-B from the map (fig. IV-5).

Fig. IV-7.

could be attributed to clays and sands of the Upper Miocene, and V_2 = 2400-2700 m/sec corresponding to the Miocene gas series of sand, gravels and thin sandstones, which constitute part of the first gas series. The last and highest velocity obtained with lines 2-3 km long amounted to V_3 = 2900-3000 m/sec and might be attributed to the sand and gravel series underlying the first gas horizon.

A traverse 4 km. long with a depth of penetration down to 800 m. did not give any greater increase in velocity; this fact proved that lines 2 km. in length would give the same information concerning the subsurface as lines 4 km. long. Also the surface conditions in that area rendered the application of longer lines fairly troublesome.

A topographical section across Daszawa, perpendicular to the River Stryj, is shown in fig. IV-7. (section A-B from fig. IV-5). It is a valley filled with gravels, which, with the Diluvial clay, form three terraces on the eastern side of the river. The Diluvial clay had a wave velocity ranging from 300 to 500 m/sec. This clay, being a medium of great absorption and low resistance, handicapped to a great extent the seismic survey. The gravel in the first terrace is almost at the surface. The second terrace is covered with a mantle of 20-40 feet of dry clay, while in the third terrace this mantle increases to 90 feet. The thickness of this clay confined refraction shooting mainly to the second terrace; partly on account of this clay also the length of the lines applied was reduced to 2-3 km.

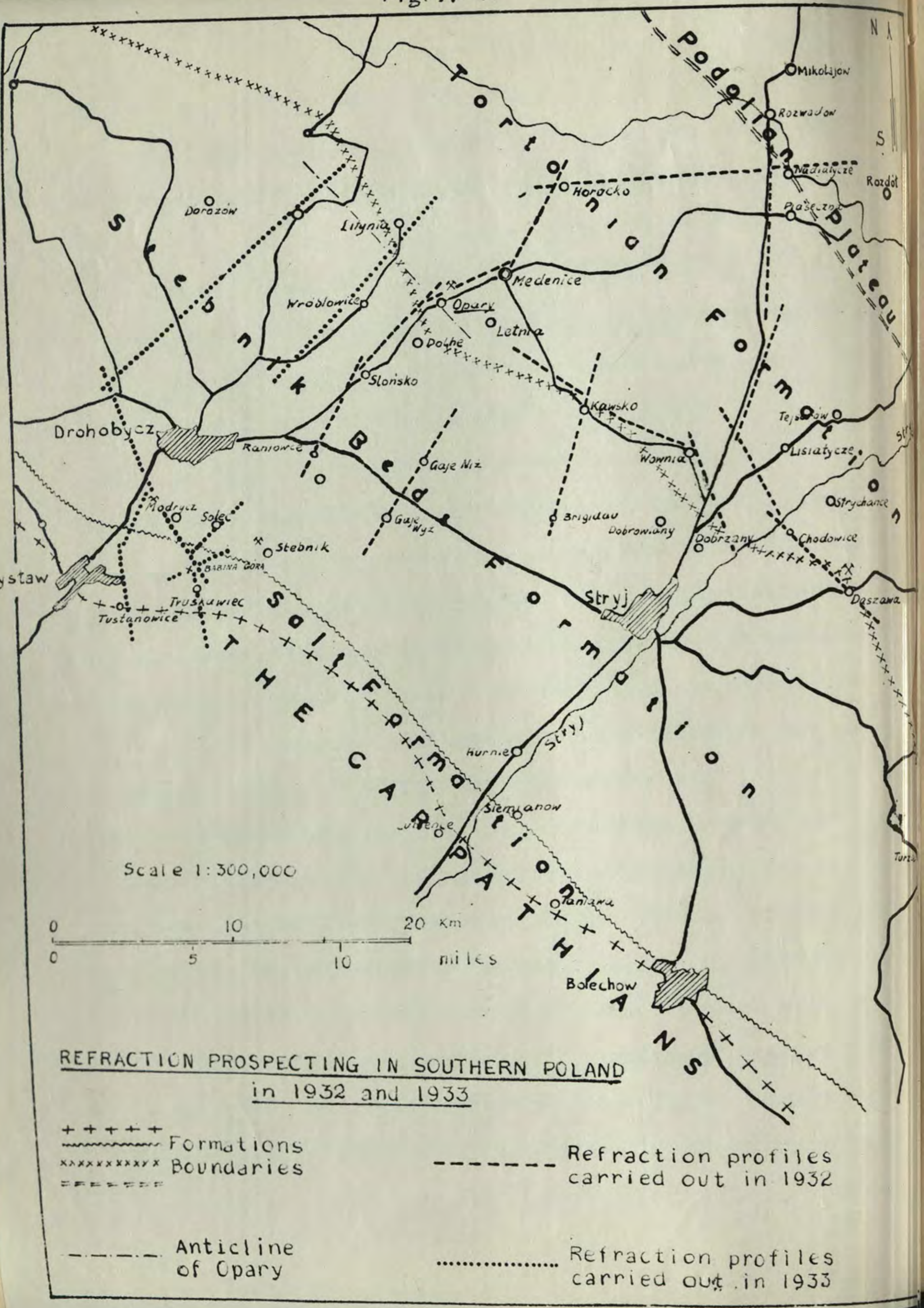
In 1930 several lines were conducted in Daszawa by the Seismos Co. The longest of these lines was 6 km. and yielded the following velocities (Ref:IV-2):

$$V_1 = 2650 \text{ m/sec}, V_2 = 3000 \text{ m/sec}, V_3 = 3400 \text{ m/sec}.$$

The last velocity was revealed only on that line. It could be attributed to the lower coarse gravel series forming the bottom of the second gas horizon, if one considered the dip negligible. It was not however, observed on any other lines, and lines were shot only in one direction, therefore no conclusions can be drawn regarding the behaviour of the respective horizon.

The refraction work of 1932 in the Daszawa area lasted about 3 weeks and included all the initial preparations and adaptations necessary for seismic field work. As a whole, it had rather an experimental value, and compared with the earlier survey conducted by the Seismos Co. was more accurate and the classification of the shallower bed was more precise. The shooting of two-way lines gave the evaluation of depth more correctly and some idea of the range of the dip prevailing in Daszawa, which was from 5-10°.

Fig. IV-8.



REFRACTION PROSPECTING IN SOUTHERN POLAND in 1932 and 1933

The refraction prospecting in the region west of the River Stryj.

The purpose of the survey carried out in the north-west of Daszawa was to follow the velocities obtained at Daszawa and to investigate their variations outside the Daszawa area. Moreover, an attempt had been made to obtain refraction from the deep bedrock, which was supposed to belong to the same formation as the rocks of the Podolian Plateau. The map (Fig.IV-8) shows the traverses carried out in 1932 and 1933. Those of the first year are shown in red. The River Stryj was crossed by two lines, and with another two the Stryj Mikolajow road was reached at the village of Lisiatycze. The refraction lines were of the same type as at Daszawa. No significant variations in velocities were observed. The surface velocity showed a small increase, due to the thin cover of clay overlying the water-gravels. On the lines mentioned this velocity amounted to 1000 m/sec. The deeper velocities, were a fraction smaller than those of Daszawa. It might indicate that the near Carpathian zone of the Daszawa beds was passed and the sand and gravel series reached at Daszawa at a depth of 400 m. were here either absent or considerably deeper. These changes in velocity were already observed on the first lines conducted on the west side of the river.

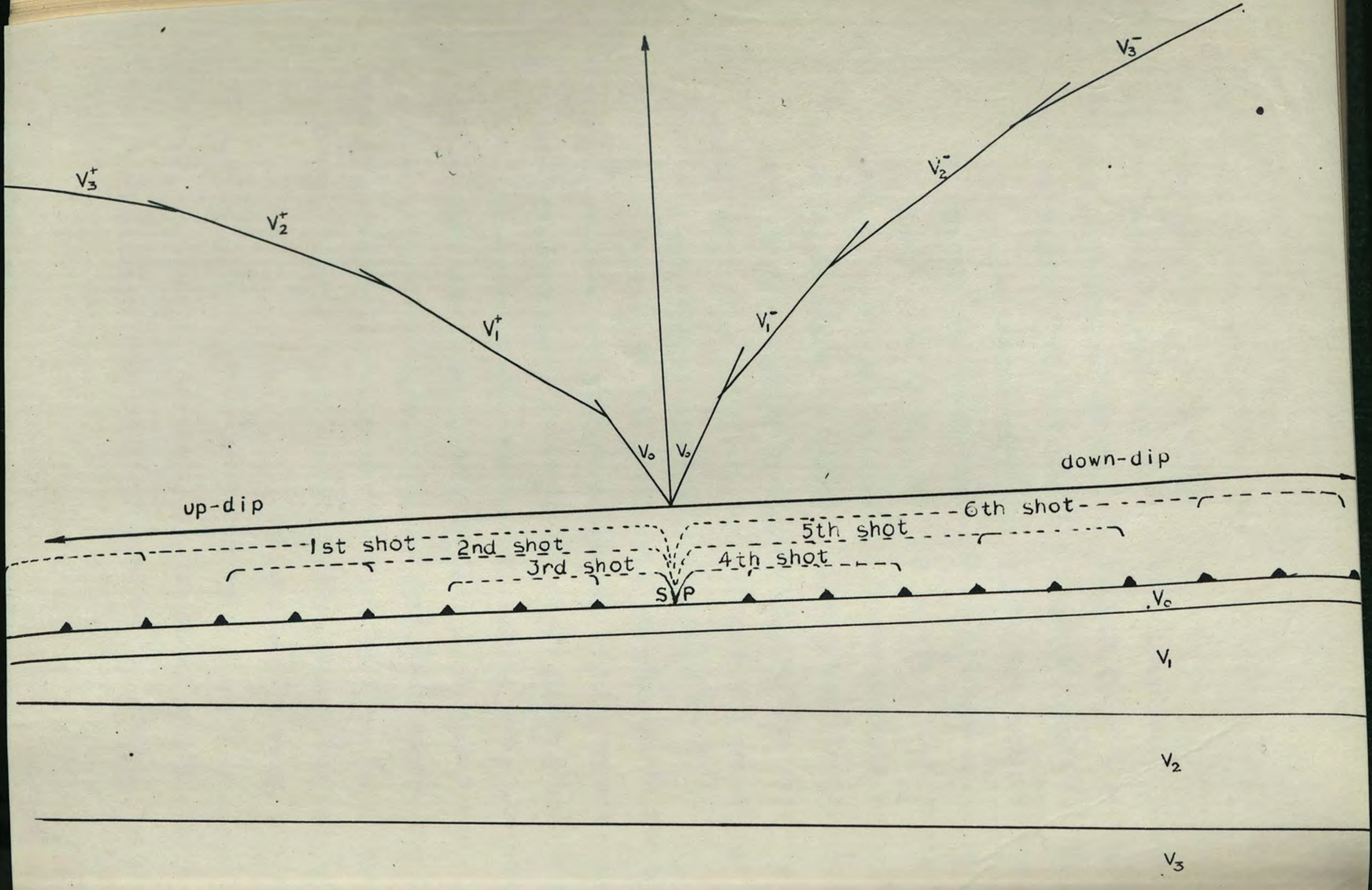
Along the Stryj Mikolajow road from Lisiatycze to Piaseczna experiments were made to reach the top of the Cretaceous Limestone by long lines. It was not, however, achieved. The geologists, at that time, placed that limestone at a depth of about 6000 feet. The applied line should thus be at least 5.5 miles long. The shooting of such lines was hampered by the coarse gravels at the surface about 30 feet thick. These gravels contrary to those of the Daszawa region, conducted the seismic energy well. Nevertheless for a line of the length mentioned the amount of explosive used should have been great enough (at least 500 pounds) and concentrated at one point. As it was it could only be placed on the surface of the ground.

In this case, the energy freed would cause only a negligible effect on the seismograms. If this explosive were placed in a hole drilled through the gravels, it would act as a long charge. Several holes drilled near each other could, to a certain extent, help the matter. One must have considered, however, that drilling through the gravels was extremely long at that time. These were probably the causes which prevented the making use of long lines. The idea of obtaining the refraction from the limestone bedrock was abandoned and the survey proceeded with shorter lines of 2-3 km. up to Piaseczna on the north. A later investigation by the reflection method carried out in 1934 (see Chapter XI) revealed the presence of this bedrock only at a depth of 1000-1200 m. But this bedrock was only 30 m. thick and overlay a series of softer rocks. Therefore even if it were reached by the exploring wave it could not cause refraction which could be observed at the surface on at least three receiving stations.

As shown on the map, beyond the village of Piaseczna a line of 3.5 km. was shot in an easterly direction. This line in E direction revealed a velocity of 4500 m/sec at a depth of about 900 m. This fact might be attributed to the rising of the bedrock in the direction mentioned, though it was not checked from the other end of the line.

From Nadiatycze the investigation was diverted westward to Horucke and then along the field road to Medenice. Along this profile no greater change in the shallow velocities was observed which continued to be of the ranges previously mentioned. The surface bed changed its aspect from hard and compact clay to a silt of loose compactness under which peat and watery sand took the place of Diluvial gravel. This Alluvial zone of about 20' deep, prevented neat impulses being obtained on the records even with charges of 100-200 pounds on lines of 2-3 km.long.

Having reached Medenice on the road to Drohobycz, the length of the lines and the way of their shooting were changed. Instead of using two-way shooting traverses,


V_3^+
V_2^+
V_1^+
V_0
V_0
V_1^-
V_2^-
V_3^-
down-dip
up-dip
1st shot
2nd shot
3rd shot
4th shot
5th shot
6th shot
SP
V_0
V_1
V_2
V_3

lines as shown in fig. IV-8, were applied. The distance between the receiving stations had been increased from 200 m. to 400 m. and the spreads were consequently 400-1200 m. 1600-2400 m. and 2800-3600m. The short-distance shots were used as before in order to obtain the velocities of the surface layers which were changing at almost every second line.

The velocities obtained south of Dolhe differed from those obtained at Piaseczna or LIsiatycze. A line of the type shown in Fig.IV-9 yielded, the following velocities :

V_0 = 1000 m/sec, V_1= 2300 m/sec, V_2= 3000 m/sec

V_3= 3400 m/sec, thus almost the same as near the Daszawa gas-field area; here the presence of the overthrusting formation of the Stebnik beds, which were clearly indicated in the Stonsko area (north of Drohobycz) might be the cause of the increase in velocity.

A traverse at Opary showed a difference between that surveyed at Medenice (north of Opary) and that at Dolhe (south of Opary). It gave a slope of about 10° which might indicate the anticlinal conditions of Daszawa. It was an indication that this part should be investigated in greater details.

At Raniowce and Nowa Wies on the Stryj-Drohobycz road a West-East profile composed of two traverses was shot in the last days in November, which were marked by snow and heavy wind, snow interfering with the wireless communication while wind compelled greater charges to be used.

The programme of 1932 was achieved by three intermediate profiles shown on the map in fig. IV-8. The first ran from Pukiennicze on the Stryj-Mikolajow road through Wownia Kawsko to Letnia, the second through Brigidau and Kawsko, the third through Gaje Wyz. and Niz. The first profile at its west end near Letnia checked the higher slopes met before at Opary. The drilling performed in this area in the succeeding years, on the strength of these observations, revealed the existence of another extensive gas-field at Opary.

The two latter profiles carried out through the woods of Brigidau and Gaje had rather an informative character and formed the closing profiles for the whole area investigated. These profiles had the velocities of the Stebnik beds overthrusting the Tortonian clays and shales, similar to those revealed at Slońsko.

The total length of the traverses shot in 1932 was about 110 km. of which 50% belonged to the two-way lines The number of shot-points was 187 (see table on p. 121.) and the amount of explosive expended about 5,000 pounds (ammonit Nr.5). The number of work-days in the field was 60 during the period from 1.9.32 to 15.12.32.

To end this period of prospection, some historical data are worth adding.

The field work was conducted by Dr. Z.A.Mitera, Dr. Drath, both mining engineers, and geophysicists, Dr. Stenz, the physicist, Mr. Janczewski as representative of the Geological Survey, and by the writer. In charge of the interpretation was Mr. Janczewski. In charge of the field work was Dr. Mitera. The duties of observers at the receiving stations were undertaken primarily by Dr. Drath, Dr. Stenz and the writer. The whole equipment was brought from Warsaw just as it had been purchased in Germany. A few weeks passed for the adaptation of the equipment to field work, for acquaintance with the instruments and for obtaining the harmonious working together of all the observers and other personnel. In charge of the shot-stations was Mr. Dzierzbicki, a mining engineer who had for his assistant a shooter from the salt mine.

At the end of the work three younger technicians were trained to take over the receiving stations. At the end of November, Dr. Mitera left for America and the charge of the field party was given to the writer.

I.c. <u>Seismic prospection carried out by the Geological Survey in 1933</u>, with the same equipment as in the previous year, began in May and lasted uninterruptedly till the end of September.

The subjects of this research were:-

1. Beginning the refraction work on the outcrops of the Miocene conglomerates in Truskawiec to find their prolongation beyond the Truskawiec area.

2. The investigation of the area north of Truskawiec in relation to the salt beds found in the Modrycz well and those of the Salt mine in Stebnik.

3. An experimental profile from Modrycz to Tustanowice, in order to locate the relation between the Modrycz salt beds and the Tustanowice fold.

4. An investigation from the Modrycz well through the Drohobycz salt mines.

5. A reconnaissance prospection over the area north of Drohobycz in the direction of Hruszow and a more detailed research carried out in the northern part of this area with a view of locating the anticline of Opary and Letnia. Finally the connection of the last year's researches with the new ones.

It is evident from the above that the investigation of 1933 has almost lost the general character which it had in the previous year and attempts were made to apply the refraction method to more detailed work. Its range, however, was limited to a depth of 500 m. since the experience of the previous year showed there were difficulties in

Fig. IV-10

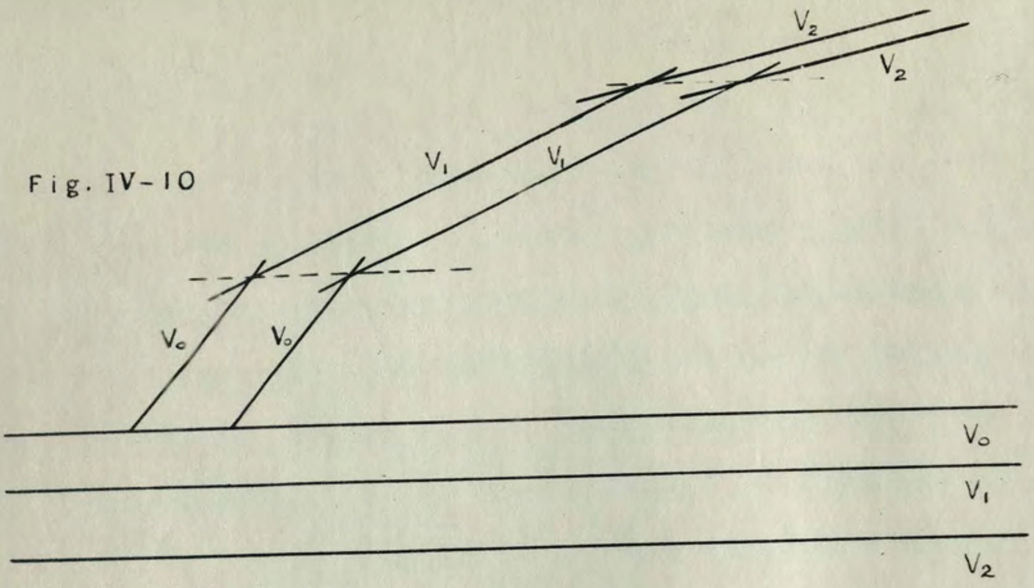


Fig. IV-11.

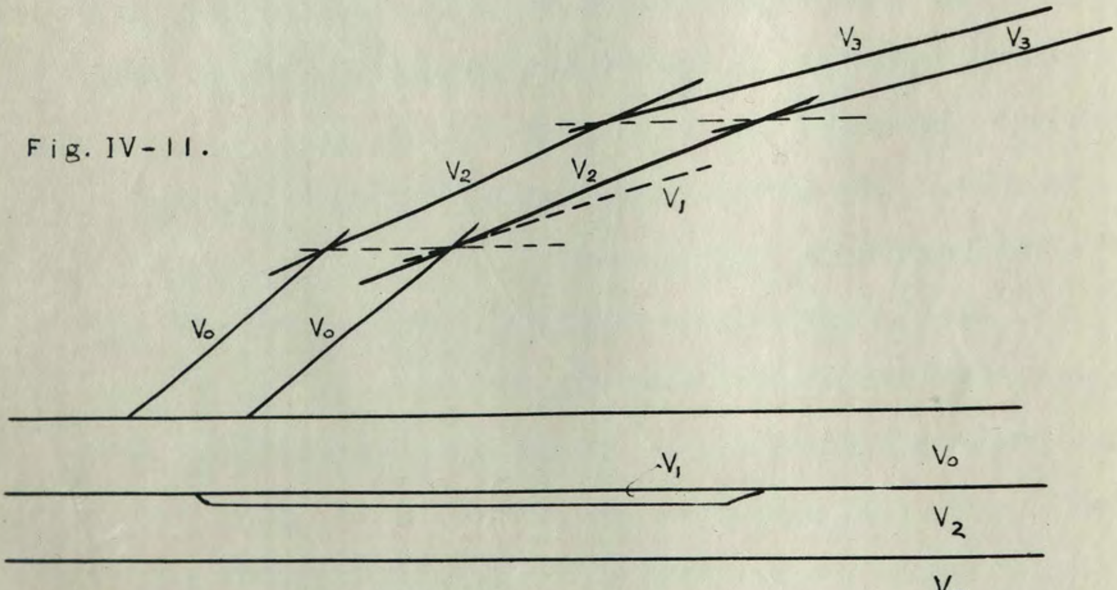
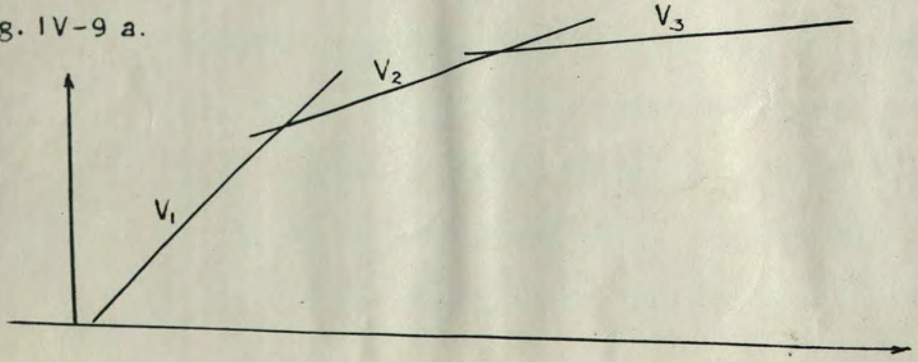


Fig. IV-9 a.



obtaining results at greater depths.

The more detailed programme of 1933 was thought to be accomplished by applying more detailed shooting traverses, mainly two-way lines with two or even three shot-points at each end. A time-distance curve of a line shot in one direction from two shot-points is shown in fig. IV-10. It has several advantages which are as follows:-

a) It doubles or completes the first travel-time line. Some of the first impulses of the lower travel-time line were indistinct or disturbed due to some uncontrollable factors such as surface beds under the shot-point or under the stations. A correspondingly bigger charge used at the second shot-point may secure the sharpness of the impulses in the second travel-time line.

b) A geological insertion, that is a hard layer of a limited surface area and of a thickness less than half the length of the refracted wave occurring between two other layers of lower velocities, may cause some irregularities in the travel-time line (as shown in fig.IV-11). This case may arise certain difficulties in the calculation of depth, or even make it impossible. If the higher travel-time line received from the farther shot-point for the same disposition of the seismographs gives no evidence of velocity V_1 , one can assume a presence of a subsurface geological insertion, which has a limited surface and will not interfere

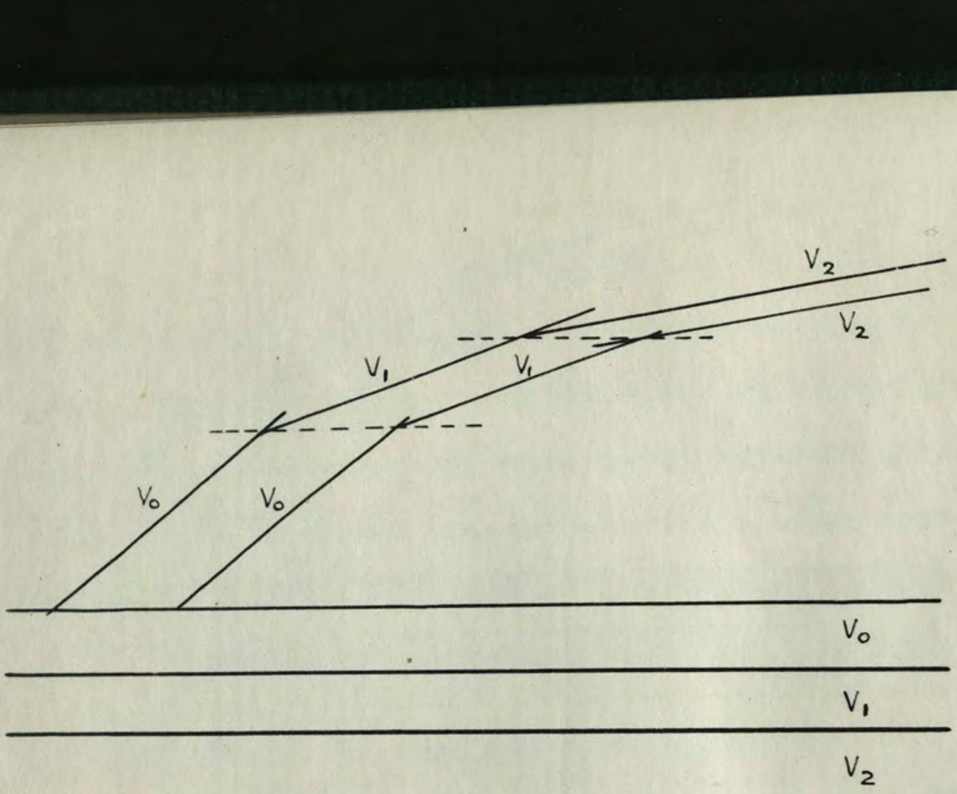


Fig. IV-12.

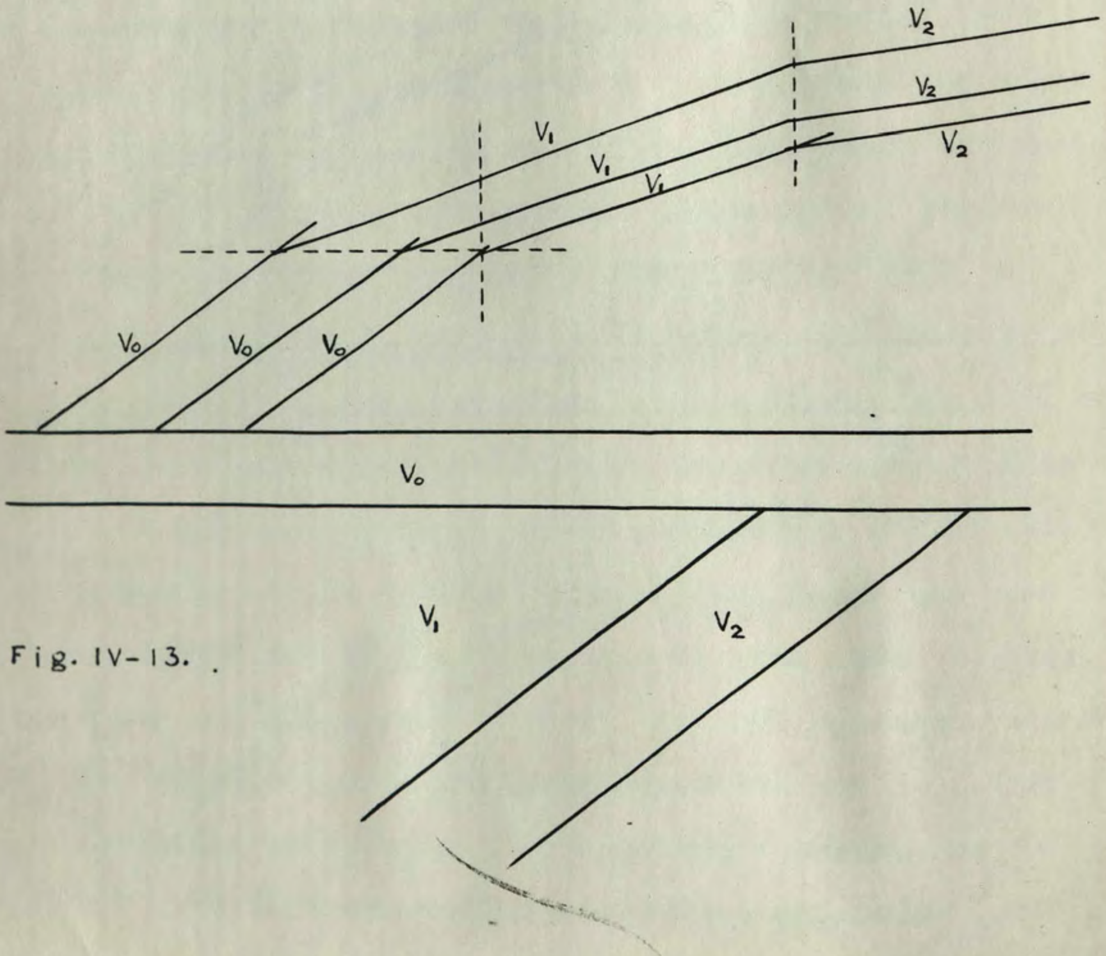


Fig. IV-13.

with the waves generated at the second shotpoint.

c) In a more complicated terrain, where outcrops of layers, at the surface or under the surface, occur, a single refraction line may lead to great errors in interpretation. As was said before, a single travel-time line may refer to a parallel arrangement of layers which are more or less inclined to the surface. fig IV-12 But it may also refer to the arrangement shown in fig. IV-13 and thus to a system of outcropping beds, the velocities of which change progressively. To ascertain oneself it is advisable to shoot a second or even a third line, the travel-time lines of which lie above each other. In the case of outcropping beds the breaking points of each travel-time line will lie on a vertical to the axis of the distances. (Fig. IV-13).

The only disadvantage of a double shooting profile is a greater expenditure of explosive, but it is compensated by more accurate and certain results.

The Geological Survey of Madrid published in 1933 their researches carried out by the refraction method over the Potassium area in Spain. They had applied single shooting traverses, with the help of which they determined the depth at different places, assuming they were dealing with almost horizontal layers of salt. In 1938, after borings were carried out, it turned out, that almost all these beds slope sharply and their outcrops could be found at the computed depth only at some of the places indicated.

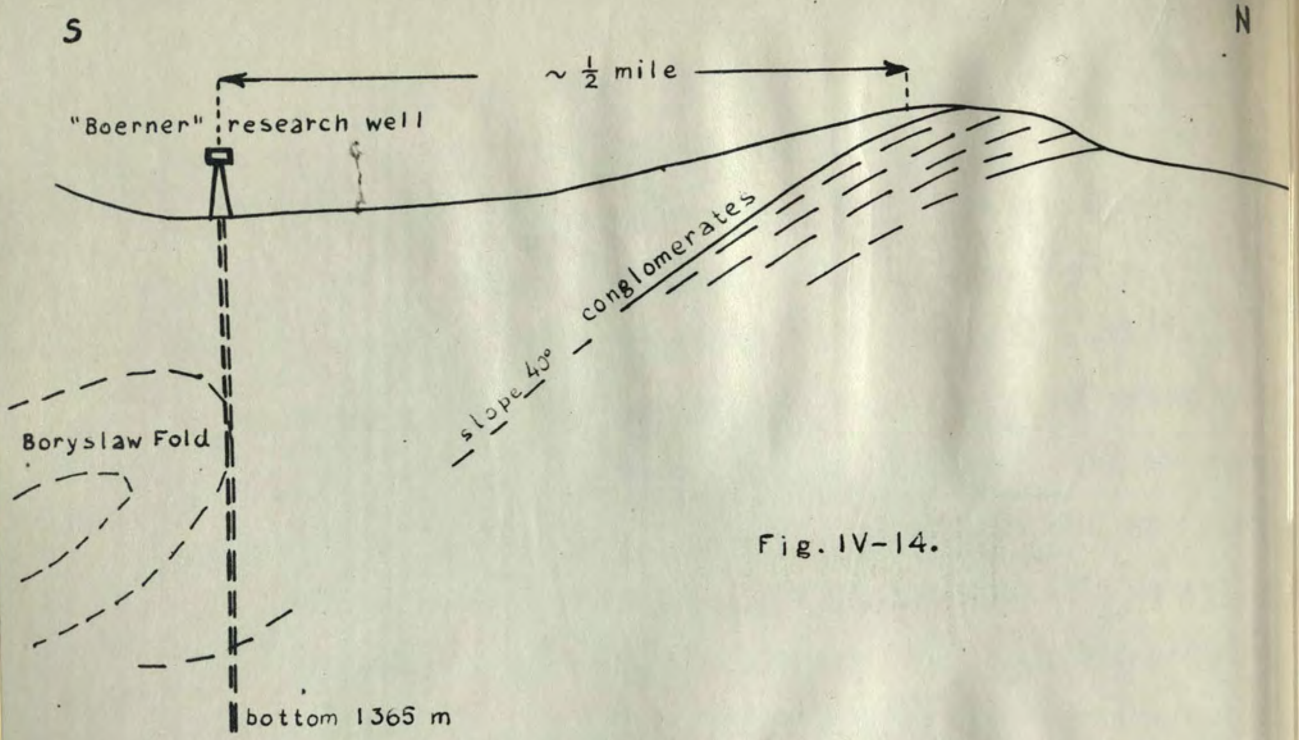


Fig. IV-14.

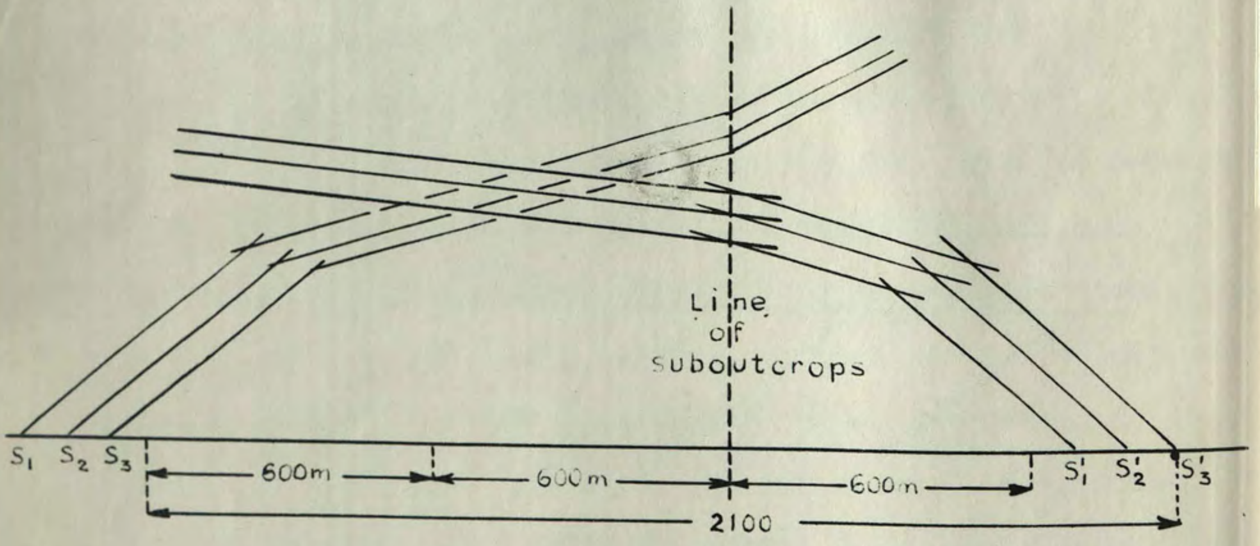


Fig. IV-16.

1. The refraction surveying of 1933 began in the Truskawiec area to deal with the problem of outcropping conglomerates which correspond with those occurring at the front of the Boryslaw fold. These conglomerates outcrop at the "Babina Gora" in Truskawiec and disappear under the Carpathians towards the south(Fig. IV-14). Along the steep hill composed of these conglomerates, a two-way traverse was shot with two and three shot-points at each end. Some apparent velocity which might refer to these conglomerates was received, but the adjoining salt formation had velocities which did not differ appreciably from those of the conglomerates. In some places they were even higher than the latter, and the conglomerates could not be regarded as a guide horizon. The reflection prospection carried out here in 1934 (see page 255) has shown that these conglomerates sloped southwards at an angle of 30° to 40° . This fact was a handicap to obtaining the true velocity of the conglomerates by refraction shooting.

In further prospecting, south of this area, several other tests were made over a fairly folded Carpathian structure. To obtain good onsets for traverses 1 to 1.5 miles long, it was necessary to use big charges (over 50 lbs.) However, the vicinity of the town of Truskawiec, where some of the lines and shot-points had to be placed, prevented these charges to be applied on a larger scale. Refraction survey was further handicapped by the size and slope of the object being investigated. The conglomerates did not occur there in a bed thicker than 50 yards at its outcrops. In the case of a horizontal subsurface when refraction shooting is being applied to any structure at a depth of 500 m. the structure should be of a width exceeding the double distance between the stations before it can be located on a refraction line. The area of Truskawiec nearest to the Carpathians, is composed of small folds and foldings overlapping one another, the deeper parts of which could only be reached by traverses longer than 1 mile. Thus a refraction wave, along such a traverse, may on its way cross other small structures composed of beds of different petrographical and lithological character, and if these beds do not differ appreciably in their velocities, as was the case, no appreciable changes can be obtained on the travel-time curves. These disadvantages of the refraction method in the areas mentioned were discovered in the first days of the prospecting and the experiments had to be dropped.

In December of 1933, a research well "Boerner" was sunk in the vicinity of "Babina Gora" the object of which was to investigate the Precarpathian Salt Formation. The sketch IV-14 shows the section through the well and Babina Gora.

2. Field work in the northern area of Truskawiec was continued with the object of relating the area of Truskawiec with that of the Stebnik salt mine and the Modrycz well. Salt occurred in the latter at a depth of from 50 to 300 m.

Double traverses shot in two directions were used. The distance between the receiving stations was 200 m. These profiles, however, failed to answer the questions put forward. The salt in the "Modrycz" well was registered on the seismograms by the quick arrival of the refraction wave. Its outcrops north of Modrycz were distinctly detected, but the complicated geological and tectonic structure prevented any definite picture being obtained. The relation between the "Modrycz" well formations and those of the Stebnik mines was not established. In short, the apparatus used was not adequate for these areas, since it was a question not only of dips greater than 10° but also of great inconfirmity of the subsurface beds. The profiles investigated are indicated in the map fig. IV-8.

3. The experimental profile from Modrycz to Tustanowice i.e. in the southern direction towards the Carpathians added no more to the geological knowledge of that area, except that it revealed almost uniform velocity of 2700-3300m/sec. down to a depth of 400m. Any deeper velocities were not

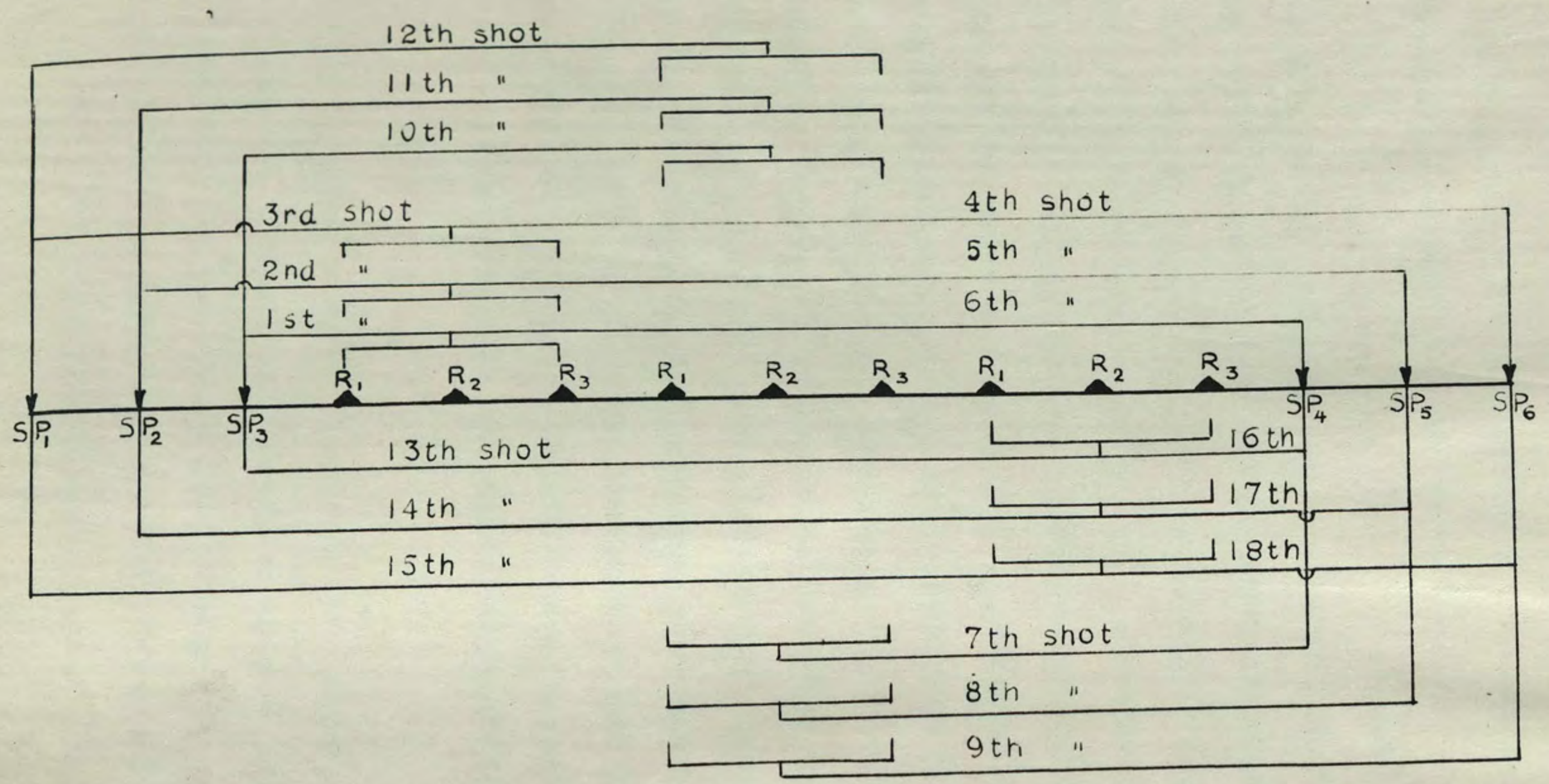

12th shot
11th "
10th "
3rd shot
2nd "
1st "
4th shot
5th "
6th "
R₁
R₂
R₃
R₁
R₂
R₃
R₁
R₂
R₃
SP₁
SP₂
SP₃
SP₄
SP₅
SP₆
13th shot
14th "
15th "
16th
17th
18th
7th shot
8th "
9th "

Fig. IV-15.

searched for since the great absorption of seismic energy limited the length of the traverses applied to 2,0 km. For greater distances the size of the charge which would have been required was too dangerous to the numerous oil wells beside which the prospection was carried out. The profile mentioned is shown on the map, fig. IV-8.

4. The survey conducted north of the Modrycz well through the Drohobycz salt mines (fig. IV-8) was of the same character as the previous one and gave only the surface velocities down to 300 m. which were more or less disturbed by salt masses occurring near the surface.

5. Several useful observations were obtained from a reconnaissance prospection carried out over the area north of Drohobycz in the direction of Hruszow and from more detailed profiles investigating the anticline of Opary and Letnia. The profiles set up here consisted of the double two-way traverses which joined each other by the shot-points. A continuous profile of this kind went through Drohobycz to Hruszow, another through Wroblowice and Litynia. In the area of Rolow and Wroblowice, traveses with three shot-points at each end were shot. Each traverse was 3 km. long with 9 observation-points, (Fig.IV-15).

The final results of this whole survey were not published. This was mainly due to the insufficient data.

obtained and probably difficulty in the right interpretation. From the commercial point of view, the only valuable result of this two year survey was the discovery of the new rich gas field at Opary.

General remarks regarding the survey of 1932 and 1933.

As has been mentioned on page 101, Mintrop's refraction seismograph gave good results when applied over the suboutcrops of the Potassium beds or over the suboutcrops of Limestone in the Podolian Plateau. In these surveys, carried out in 1929-30, the traverses used were 3-4 km. long with distances of 300-400 m. between the receiving stations. Used in a more detailed way in 1932 and 1933 in the search for structures in the Foreland, the refraction method proved very helpful in the discovery and location of the new gas anticline of Opary. This apparatus was last used in field work in refraction in 1933. The method had proved worthless in the actual area of the Carpathian oilfields as well as incorrect in the determination of depth where there were no harder beds in the subsurface to guide the refraction survey. Being unsuitable for dips greater than 10° in more complicated regions, it could not be used for a detailed research required by the geologists.

After 1933, the apparatus itself was deposited in the Geological Survey in Warsaw being of no further practical use in field work, except on one occasion when it was applied in 1934 to determine the average velocity by well-shooting method.

It is worth noting that from 1934 - 1939 the mechanical outfit of Mintrop was used in a fairly successful reconnaissance survey of the deep bedrock over large areas of northern Germany. A similar method was applied in 1939 in the northern regions of Poland using a 12 geophone reflection set for the refraction work in the field (see the end of this chapter).

The table (Ref: IV-1) given below shows the number of shot-points and the number of shots, including the expenditure of explosives during the prospectings of 1932 and 1933. It also gives the total length of the profiles. In 1932 most of the traverses were single and shot in one direction. In 1933 more than 50% of them were double and shot in two directions.

On the whole the investigations described above have given an idea of the general distribution and quality of the shallow beds down to a depth of about 400 m. in the areas of Stryj, Daszawa, Mikolajow, Drohobycz and Hruszow. The refraction method, as it was, gave encouragement for its further application provided more accurate and more sensitive instruments could be applied, which would simultaneously secure a higher efficiency than had so far been achieved.

	1930	1932	1933
Prospected area in sq.k.m.	500	-	-
Length of profiles in k.m.	-	110	60
Number of shot-points	142	187	154
Number of shots	?	?	517

To conclude the refraction prospecting by means of mechanical seismographs, some values of the velocities of the propagation of elastic waves, determined during the seismic survey in the Carpathian Foreland, (Ref: IV-2) are given below.

Type of rocks	Velocity of longitudinal waves.
Clays and shales of the surface	1800 - 2200m /sec
Salt formation of the Miocene (shales)	2800 - 3000 "
Shales and sandstones of the gas series	3200 "
Pure salt rock	over 4000 "
Formations of Podolian Plateau (gypsum)	5000 - 5600 "

It must be mentioned that it was not easy, even sometimes impossible, to identify different horizons on the basis of the velocities encountered. It is more probable that the differences in the velocities of elastic waves observed during the surveys are related more to different facial conditions of the beds mentioned, than to the stratigraphical division.

II.a. Refraction prospecting carried out sporadically from 1934 to 1939 with the use of the 6 - geophone set of Seiscor or 12 - geophone set of Heiland Research Corp. parallel with the reflection survey.

The general way of investigation by the refraction method did not differ essentially from that carried out in the previous years. Being conducted independently of the reflection survey, but with the use of the same instrument, these refraction surveyings fall into two periods:

a) The first from 1934 to 1937 during which the investigations were carried out by the Pioneer Institute of Applied Geophysics, with the use of the 6 - geophone set of Seiscor, and

b) The second from 1938 to 1939, during which the refraction work was carried out by the Geotechnika Expl. Co. Ltd. with the use of the 12 - geophone set of Heiland Research Corp.

The first period comprised some minor refraction problems, which owing to their character, can be dealt with separately from the reflection survey. The second period comprises refraction work which was mostly carried out supplementary to the reflection survey.

The seismographs (also called geophones, detectors pickups, seismo-receivers) in each of the outfits mentioned were of the electromagnetic type. The ground vibrations produced by the explosion were converted in the geophone into fluctuations of electric currents, which being afterwards amplified in filter-amplifiers, were reconverted into rotational motions of the recording galvanometers. Each geophone corresponded in its application to a single mechanical seismograph; the deviations of its mass, after having been enlarged mechanically and optically, were recorded separately by individual recorders for each mechanical seismograph. In an electromagnetic set, a recorder system carries at least 6 to 12 oscillograph-elements, all focussed on the same strip of photographic paper. The use of electro-magnetic seismographs instead of mechanical ones, allowed the constructor to place the amplifier, the recorder with oscillographs and the camera system, in one truck or traviler, manned by one observer, who controlled the shooter at the shot-point by telephone. The shot-instant was recorded by coupling the shot-instant circuit to one of the oscillograph circuits used for recording the impulses of the seismograph. Thus, the field party, for manning the reflection apparatus was reduced from three observers and three assistants, as was the case with the Mintrop set, to one observer and one or two assistants. Moreover, instead of three mechanical seismographs, 6 and even 12 were used simultaneously, which secured higher efficiency and lower cost.

The reflection geophones, having been disposed for reflection work, needed some small adjustments concern9 ing the increased weight of the suspended mass and accordingly stronger springs. These adjustments were made in the field, any time separate refraction work was carried out. The geophones could be strung along a traverse with a displacement of 50 to 100 m. from each other covering the spread of 50 - 300 m. or of 100 - 600 m. for one shot in the case of a - 6 - geophone set. A suitable number of double leads were provided to connect these detectors with the recording truck. The detailsof this apparatus will be given in the next chapter.

Examples of the refraction survey conducted with the six-geophone set of Seiscor.

During its normal reflection survey, in the years 1934 - 1937, the seismic group of the Pioneer Institute of A. G. conducted several refraction measurements. These dealt with the average velocity for reflection purposes by continuous profiling or by well-shooting and with three separate refraction surveys concerning:- 1) the determination of suboutcrops of the older formations near Przemysl (Medyka area), 2) the salt uplifts near Dolina and 3) the locations of Potassium deposits near Holyn and Lubience.

1) In the Medyka area (near Przemysl) some additional indications were wanted regarding the subsurface conditions in which the reflection survey did not yield sufficient data. It is the area of the Stebnik beds overthrusting the Tortonian sediments of the Foreland. The older rocks have a southern dipping, whereas the adjacent zone of the Tortonian is slightly folded and horizontal. The outcrops of older rocks, which had higher wave speeds than the Tortonian sediments were located by the refraction lines. Two of them, 4 kms. long, have been made at right angles to the strike, geophones being placed 100 m. from each other. One of these lines is shown in fig. IV-16 (p. 115). Three spreads of geophones were involved, each spread having a length of 600m. Three shot-points for down-dip and three for updip shooting were made. The length of the longest shot-line did not exceed 2100 m. as only the shallow depths down to 400 m. were concerned. The break-points of the travel-time lines for three successive shot-points being at the same vertical, the existence of the suboutcrops and their boundaries under the breakpoints was proved.

2) The second survey concerned the diapiric salt uplifts of the lower Miocene age in contact with the younger formations of the Foreland in Dolina. This investigation was to determine whether the salt which occurred near the surface was of diapiric character and thus whether it had any connection with the deep subsurface. The place under investigation was of 1 to 1.1/2 miles in width and length with very irregular topography bounded on the north by the hills of the Podolian Culmination and on the south by the hills composed of the Upper Miocene formations. Some shallow wells, pumping the light petroleum from a depth of several hundred feet, are sunk in the southern part of the salt uplift. Here again the reflection survey failed. Refraction prospecting was undertaken on an experimental scale. The field work consisted of carrying out a few refraction traverses 1 mile long, the geophones being placed at a distance of 50 - 100 m. from one another. The surface conditions were unfavourable to an easy drilling since coarse gravels occurred from the surface down to 50 feet, underlaid by the shales and clays of the Upper Miocene age. The drilling was done by the aid of simple rotary drills or by hand-winch and derricks. The surface conditions, such as they were, produced the greatest handicap to obtaining good and neat first refraction onsets on the seismograms, even for such sensitive geophones as were in use, a considerable

amount of explosive had to be spent (e.g. 20 pounds for a distance of 1 mile in a hole 60 feet deep).

As a result the southern boundaries of the salt were located, as well as the depth of its top at several points investigated. The methods, however, failed to prove the existence of a diapiric form of the salt uplift. The irregular form of the top and the very irregular form of its boundaries in the south, might be interpreted as an irregular mass of salt which intruded into the younger formation. The object, however, being too small in dimensions and being very erratic in shape, should have been more thoroughly investigated by shallow drillings or by a very elaborate refraction work and perhaps also by a gravimetric survey in order to prove the correctness of the theory of diapiric salt uplifts in those areas.

3) The location of the Potassium and Salt deposits in the region of Holyn (near Kalusz) and in Lubience (near Stryj) had for its purpose the location of their suboutcrops beyond the boundaries of the Salt mine in Holyn, the existence of Salt being proved there by a reconnaissance investigation undertaken in 1930 and by shallow research drillings in the following years. The refraction survey by a reflection set was carried out in 1937 during three weeks of field survey.

The suboutcrops were easily located with traverses

1 - 2 km. long with 50 - 100 m. geophone distance. They were mostly double traverses shot in one direction from two shot-points with 200 m. intervals between. When the presence of suboutcrops was doubtful, the traverses were shot in both directions to determine the eventual dip and depth of the layer under investigation. The top of the suboutcrops was determined by short refraction traverses shot along the strike. The result obtained during this survey encouraged the Potassium Exploration Company to undertake in the summer and winter of 1938 a detailed refraction and reflection prospecting over the large area of Holyn and Kalusz; this survey was successfully carried out by the Geotechnika Expl. Co., and is given below.

II.b. Examples of refraction survey carried out with the reflection set of Heiland (12 geophones).

The seismic exploration carried out by Geotechnika Expl. Co. in years 1938 and 1939, contained, besides several reflection prospectings, also a number of refraction surveyings which can be divided into two groups; a) those carried out in the Foreland area and in the Marginal zone of the Carpathians, and b) those carried out in north-western and middle Poland.

The most important of the first group were:

1) A detailed location of the suboutcrops of

the Potassium-Salt deposits in the Kalusz and Holyn areas (RER; 5 on Plate 1 in part III of this paper), involving the determination of the subsurface structure, the latter having been done by the reflection method. The determination of the suboutcrops mentioned was carried out with the aid of double two-direction shooting refraction traverses with 12 geophones spread along a 550 m. or 1100 m. long line, the distances between the geophones being 50 m. or 100 m. respectively. In detail, the field procedure did not differ from that used in 1937 with 6 geophones sets, greater accuracy and efficiency being gained on account of a double number of geophones being use. The individual charges for 2 km. long lines did not exceed 5 pounds in wieght.

2) A refraction survey across the Bochnia Salt mine (RFR 9 - Plate 1) in the direction of the Carpathians (N-S) carried out along a 15 miles profile, and a second survey across Brzesko (RFR 8) along a profile of the same length, revealed the probable existence of another salt anticline. The shooting profiles were of the same type as those applied for the determining of Potassium suboutcrops (point 1), but the survey had also for its objective the delimitation of the shallow structures encountered in the belt of the Foreland adjacent to the Carpathians and in the overthrust of the Carpathians themselves.

3) In a similar manner there was accomplished

the location of salt uplifts in the Pilzno-Debica area (RFR 7) in the part immediately adjacent to the Mountain Range of the Carpathians, from under which these salt masses emerge in the shape of irregular domes, rising to the surface. The refraction method applied involved short shooting lines with 12 geophones strung along a 550 m. long traverse, the shot-holes being successively moved away until the corresponding high wave-velocity (over 5000 m/sec) was obtained. In this way the successful mapping of the top of the irregular hard masses was achieved.

To the second group of seismic investigations belong those carried out in the north-west and middle of Poland, where the geological conditions are different from those of the Foreland and the Carpathians:-

1) Refraction and reflection surveys were carried out in detail over the large negative gravimetric anomaly in the Pomerania-KUjawy area. Refraction prospecting by means of 2 to 3 km. long shooting traverses (double or triple) resulted in the mapping of a) two horizons with a wave-velocity of 3000-3500 m/sec and 5000-5500 m/sec respectively, in the middle of the anomaly mentioned, and b) the Jurassic limestone which in the southern and northern parts of the anomaly outcrop at the surface in several quarries. The wave velocity of the limestone did not exceed 4200 m/sec. This anomaly, presumed to be a salt

dome of rather large dimensions, emerged between Barcin and Pakosc. The depth of this mass, as determined by the gravimetric survey, was presumed to be not greater than 400 m. whereas that obtained from the seismic survey was 300 m. A reflection survey, carried out by dip-shooting, proved the existence of steeply dipping beds around the mass as well as the occurrence of new, shallow, discontinuous reflections when passing across the mass. It is noteworthy that the seismic survey carried out in this region in 1929 by the refraction method with mechanical types of seismographs (Mintrop-Schweydar) failed because of the great quantities of explosives required and the first very weak impetus produced, most likely caused by the great masses of diluvial clays and conglomerates, which in some parts form a mantle 200-300 m. thick. However, they did not prove a hindrance to the refraction survey made with electro-magnetic geophones and the quantity of the charges did not in any case exceed 5-7 pounds of dynamite placed in shot-holes not more than 20 feet in depth, the longest lines applied being 3 km.

2) South of this region in the Kruszwica and Goplo area a continuous reflection profile was carried out to investigate the shallow and deep structures of the Jurassic limestones and sandstones. Around this reflection profile a deep fan-shooting by the refraction method was carried out

to map the horizons with a wave velocity higher than 4000 m/sec. The survey promised good results, but was interrupted by the outbreak of war.

3) Refraction and reflection prospectings were carried out over the shallow and deep limestone structures on the left side of the river Vistula in the region of Pacanowice, Wojcza and Stopnica. In this area, the shallow structures being very pronounced and the limestones occasionally outcropping at the surface, the refraction prospecting yielded good results. Three refraction profiles each about 8 miles long (RFR 10,11,12, Plate 1), were conducted across the structures investigated from NE to SW. Each profile consisted of several 2 km. long refraction shooting traverses with 12 geophones on each traverse and with two or four shot-points. The survey was not completed and required more seismic work both by refraction and reflection means.

Inferences regarding the refraction method of prospecting.

Concluding the first part of this paper which deals with refraction shooting, it is evident that with the use of the refraction seismograph one cannot convey any direct structural message, unless the anomalies encountered belong without any doubt to the hard members of the earth's crust, such as sandstone, salt limestone or igneous rocks.

The refraction apparatus records the time required for a wave to travel between certain points through the subsurface. It registers any radical change in the rate of velocity that would indicate a variation in the composition of the conveying medium along the path of the seismic wave. This variation may be caused by harder rocks, (such as the above mentioned) encountered during surveying, or by uplifted sediments of the same velocities.

A higher velocity encountered, may then result not only from the presence of harder rocks, but from the compactness of the sediments due to the structure and these structures may be anticlines, synclines, faults etc. On the other hand it does not imply that abnormally high velocity indicates only a favourable structure, as it may also be due to unfavourable conglomerations of hard sedimentary rocks or to intrusions of igneous rocks. From these facts it follows that before proceeding to any kind of interpretation, which should be done concurrently with the field work, it is absolutely necessary to collect all available knowledge about the geology of the terrain investigated. A geophysicist who wants to supply the company, for which he surveys, with a reasonable interpretation, should be himself either a good geologist or should collaborate with a geologist who understands the principles and possibilities of Geophysics.

Limitations of refraction prospecting.
Conclusions.

Refraction prospecting supplies us with the lateral distribution of subsurface velocities. The depth determinations are largely limited to the first harder rock and in the case of several hard beds successively deeper, the determination of slope and depth can be seldom obtained without considerable error unless the average velocity of the overburden is well known. As the distance between the shot-point and receiver is almost four times larger in comparison with the depth of the bed surveyed, the method for the deep structure becomes very expensive as far as explosives are concerned; moreover, in the case of determining the depth from the time-distance curve only, that is to say, without a knowledge of the average velocity of the overburden, the error introduced by long traverses may reach a value which will make the result very doubtful.

In the prospection described, the only valueable information obtained without errors, was reached when prospecting the suboutcrops of shallow layers of Salt or Limestone. In the complicated structures of the Carpathian region, the refraction method gave only the lateral distribution of different velocities without any true information concerning the depth or slope of the beds encountered.

Small discrepancies in velocities, in the successively deeper beds, as was the case in the Carpathian Foreland, introduced many errors into the computation of their depth and slope. The distance between the successive stations being large (200 to 300 m), the travel time lines were usually drawn through two or three time-points, which were not sufficient in number to secure the right value of the wave-speed in the layer prospected.

As has been proved by later drillings in the area prospected, hard components like sandstones often occurred imbedded in softer clays and shales. These sandstones, however, could not be detected by the refraction wave, since they were of small thickness, seldom exceeding 50 feet. According to the law of refraction the thickness of a bed must be at least equal to half the length of the refracted wave in order to cause any refraction and should be several times bigger than the length of the refracted wave to yield a prominent refraction and consequently diffraction obtainable along a considerable length of the traverse prospected.

It follows from the above, that without the presence in the subsurface of such beds, refraction prospecting will always have a limited application.

As a result of the field experience gained during the prospectings from 1934-1939, the refraction part of which was described on the previous pages, it has become known that in the case of big irregular masses of hard rocks in the subsurface, the refraction method would yield good results in mapping their lateral boundaries, and often the depth of their top surface (the salt masses in the Bochnia area, the salt domes in Pomerania, the Potassium layers of very irregular dip in the Kalusz or Holyn area). This kind of surveying was, as has been mentioned, conducted parallely with the reflection survey, which in its exploration failed to yield results here, and thus the refraction method was more favourable in application than the reflection. If the subsurface hard members were of considerable thickness, as occurred with the limestone beds in the Wojcza area (the St. Cross Mountain's Foreland), poor reflections were in some parts observed and the prospection had to be supplemented by the refraction method.

In the Carpathian Foreland, good shallow reflections were observed (see Part III) from the beds which did not yield any refraction.
Apparently these beds were too thin to produce any evident refraction. Very good reflection were observed from the deep bedrock, which being at a depth of about 1200 m. did not produce any refraction, because, as was revealed by later drillings, this bedrock was only 30-50 m. thick.

From the above the following practical conclusion can be drawn: Thin beds yield good reflection, but are transparent to the refraction wave, while thick beds and irregular masses yield good refraction but seldom can be good reflections obtained from them. The mechanism of this fact is not sufficiently known. Perhaps thin beds respond better to the impinging wave, which sets them in vibrations, and the latter are in turn reflected back to the surface, while thick beds are more inert, and therefore unable to vibrate, but they form good media for producing refraction and diffraction of the striking wave.

The refraction method, as it was applied in Poland, showed its value only when used on a detailed scale for the shallow structures. It was applied when the reflection method, which was well developed, failed to yield success. In Germany and Persia, the application of the refraction method also yielded good results in the mapping of the deep bedrock, whereas reflections in these areas were poor. Therefore, the refraction method may be of considerable value to further prospecting in Poland, especially in its north-western parts, where beds of considerable thickness form the bedrock of the Permian basin.

In Poland the refraction method was treated like the step-sister of the reflection method, and thus better than in the U.S.A. There the reflection method almost entirely ruled in seismic prospection. The writer, however, thinks that both methods have their value and no seismic prospection should take place in an unknown terrain unless experiments have been made by both methods. Besides he thinks, that refraction exploration should not be abandoned in favour of reflection survey unless sufficient evidence shows that reflections are easily obtained and can be fairly well correlated to reconnaissance purposes.

REFERENCES:

Ref: IV - 1: P. Wrangiel "The activity of the Pioneer Company in 1928 - 1937." - Polish Oil Industry 1938 (in Polish)

Ref: IV - 2: Z. Mitera "Studies in Seismic methods of Prospecting and their Application in Exploration for Oil in Poland". Report of the Congress of Petroleum in Paris in 1937. Vol. 1.

PART II

REFLECTION SURVEY

EQUIPMENT -- DISTRIBUTION OF SEISMIC ENERGY -- SEISMOGRAM

C O N T E N T S

PART II

CHAPTER Page

V. THE SIX-GEOPHONE REFLECTION SET OF SEISCOR

- The detecting channel 141
- The time-marking instrument 157
- The recorder 158
- The shot-instant transmitter 159
- Auxiliary equipment 162
- Shot-point equipment 163
- Transport 163
- Drilling equipment 164
- Explosives 165
- Loading and tamping 167
- Setting-up and work on a reflection traverse 168
- Organization of a reflection field party 170
- Efficiency and cost 171
- References to chapter V. 172

VI. THE SIX-GEOPHONE REFLECTION SET OF HEILAND 173

VII. THE DISTRIBUTION OF SEISMIC ENERGY

- The generation of elastic vibrations 177
- The behaviour of longit. impulses at an interface 180
- Losses of seismic energy 186
- Effects of stratification 192
- Examples of distribution of seismic energy 193
    - Energy distribution with regard to the angles of incidence and stratification 200
    - Energy distribution allowing for losses due to absorption and spreading 210
- References to chapter VII 220
- Table I 221
- Table II 222

VIII. THE REFLECTION SEISMOGRAM

-

- General 223
- Conditions of observation 230
- Coefficient of reflection and transmission 237
- The thickness of the reflecting medium 245
- The direction of shooting traverse with regard to the dip of the reflecting horizon 250
- Distribution of seismic energy in dipping strata 254
- References to chapter VIII. 256

Part II contains 43 figures in the text.

The seismic exploration of 1934-1937 was entirely conducted by the "Pioneer Institute of Applied Geophysics" organized in 1934 as the wholly owned subsidiary of the Pionier Oil Expl. Co. of Lwow. This exploration involved an extensive reflection survey with the use of two 6 geophone reflection outfits of 'Seiscor' and of 'Heiland R. Cor.' respectively. Both equipments are described in the following chapters.

C H A P T E R V.

The 6 - geophone reflection set of Seiscor (Seismograph Service Corporation. Tulsa. Oklahoma) model 1934.

This outfit consisted of:-

a) Six electromagnetic seismographs, called also geophones or detectors.

b) Six amplifier-filters in two metal cases.

c) One recorder with a bank of galvanometers, and timing device.

d) One tuning fork system.

e) One shot-instant transmitter forming one working unit with the blaster and telephone at the shot-station.

f) Three accumulators of 2 and 6 volts.

g) Auxiliary equipment.

The items from b) to f) were mounted rigidly inside the recording truck, and, constituted a single working unit operated by one observer. Later on, on account of transport difficulties, a special light trailer was constructed for the above apparatus. It could be drawn by a truck or, in an emergency by horses.

The detecting channel.

One seismograph, one amplifier-filter and one galvanometer represent one coupled detecting channel, which must be able not only to detect and amplify seismic vibrations but also to show sufficient discrimination against undesired seismic energy and have sufficient damping, so that the successive seismic impulses can be easily distinguished on the records.

To fulfil this, the whole detecting channel must have a natural frequency easily adapted to those encountered in the ground. In seismic practice one may encounter the frequencies of ground vibrations which are of a range from 5 to 80 cycles per sec. These frequencies vary according to the depth of penetration and the distance travelled from the point of disturbance. The frequency range is great in the vicinity of the shot-point, the higher frequencies being attenuated more than the low with the increasing distance from the source.

As far as reflected waves are concerned, experience shows, that most of that energy is carried on a wave-length corresponding to the frequencies varying between 30 - 60 cyc/sec. By adjusting then the detecting channel system to this narrow band of frequencies, the reflected waves can be readily recorded, whereas the others, such as ground rolls or some refracted waves, can be suppressed to a sufficient degree.

The mechanical type of seismograph was not sufficient for recording the reflected waves, since its natural frequency was about 15 cycles per second. Another reason for the replacement of the mechanical type of seismograph by the electric one lay in the greater adaptability of the electric type to filtration of waves of different frequencies, this principle being of vital importance in the reflection work.

All three parts of the detecting channel will be shortly discussed below. The above principles and their applications in the individual parts of this channel will be also shown with the aid of simple theoretical considerations.

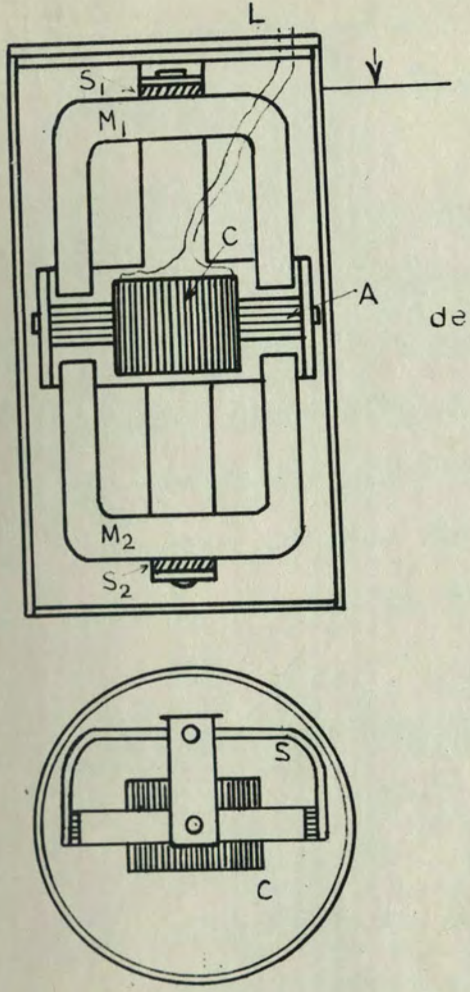


Fig. V-1.

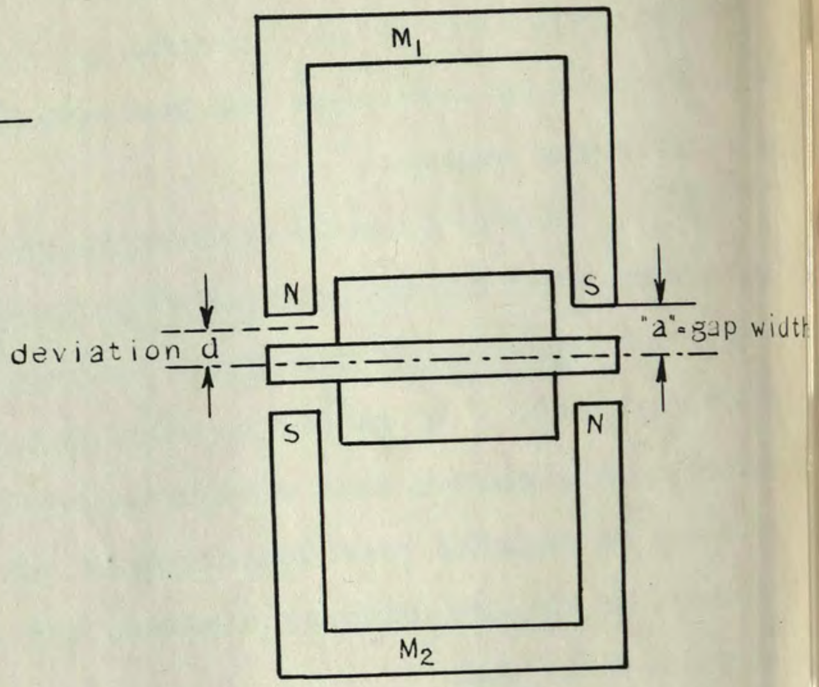
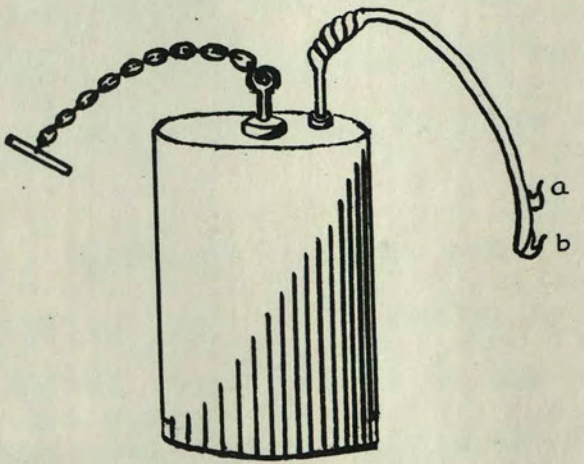


Fig. V-2.



a) The electromagnetic seismograph of Seiscor.

A seismograph as used in practice, is shown in fig. V - 1. It consists of two permanent magnets M_1 and M_2 which are supported by two flat springs S_1 and S_2 attached to a support S in the cover (lid) L. In the air gap between the magnets is mounted a laminated armature A, the latter being rigidly connected to the lid through the support. A coil C consisting of many turns of very thin insulated wire is wound on the armature, the ends of the wire being pushed out through the lid to the external connections a and b. The whole instrument, being attached to the lid, is placed in a cylindrical metal case to which the lid can be screwed. For easier handling during the field work, each geophone had a chain attached to the top of the lid. Before screwing in, the case was filled with lubricating oil of a viscosity corresponding to the season of work. This oil being put in to a marked level, provided the necessary damping.

The mechanical ground vibration produces a relative motion of the magnets (mass) with respect to the armature (support) varying the width of the air gaps. Consequently, these changes produce variations in the reluctance of the magnetic flux path through the armature and induce in the coil an electromotive force. In this way the mechanical ground vibrations are converted into fluctuations of electrical current. The generated electromotive force is proportional to the relative velocity of the moving parts, i.e. the movements that takes place in such a geophone (owing to the fact that natural frequency of the oscillation is approximately equal to the natural frequency of the waves that are to be recorded) in response to the earth's movement will tend to have its maximum displacement at the time of maximum velocity of the moving earth. The geophone could then be considered as a velocity detector, which measures the rate of movements or velocity of the ground with respect to a fixed inertia mass.

On page 40. the general equation of the forced oscillations of a damped seismograph was given as:-

$$\theta'' + 2.k.\theta' + n^2.\theta = x''/l$$

Introducing more convenient signs, this equation may be written:-

$$a'' + 2.\varepsilon.a' + w_o^2 . a = x''.V \qquad V-1$$

whereas before

a - the deviation of the mass (or relative motion between coil and ground)

ε - the co-efficient of damping = $\eta . w_o$ (η - relative damping)

w_o - the natural angular frequency of the geophone (or number of oscillation in 2π sec).

V - the static magnification of the geophone, i.e. the ratio of indicator deviation to the mass deviation,

x - a single periodic ground displacement = $= X . \sin w.t$, where X the maximum amplitude of the ground deviation, w - the natural frequency of the ground.

Introducing the second derivative of x into eq. 1. one has :-

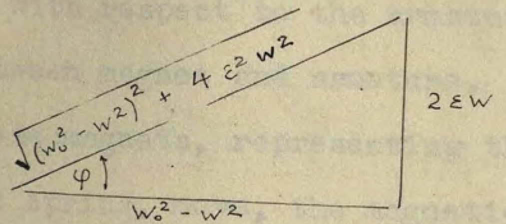
$$a'' + 2 . \varepsilon . a' + w_o^2 . a = V.X.w^2 . \sin w.t$$

the solution of which gives the deviation of the mass

$$a = V.X.w^2 . \sin (wt - \varphi) : \sqrt{(w_o^2 - w^2)^2 + 4\varepsilon^2 w^2} \qquad \text{V-2}$$

which is identical with that given on page 41 .

Considering the triangle



it is obvious that φ , being the phase shift between ground motion and the record amplitude, is given as

$$\tan \varphi = 2 \varepsilon w : (w_o^2 - w^2) \qquad \text{V-3}$$

If $w_o^2 - w^2 = 1/f_o$ and V-4

$$\sqrt{(w_o^2 - w^2)^2 + 4 \varepsilon^2 w^2} = 1 / f_d \qquad V\text{-}5$$

f_o and f_d are called the undamped frequency factor and damped frequency factor respectively (Rfr: V-1 p.587.)

Substituting the values given in V-4 and V-5 into equation V-2 , the latter will take the form:

$$a = V.X.w^2 . \sin (wt - \varphi) . f_d \qquad V\text{-}6$$

and its peak value for $\sin (wt - \varphi) = 1$, will be

$$a_m = V_d . X. w^2 f_d \qquad V\text{-}7$$

Thus the dynamic magnification of the seismograph, i.e. the ratio of the maximum mass deviation to the maximum ground amplitude, is

$$W_d = a_m : X = V_d . f_d . w^2 \qquad V\text{-}8$$

For the reluctance seismograph of the type described, a_m represents the maximum available relative deviation of the magnets with respect to the armature, and this the width of the gap between magnet and armature.

When these magnets, representing the mass suspended at the end of a flat spring, move, the magnetic flux through the armature changes with the change of the gap width. The change of the flux induces the electromotive force in the coil, Let us calculate the value of this force.

The magnetic flux may be given by $\phi = S. H$, where S is the section of the magnet , H the number of magnetic lines per unit area; if M is the magnetomotive force of the magnet, then H for the upper magnet (see fig. V-2) is equal to M/2 (a - d) which produces the flux $\phi_1 = S.M/2(a-d)$ / [illegible]. At the same time the H for the lower magnet is equal to M/2 (a + d) which produces the flux $\phi_2 = S.M/2(a+d)$ / [illegible]. The total flux through the armature is then

$$\phi = \phi_1 - \phi_2 = S.M.\ d\ /\ (a^2 - d^2)$$

Neglecting d^2 against a^2 one has $\phi = S.M.\ d/\ a^2$: the maximum flux is obtained for the deviation $d = a$, thus $\phi_m = S.M./\ a$.

The change of a induces in the coil of N turns the electromotive force

$$E = \frac{d\phi}{dt} = \frac{d\phi}{da} \cdot \frac{da}{dt} = -\frac{N.S.M}{a^2} \cdot \frac{da}{dt} \qquad \text{V-9}$$

The time derivative of the value a is obtained from eq. V-6, whence $da/dt = V.X.w^2 . f_d . w. \sin (wt + \frac{\pi}{2} + \varphi)$, Substituting this value in eq. V-9 one has

$$E = -\frac{N.S.M}{a^2} . V_d . x. w^3 . f_d . \sin (wt + \frac{\pi}{2} + \varphi),$$

whose peak value is

$$E_m = -\frac{N.S.M.}{a^2} V_d . X. w^3 . f_d \qquad \text{V-9a}$$

The dynamic magnification of the electromagnetic seismograph, i. e. the ratio of the maximum voltage output to the maximum ground amplitude is then

$$E_m : X = -\frac{N.S.M.}{a^2} \cdot V_d \cdot w^2 \cdot f_d \cdot w - W_d \cdot T \cdot w \qquad \text{V-10}$$

where

$T = N.S.M / a^2$, so-called transmission factor.

From the formula V-9a , it is evident that for a given seismograph (N,S,M,a, constant) the voltage output of a seismograph is in direct proportion to the third power of natural frequency of the ground and thus to the velocity of the ground movement, then to the peak amplitude of the ground and to the damped frequency factor f_d . The bigger the charge, the higher is the ground amplitude, the greater is the output voltage and thus the larger is the amplitude on the record. Since w is in direct proportion to Young's modulus (see the next page) , thus with the same amount of explosive, placed in the compact rocks, one would obtain larger amplitudes than for unconsolidated rocks. However, due to the absorption and dissipation of the seismic energy, there is a decrease of seismic intensity with the distance. The absorption increases with the second power of natural frequency (see Chapter VII). Hence high frequences are largely eliminated with increasing distance from the source of vibration wheras the low frequencies are left over. Thus the increase of the voltage output proportionately to the third power of ground frequency may occur only to very short distances.

The third factor which influences the output voltage is

$$f_d = 1/\sqrt{(w_o^2 - w^2)^2 + 4\varepsilon^2 w^2}$$

from which it is seen that the more w_o (nat.freq.of seismograph) approaches w (nat.ground freq.), and the smaller is the co-efficiency of damping $\varepsilon = \eta \cdot w_o$, the higher is f_d, the greater is the electromotive force.

When $w_o = w$ and $\varepsilon = 0$, $f_d = -\infty$, one the resonancy occurs i.e., a very small ground motion produces large and unbalanced currents in the seismograph and thus large and unbalanced amplitudes on the record. There is, however, a tendency to approach this limit, by adjusting w_o as near as possible w, but damping the vibrations, by making η equal 0, 7 of the critical damping; for the latter there are almost no oscillations of the seismograph.

The natural frequency of th~~e~~seismograph, for free oscillations is determined by the ratio of the effective stiffness of the spring c, (which links the mass and support together) and the suspended mass m; is given by the formula $w_o = c/m$, and characterises the sensitivity of the seismograph. For the electromagnetic seismograph this value is smaller, due to the presence of a magnetic field which reduces the stiffness of the spring. Here it is given by the formula

$$w_o = \sqrt{(c - c_m) : m} \qquad \text{V-11}$$

in which c - spring constant $= E.b. \left(\frac{h}{l}\right)^3 : 4$

c_m - negative constant due to the magnetic field and is equal to $S.M^2 / 4. \pi . a^3$

where E is Young's modulus, b breadth, l length, h thickness of the spring, S section of the magnet, M magnetomotive force, and a the gap width.

For the reflection work the adjustment of w_0 is done by a special selection of flat springs for a given range of frequencies, usually from 30 - 60 cycles per second. This adjustment would take place when one enters a new region of exploration and the previously adjusted natural frequency differs too much from that encountered in the new region.

For refraction work carried out with the aid of reflection seismograph, one had to reduce the natural frequency of the geophone to the range of from 15-20. This was done by increasing the mass (see formula V-11) with additional weights attached to the magnets and by suitable selection of flat springs so as to keep the augmented mass symmetrically with respect to the armature, i.e., the lower and upper air gaps should have been equal.

b) Amplifier-filter.

The next instrument in the recording channel is the amplifier - filter. The Seiscor set contained six amplifiers placed in threes in two metal cases. Each amplifier-

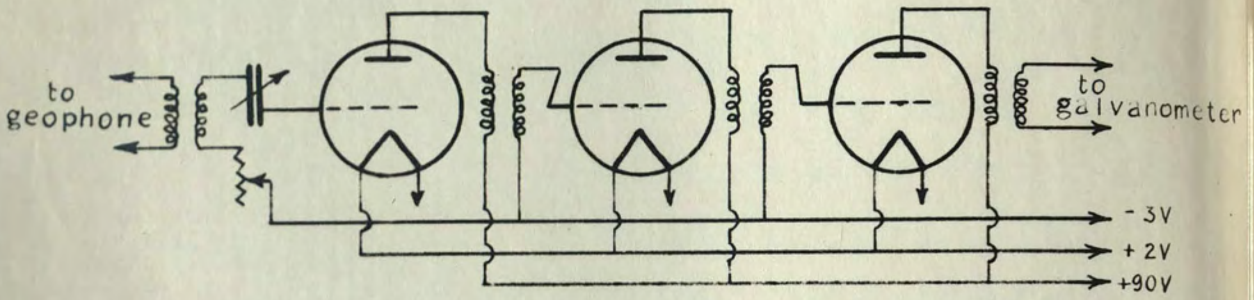


Fig. V-3.

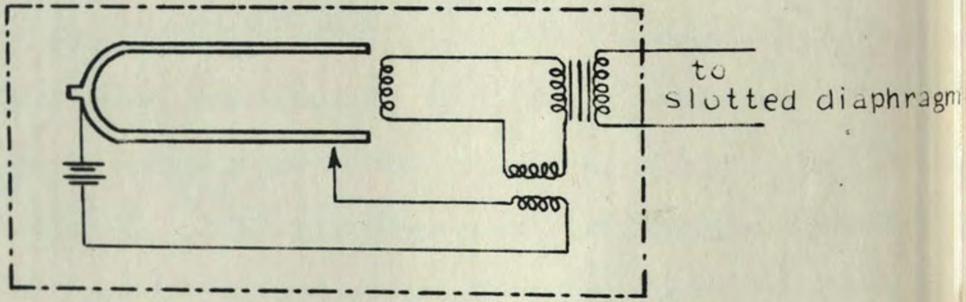


Fig. V-4.

filter consisted of three stages transformer-coupled. A scheme of this type is shown in fig. V-3. It consists of input and output transformers which matched the impedance of the geophone and galvanometer respectively, one or two intermediate transformers, three vacuum tubes, the first in a series resonant system used for filtering, the next two in normal amplification systems. The grid voltage was supplied by a small battery of 3 - 5 volt, the anode voltage being supplied by two 45 V Burgess batteries. The heating of the filament was done by an accumulator of 2 volts.

The filter formed an electrical damping system whose range of frequency varied from 20 to 100 cycles per second. Its purpose was to select and accentuate the currents of desired frequency picked up by the geophone which were afterwards amplified in the next two stages of the amplifier. Had there been any undesired currents as the result of direct waves or of ground rolls, which usually carried most of the energy and were of low frequency, they were suppressed by the filtering system adjusted to a range of 30 to 50;. Including the seismograph, each filter system selected the currents of desired frequency and passed them to the amplifier and finally to the galvanometers. The filters and the gain controls were calibrated linearally from 0 to 100 in decibels.

Consider briefly the magnification of the amplifier. The current entering the amplifier with a peak value of the input voltage E_m (or the output voltage of the geophone) has, after leaving the amplifier to the galvanometer, the value (Ref: V-1, p. 598.) :-

$e = V_a \cdot E_m \cdot \sin (wt - \varphi) \cdot f_a$, whose peak value for $\sin (wt - \varphi) = 1$ is

$$e_m = V_a \cdot f_a \cdot E_m \qquad \text{V-12}$$

where

e_m - the peak value of the output voltage

E_m - the peak value of the input voltage

V_a - the static magnification of the amplifier

f_a - the equivalent of the damped frequency factor equal to $1 / \sqrt{(w_a^2 - w_o^2)^2 + 4 \varepsilon_a^2 w^2}$

w_a - the equivalent natural frequency

- the equivalent damping constant

w_o - the frequency of the entering current

w - the frequency of the ground motion

The dynamic magnification of the amplifier i.e. the ratio of the input and output voltage is then:-

$$W_a = e_m : E_m = V_a \cdot f_a \qquad \text{V-13}$$

c) Galvanometer.

The output of each amplifier was connected to a coil galvanometer. It consisted of a tiny coil, with a mirror attached, in a strong magnetic field. The current, passing through, produced rotation of the coil due to the magnetic field.

The forced oscillations of the damped galvanometer are given by the equation of the movement similar to the above for the seismograph, which is:-

$$b'' + 2 . \varepsilon_g b' + w_g^2 . b = V_g . I / K \qquad \text{V-14}$$

where

b = 2. φ . D = the record amplitude, φ the deviation of the mirror, D the focal length of the lens in the from of the mirror,

ε_g - damping constant

w_g-- the natural frequency of the galvanometer

K - moment of inertia of the wire and coil

I - the input current entering the galvanometer.

V_g - the static magnification which for each coil galvanometer is equal to 2.D.H.S.N, where H is the magnetic field strength, N the number of turns of the coil, S the area of the coil.

The solution of the equation (Ref: V-1, p.602) is

$$b = e_m . V_g . \sin (wt + \varphi_g) : K . \sqrt{(w_g^2 - w^2)^2 + 4\varepsilon_g^2 w^2} \qquad \text{V-15}$$

where φ_g is the phase shift between the galvanometer record and the impressed current.

The peak value for $\sin (wt + \varphi_g) = 1$, is

$$b = I_m . V_g . f_g / K \qquad \text{V-16}$$

where f_g is the demped frequency factor for the galvanometer.

The dynamic magnification of the galvanometer is then

$$W_g = b / e_m = V_g \cdot f_g / K \qquad \text{V-17}$$

For a given galvanometer, as it was, the only factor which could be changed was the damping constant $\varepsilon_g = \eta \cdot w_g$. The damping of the galvanometer was done by the glycerine in which all six galvanometers were immersed in a metal case. The viscosity of the fluid was very much affected by temperature changes and so, w_g and w being nearly equal, the damped frequency factor f_d became very small when η, and thus the viscosity of the fluid increased. Thus the amplitude on the record b became very small. In the morning or during the winter days the viscosity of the damping fluid was very great, which compelled the observer to heat the galvanometer case with a hot soldering iron, till the fluid became less viscous. It was very inconvenient, because the lenses of the galvanometers case misted over and produced the undesired parallax on the record.

The record amplitude b, when compared with the ground amplitude X, gives the over-all dynamic magnification of the recording channel

$$W = b : X = E_m / X \cdot e_m / E_m \cdot b / e_m =$$

$$= W_d \cdot T \cdot w W_a \cdot W_g = W_d \cdot W_a \cdot W_g \cdot T \cdot w \qquad \text{V-18}$$

It is seen then that the resultant dynamic magnification of the entire channel is proportional to the product of all dynamic magnifications, the transmission constant and the natural frequency of the ground motion.

This over-all reaction, the value of which is expressed by W and its character by the appearance of the record, depends on a proper balance of all the component parts of the recording channel with respect to its electric and mechanical characteristics expressed by all the factors entering the considered equations.

In the reflection set under consideration there were six recording channels. Each of them should have had the same characteristic and given the same over-all response on the record. The observer was instructed to check it before beginning any new exploration, otherwise at least once a week.

This test was done in a so-called "Phase shot" i.e., a reflection shot taken with all the geophones set closely together at the same distance from the shot-point. From the results received in this type of alignment record, the observer was able to state whether and to what extent there existed any phase difference between the different recording channels and which channel was affected.

In case of the existence of such a phase difference, (also called the time parallax between the individual recording traces on the seismogram) the observer had to adjust it properly, this work consisting of repeated examination and adjustment of the affected channel.

By interchanging the affected geophone, amplifier or galvanometer to different recording channels, the instrument actually affected was found. The next procedure was as follows:-

1) In the case of the geophone, the test included:

a. The geophone being removed from its case, the air gap between the armature and magnets was checked to verify that it was clear and of the same dimensions on both sides, i.e. the moving part (magnets) was symmetrically disposed with respect to the fixed armature. This involved adjustment of the length and clamping of the flat springs. A special set of gauges was provided for this purpose.

b. The thin insulating wires from the coil to the outside double lead were checked, as well as their outside contacts.

c. Before screwing in, the quantity of oil and its level was checked.

2) In the case of the amplifier, the test included:

b. The voltage of each battery. A voltage-drop of more than 1 volt below 45, necessitated the removal of the old and replacement by a new battery. The individual vacuum tubes were checked by interchanging them to different stages or replacement by the new tubes tested before in the field laboratory.

3) In the case of the galvanometer, the test included:

The removal of the whole bank of galvanometers placed in a metal case between the poles of a permanent magnet. The front side of the box contained six lenses. The glycerine being poured out through a special drain, the back side of the case was unscrewed. The whole row of galvanometers were then accessible and the affected string might be checked to find whether the stretched silver wire was not too taut or distorted. A new string with coil and mirror would be put in, though this task was usually done in the field laboratory. The upper side of the galvanometer case contained six screws which, being attached to the individual strings, permitted the observer to adjust the position of the mirrors so that the individual light-spot reflected from these mirrors fell at the desired place on the record.

B) Time marking instrument

Each seismogram was marked across with black time-lines about 0,2" apart which corresponded to an interval of time exactly 0,01 sec. These time-lines were produced by the light passing through slotted diaphragms, the slots in which opened every hundredth of a second, letting the light fall through a cylindrical lens directly upon the recording paper.

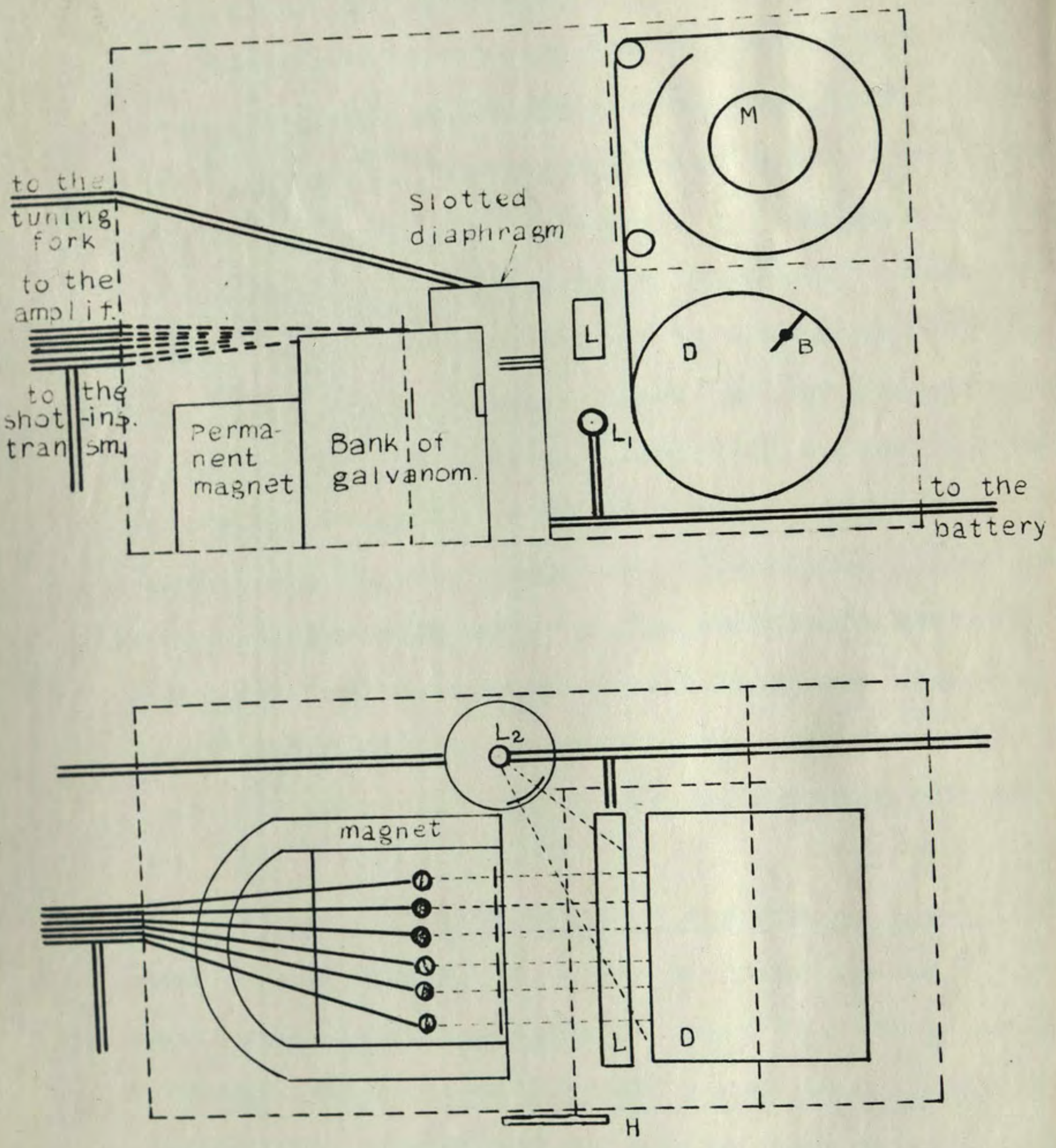

to the tuning fork
Slotted diaphragm
M
to the amplif.
L
D
B
to the shot-ins. transm.
Permanent magnet
Bank of galvanom.
L_1
to the battery
L_2
magnet
L
D
H

Fig. V-5.

uniform opening of the slot was controlled by an alternating current supplied by an electrically driven tuning fork, the latter being placed in a separate box. The The schematic plan is shown in fig. V-4. The timing system was tested for accuracy by comparison with a standard tuning fork, whose timing circuit could be easily connected to one of the galvanometers.

C. The recorder.

This instrument, called also, the recording camera, contained a bank of galvanometers and slotted diaphragms for time marking and registered the amplified signal currents producing a respective written record. The plan of this recorder is shown in fig. V-5. : The drum M holds a roll of sensitized paper 200 feet long and 3,5" wide. The paper comes out through a slot and is rolled on to the drum D, the latter being driven by a spring motor: a beam of light from a cylindrical lamp L, falls through a diaphragm at the mirrors of the galvanometers. The reflected beams are focused by the lenses placed in front of the galvanometer-box into small bright spots on the recording paper. Behind the galvanometer bank, another cylindrical lamp L_2 placed inside the slotted diaphragms, throws a beam of light through the opening slot, the latter being controlled by the tuning fork. This beam of light is focused by a cylindrical lens L into parallel lines on the record strip. The drum D is driven by a spring motor, which has to be wound up every second or third record taken, the button B being used for this prupose. The handle H serves to release the spring when recording. Five plugs are provided to connect the recorder with amplifiers, tuning fork, shot-instant transmission, and battery for lighting the two cylindrical lamps L_1 and L_2 , as shown in the figure.

D. The shot-innstant transmitter.

The shot-instant time i.e. the exact moment of the explosion and thus the time of origin of the vibrations must be recorded and transmitted with as much accuracy as the record can be read. In refraction shooting the accuracy of marking the shot-instant varies from 1/100 of a second for short distances to several hundredths of a second for great distances. In reflection work, however, the accuracy of determining the time is/of range from 0,001 to 0,002 seconds and thus the shot-instant transmission must secure this accuracy. Present refraction instruments have the same accuracy of determining the time.

In reflection set concerned this transmission has been accomplished by a line which also served for communication between the observer and the shooter at the shot-point station. The plan of the shot-instant transmission

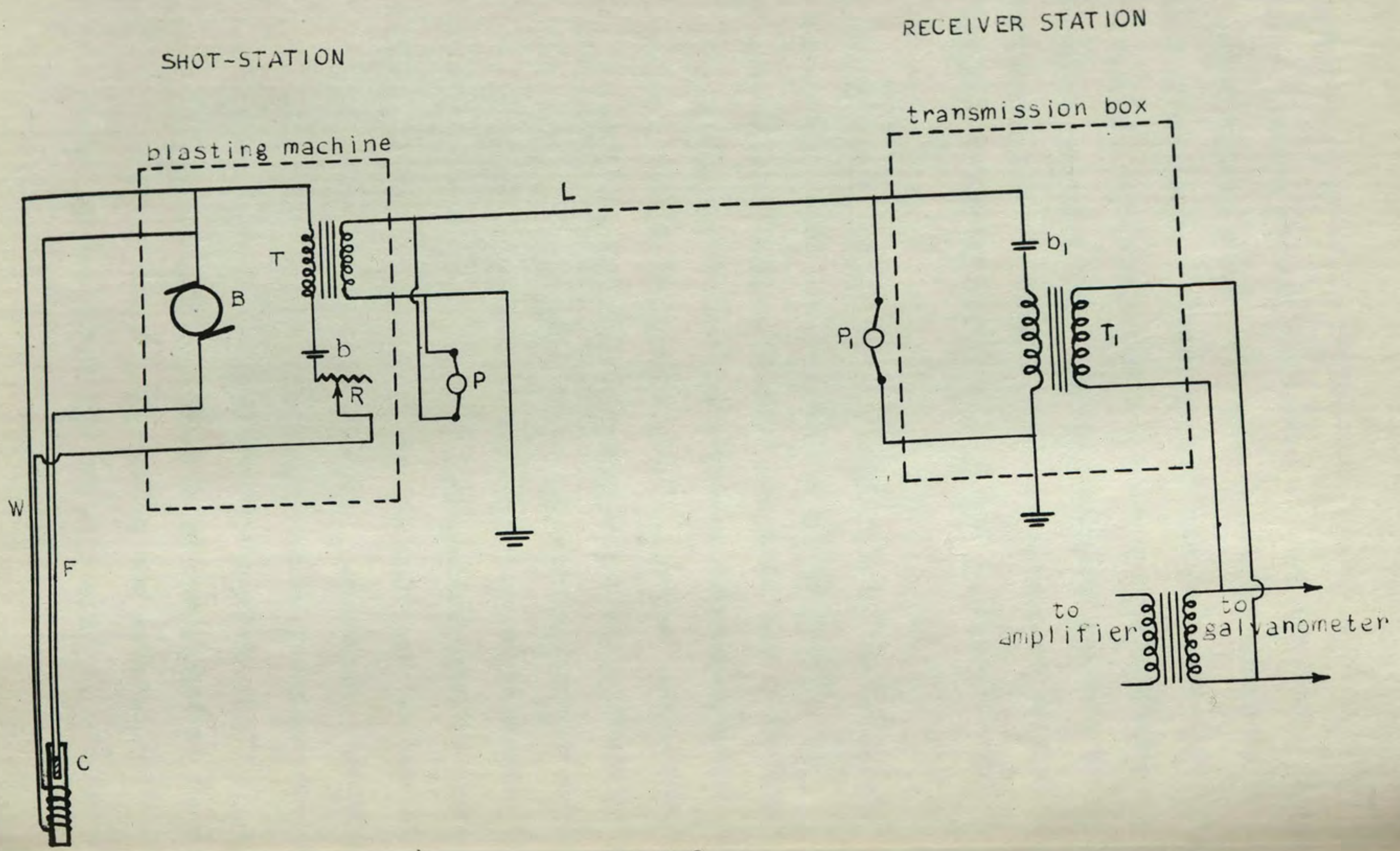

SHOT-STATION
RECEIVER STATION
blasting machine
transmission box
L
T
B
b
R
P
W
F
C
P_1
b_1
T_1
to amplifier
to galvanometer

Fig. V-6.

is shown in fig. V-6. It consisted of a simple arrangement of a blasting machine and a phone at the shot-point station and of a transmission box and a phone at the receiving station on the other hand. Both the shot and the receiver points were connected by a double telephone cable or a single signal cable and earth. The small dynamo-machine B in the blasting box produced the electromotive force which initiated the detonating cap C, through the firing circuit F. Another wire wrapped round the cap or the explosive charge was connected with the primary of the transformer T, a small dry battery b and a resistance R being placed in series in the second circuit W. The line L was connected to the secondary of the transformer T. At the receiver station, the primary of the transformer in the transmission box was in series with the secondary of the transformer in the blasting box and was connected with the line L, battery b_1, and earth by the transmission line. The secondary of the transformer T_1 was connected in parallel with one of the amplifier outputs and the corresponding galvanometer. The communication was made up by the phones P and P_1 placed in parallel with the transmission line L.

At the moment of firing, the circuit W was broken and thus a sharp impulse was transmitted along the line to the corresponding galvanometer.

The use of the double firing curcuit was necessi-

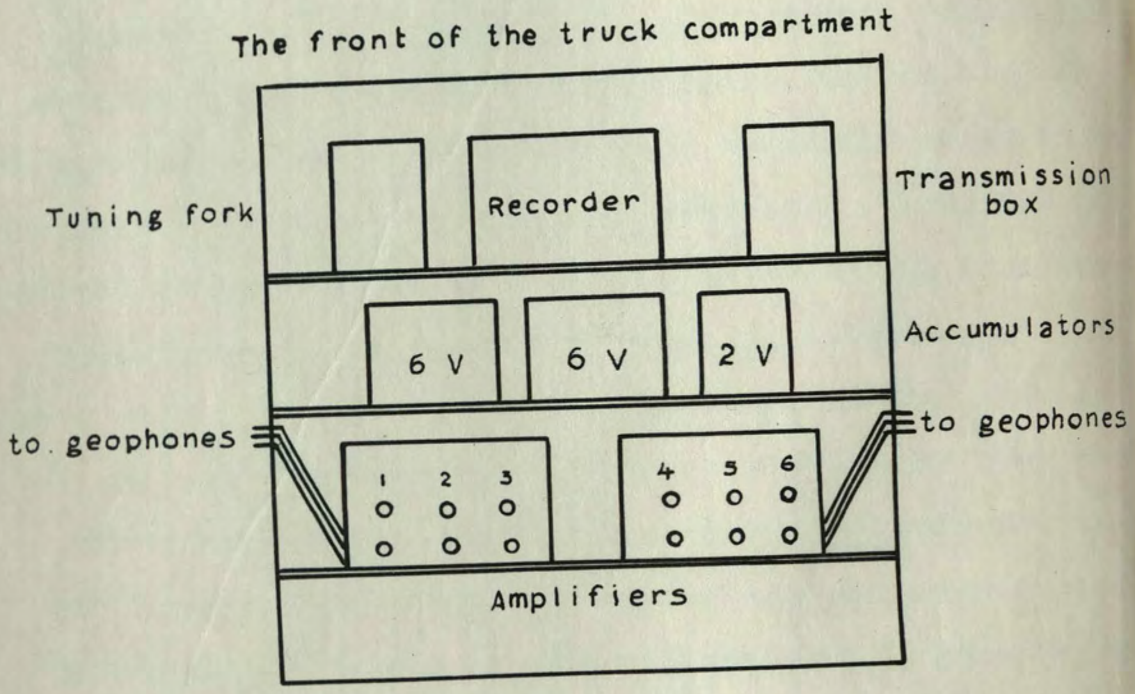

The front of the truck compartment
Tuning fork
Recorder
Transmission box
6 V
6 V
2 V
Accumulators
to geophones
to geophones
1
2
3
4
5
6
Amplifiers

Fig.V-7.

tated by the differences in the times of fusing of the fusing bridges in the detonating caps applied; the instant of the passing of the first fusing current through the cap did not always correspond to the actual moment of explosion and varied from 0,001 to 0,04 sec. for different caps. Later improvements in the manufacture of detonating caps made it possible to remove the second circuit. Until that time, however, it was almost imperative to apply two firing circuits and so to place in the shot-hole four leads instead of two. For the single firing circuit the externals W and C could be joined together as is shown by dotted lines in fig. V-6.

A lay-out of all the above given instruments in the recording truck is given in fig. V-7. For comfort in operation by a single observer the front of the recording compartment of the truck or trailer was provided with three shelves. The tuning fork, recorder and transmission box were mounted on the top shelf. The bottom shelf contained the heavy cases of amplifiers. On the middle shelf two wet batteries of 6 V each, and one of 2 V completed the inside equipment; the 2 V battery supplied the vacuum tubes of the amplifiers and tuning fork; the 6 V batteries supplied the recording lights. All three batteries were of high capacity (200 to 270 Ah.).

The operator sitting in front of these instru-

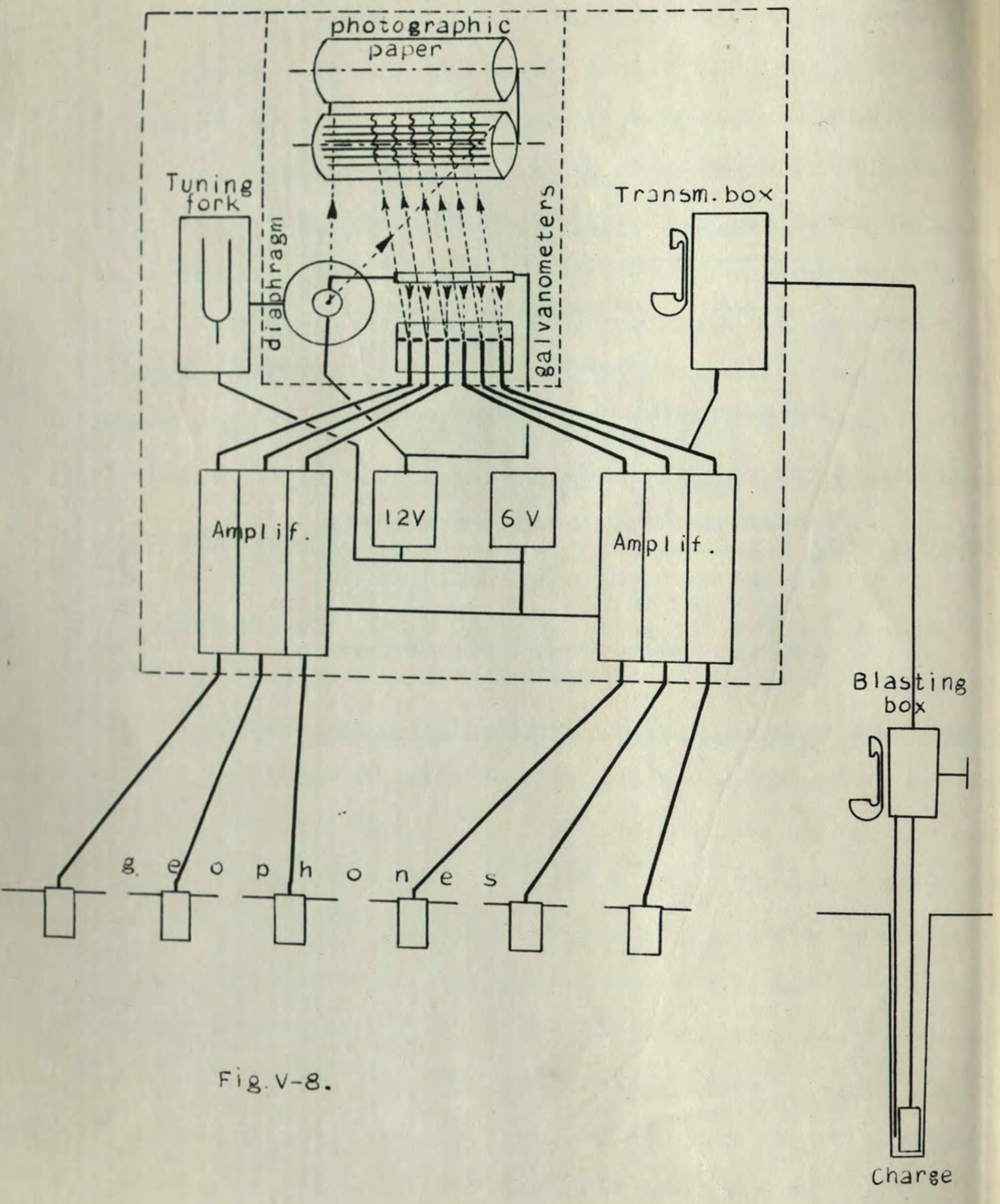

photographic paper
Tuning fork
diaphragm
galvanometers
Transm. box
12V
6 V
Amplif.
Amplif.
Blasting box
g e o p h o n e s
Charge

Fig. V-8.

ments had behind him three cans with developing liquids so as to produce a ready seismogram immediately after its recording. Additional red lights in the truck compartment were provided for.

The schematic assembly of the whole set as used in field is shown in fig. V-8.

E. Auxiliary equipment.

The individual geophones, being placed in the ground at different distances from the recording truck, were connected with the amplifiers in the truck by means of leads of various lengths. Six duralumin reels were supplied for these lines. Each reel with its line weight- 40 lbs. Besides the amplifiers, weighing about 200 lbs and the wet batteries weighing about 150 lbs, these reels contributed the main part of the load carried by the recording truck or trailer.

The telephone line for communication and shot-instant transmission was wound on a portable reel, the length of cable being of at least 1/2 miles.

Three cases, one containing several geophone augers, used for drilling shallow holes in the ground for the geophones, a spade, a pick, and hammers, the second containing various small tools and the third with spare batteries, developers, photographic paper, completed the necessary field equipment of the recording section.

Fig. V - 9

. Difficult transportation conditions in application of reflection surveys in the Carpathian Foreland.

Fig. V - 10.

The recording section was manned in the field by one observer with one assistant. The driver of the truck was an additional helper in the case of emergency.

F. Shot - Point equipment.

The shot-station instrument consisted of a box containing the blasting machine and a phone, and of two suitable lengths of firing lines wound on two parallel reels. Loading poles with a number of extensions and special link couplings, loading pickets, tin pipes and sheets and string, formed the secondary equipment of the shot-station.

The shot-point personnal consisted of a shooter and one assistant.

G. Transport.

At first the instruments were mounted on a truck, which however, was too weak on difficult ground; later a special light trailer driven by a truck or by horses was constructed. It was provided with a small oven for cold weather and also special ski-planks were constructed for mounting the trailer when working in deep snow. Fig. V-9 and V-10, show the recording trailer in the woods and marshes of the river Dniester in Eastern Poland.

On the roads the trailer was driven by a truck which could take the men and all the shooting equipment. Off the road, the trailer was driven by one or two pairs of horses,

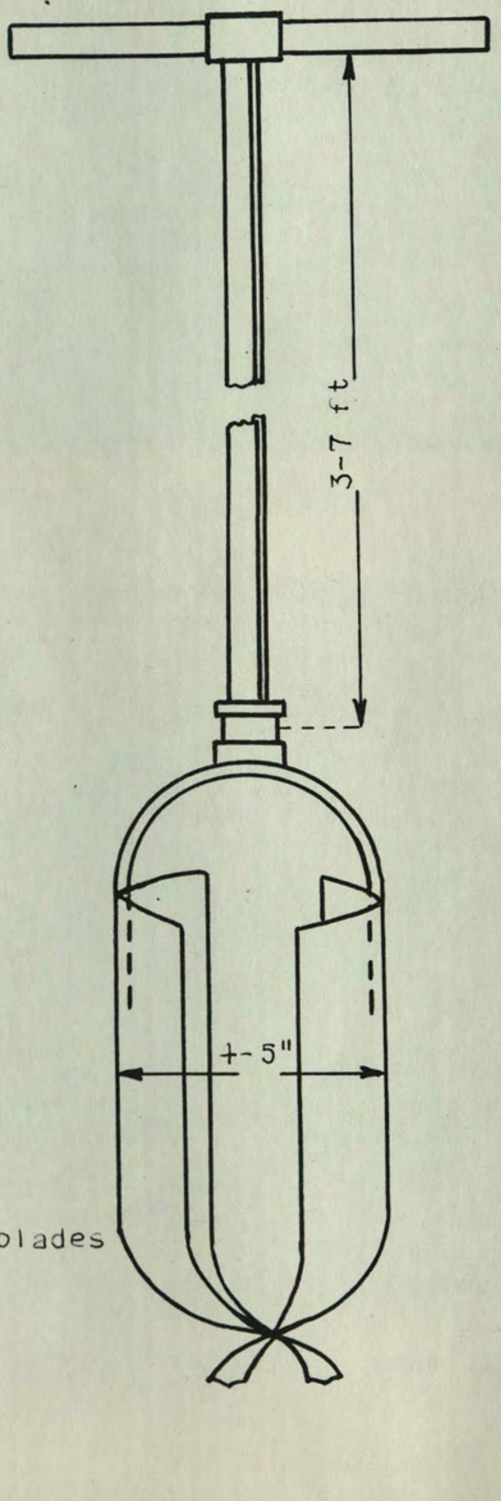


Fig.V-11.

The geophone auger.

the shooting equipment being carried on a separate cart. The part chief and the surveyor had a car, used also by the observer in case the trailer was left in the country. A separate car was designed for explosives,

All together the field transport consisted of a truck, a recording trailer and one or two cars, which provided sufficient transport facilities on the roads or on flat and consolidated terrain. In difficult terrain almost all transport was done by carts and horses.

H. The drilling equipment.

Compared with those used in refraction shooting, the individual charges used in reflection surveys being relatively much smaller, they could be more easily concentrated at the bottom of the shot-hole.

As the charge should be placed in unweathered rock with a view to the better transmission of seismic energy, the depth of these holes and thus the method of drilling depended on the thickness and character of the weathering zone in the area under investigation.

When clay, loam, or compact sands prevailed the geophone augers were used, often to a depth of 24 feet, The auger of this type is shown in fig. V-11. The diameter of such an auger is 4" or 5" and the depth of one filling about 6 - 8". Originally it was for the preparation of shallow holes for the location of the geophones. When used for the latter purpose, it was provided with a 3 foot long steel pipe of 1" in diameter, to which a horizontal wooden handle was attached by screwing. Since it gave also good results for deeper holes, separate 7 foot long extentions were supplied. Operated by two men, the depth of 20 feet in a soft clay could be reached in 20 to 30 minutes, each additional foot below 20' needing additional 5 minutes of drilling. Deeper holes than 24 feet were too difficult for drilling because of the troublesome manipulation with the long extentions, when the auger had to be discharged at the surface after each filling.

The weathering zone consisting of gravels, soft and watered sands or rocks, a special set-up of a hand drill was used. It was similar to that described for the refraction shooting, with additional tools for sinking the pipes. The latter were used for the protection of the facing of the shot-hole. A skilful driller with three assistants manned one drilling set. For transport one or two carts were used for each drill. In difficult drilling conditions, two or more drills were necessary to supply holes for one recording for the day.

I. Explosives.

The generating of elastic waves was done by the detonation of a charge of explosive placed in a shot-hole.

The "normal dynamite No.1" and "unfreezing dynamite No. 1" were generally used both containing 60% of nitroglycerine, both highly water resisting, dense and plastic. The freezing point being about +8° C, the normal dynamite was used mostly in summer and early autumn , whereas the second type was used from November to March, since its freezing point was below - 28° C.

The size of a single charge placed in a shot-hole varied from 1/10 of kg to 5 kg. Cartridges of 1/10 of kg were wrapped in a paper and packed in tens in card-board boxes of 1 kg each. 25 boxes were placed in one wooden case thus containing 25 kg of dynamite. When bigger charges were required, several cartridges of 1/10 were tied together or placed in a tin pipe and tamped.

The detonation was achieved with different mining blasting caps. After various experiments with special blasting caps manufactured for the reflection work separate detonators Nr. 8, and special electric initiators Nr.8 were introduced. In the latter the fusing bridge was so adjusted that the elapse of time between the application of an electric current to the cap and the explosion was kept in range of 0,001-0,002 sec. However, as this was not always true, one was mostly compelled to use the double firing circuit, in which the shot-instant was obtained by the interruption of a wire wound around the dynamite charge. The single-cap method

was put into practice in 1937, when the manufacturing of the special fusing bridge in the cap was sufficiently advanced in quality and greatly reduced in price.

The use of separate detonators and caps had the advantage of facility in transport. The detonators were packed in 50s in small card-board boxes which could be easily carried by the shooter. For field purposes, for safety in transport, a special wooden box upholstered inside was prepared to take 25 kg of dynamite. It had been covered with tin sheets against rain and storms.

The amount of explosives provided for one month's shooting was stored in field magazines and protected by canvas. These magazines were placed at least 300 m. away from the nearest inhabited localities and traffic. Two wardens took turns in guarding this field magazine.

K. The loading and tamping.

The effect in the transmission of the seismic energy is the best when the explosive is well tamped in the shot-hole. In reflection practice this was attained by filling the holes with water to their top. When shot-holes were cracked mud was used giving better contact between the charge and the facing. In this way a single hole could be used several times. In unconsolidated sands, gravels, etc., at most two or three small charges could be used without the

necessity of clearing or deepening the hole, which involved a steady need of a drill at the surface. When dealing with soft water sand or fine gravel of a considerable thickness, the piping had to be removed before shooting or at least lifted to a safe height. In such a case a special clearing party was provided to assist the shooter. The skill and experience of the shooter in charging the hole and lifting the piping secured the hole for the next shots. The loading in shallow holes was done before or after tamping with water. The small charges were wrapped around a loading wooden picket to which wthe firing wires were attached. They were lowered on the wires and pushed down by loading poles, the latter being provided with link caplings to reach the required depth.

L. Setting-up and work on a reflection traverse.

Under the name of "a reflection traverse" one should understand a single shot-hole and a line of geophones strung along one direction. This line was surveyed for elevation and location of individual geophones. The geophones were placed at a distance of 20 to 30 m. from one another, the distance from the first to the last geophone, numbered from the shot-hole, being called "spread". The length for the spread for each terrain had to be determined individually.

Once the spread had been selected and surveyed, the recording truck or trailer was placed in the middle of the spread, near the third or fourth geophone, or between

them. The first truck helper drilled the holes for the geophones and placed geophones in the ground, while the second helper wound out the cables from their reels and connected them with the individual geophones. The near ends of each cable were connected with the plugs in the truck, which led to the amplifiers. The geophones were placed with care, the earth around them being rammed firmly. The top of each geophone was kept level with the ground so that the influence of the wind was partly eliminated.

When the connection of geophones with amplifiers was done, the whole operation from start to this moment taking 5-10 minutes, the observer would put the currents on in all circuits as well as the lights in the recording box and checked the functioning of the geophones by their light spots, adjusting the latter on the photographic paper.

During that time the shooter at the shot-point with the aid of his helper checked the state and depth of the shot-hole, prepared the first charge (the smallest used) and placed it in the hole. The communication between the shooter and the observer being secured with a transmission cable, wound off by one of the helpers, the shooter stated his preparedness. The shooter blew up the charge at the signal sent to him by the observer on the telephone. Simultaneously with this signal, the observer put the rotating drum into motion and after about 1 second when the vibrations ceased to appear, i.e. when the light spots were again still,

he stopped the motion of the drum, put off all lights and amplifiers, cut the record off the roll and developed it in the dark room. Having developed the seismogram, the observer spread it over a ply-board marked accordingly to the time-lines of the seismogram. In this way the observer was able to pick up quickly the desired time-place of the observed reflections, which he elaborated more precisely by the next shots.

The first record would be usually unbalanced and very illegible for inexperienced eyes as far as reflections were concerned. By balancing the apparatus with amplifier control devices and by shooting alternative charges, the observer finally got the record which he considered to be the best for the chosen spread and direction. If necessary the observer elaborated other records proceeding in the same way on shorter or longer spreads, or changed the direction of the traverse.

The theoretical considerations concerning the reflection seismogram are given in Chapter VIII.

M. Organization of the reflection field party.

This organisation was identical in general features with that given for the refraction field party on page 62 , The reflection field party consisted of:-

One party chief
One observer with two helpers
One shooter with one helper

One surveyor with two helpers

One overseer

One computer

Two to three drilling parties each of one driller and three helpers

Two drivers, and two guards for the field magazine.

The above can also be grouped as follows:-

2 geophysicists : party chief, interpreter.

3 technicians : observer, surveyor, overseer.

5 mechanics : 2 drivers, 2 drillers, 1 shooter.

8 - 10 skilled workmen

6 - 10 unskilled workmen

: TOTAL 24 - 30 men.

Transport

1 lorry and 1 car; in difficult terrain two horses for the trailer, one cart for the shooting equipment, and occ. 2-3 carts for drilling equipment.

N. Efficiency and cost.

Taking into consideration the average conditions of transport (partly by motor and partly by horses) and the organisation of the field party as given above, it was possible to shoot 4 to 6 traverses per day with one or two spreads on each traverse.

According to the method of working i.e. by correlation or by dip-shooting method, 6 - 3 shot-points could be shot during an average day of 8 hours.

The cost of maintaining the field party, including the supplies of explosives, indemnities due to damage done by shooting and passing through cultivated fields or meadows was round about 800 - 1000 zl per day (£1,000 per month). This included the cost of depreciation of equipment and the cost of a maintaining the central office in Lwow, where final computations and maps were made.

The personnel there consisted of:-

1 geophysicist, 1 geologist, 1 computor, and 1 draughtsman.

REFERENCES

Ref: V - 1 - C. Heiland " Geophysical Exploration"
1940 pp 437 - 615.

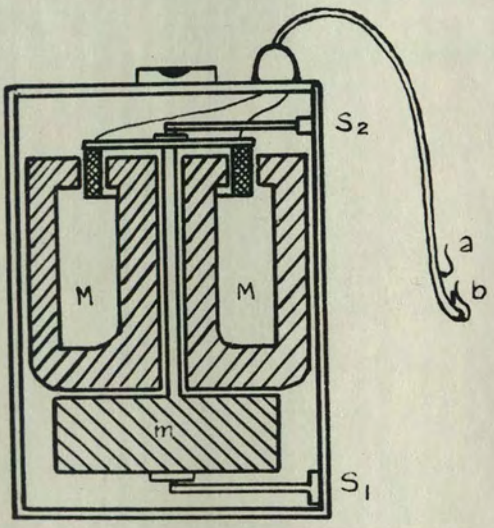


Fig. VI.-1.

CHAPTER VI.

THE 6 - GEOGPHONE REFLECTION SET OF THE HEILAND RESEARCH C 33.

This set, used by the Pioneer Institute of Applied Geophysics in the years 1935 to 1937, did not differ very much from that of Seiscor. It consisted of 6 geophones, 6 amplifiers, and a recorder with 6 oscillographs, a tuning fork and a shot transmitter. The main differnences from the Seiscor equipment lay in the types of individual components of the detecting channels which were as follows:-

1. The seismographs were of an induction type - i.e. the air-gap between the armature and the magnets was constant. (In the reluctance detector of the previous set this air-gap was variable.) A seismograph of this type is shown in fig. VI-1: a single coil of very fine wire is attached to the seismograph inertia mass $\underline{m}$ and moves in the field of a pot-type permanent magnet $\underline{M}$, The seismograph then is intermediate between the mechanical and the electromagnetic type of seismograph and therefore has the advantages and disadvantages of both. The seismograph did not need clamping. In the field operation the seismograph had always to be buried in a level position (this was done with the

aid of an attached spirit level). As it was not of symmetrical design on account of the suspension of the flat springs the sdsmograph had to be orientated in the direction of the shot-point, the latter being indicated by an arrow beside the spirit level; it was essential to orientate all the geophones along a traverse in the same way in order that equality in reproduction might be obtained.

Two flat springs S_1 and S_2, the one supporting the mass at the bottom and the second the coil at the top of the geophone, complete the sturcture of the seismograph. The damping was done with oil in which the whole structure was plunged. The ends of the coil wire outside the case were enclosed in a double insulated lead terminating in small plugs <u>a</u> and <u>b</u>. Thus the geophone could be easily connected with its amplifier using twin cable of suitable length.

The deviation of the suspended mass forced the coil to cut the magnetic lines (without changing the width of the air-gap) of the field of the permanent magnet, thereby inducing in the coil-circuit a corresponding fluctuation of the electric current.

2. Each amplifier comprised a two-stage system resistance capacity coupled. The filters were separate units preceding the input stage of each of the amplifiers, both being placed in one metal box, which also contained the dry batteries for the high tension supply.- A volume control,

filament and output switch with ammeter placed on the front panel of the amplifier box completed the equipment of the amplifier-filter.

3. The oscillograph-unit comprised 6 separate oscillographs. Each oscillograph consisted of two conductors which, being suspended in the air-gap of a permanent magnet, were traversed by currents in opposite directions so that a rotation movement resulted, in response to the fluctuation of the current coming from the amplifier.

The oscillographs had a damping of 0,7 of that of critical as in the geophone system, and this damping was achieved electromagnetically. Each oscillograph was self-contained and could be replaced easily. Each of them had separate vertical and horizontal adjustments for locating the light-spots at the required place on the photographic paper. The natural frequency of the oscillograph was adjustable within small limits.

All the oscillographs were placed in the recorder-box which contained also the lighting system, the timing unit, the drums with photographic paper and electromagnetic clutch, the shot-instant input and switch, the light switch and meter, and a combination switch to turn on the timer and paper clutch immediately before firing.

The shot-instant was transmitted to the recording truck by a double wire and coupled to one of the oscillographs.

All the instruments except the geophones, were placed in a similar way as in Seiscor equipment inside the recording compartment of the trailer, which, like the previous trailer, could be pulled either by a truck or by horses.

The whole detecting channel had a wider range of frequency, than that of Seiscor, owing to the inductive character of the geophones. On account of this, however, waves of lower frequencies, and thus the ground rolls, were not easily suppressed by the filter. Therefore on the seismogram almost always, except in terrains of higher natural frequencies of ground motion, or in cases when the seismogram was taken far away from the shot-point, high frequency waves were revealed superimposed upon those of small frequencies. Although, on the other hand, the set gave good impulses of the first arrivals, when used in refraction work, this fact did not compensate for the disadvantages met with in a reflection survey.

The other details were of similar type as described in the previous chapter.

* * *

CHAPTER VII.

THE DISTRIBUTION OF SEISMIC ENERGY IN THE GROUND.

Follow the path of vibrations from the point of their origin i.e. the shot-point to the point of their reception i.e. the seismograph and their registration on a record called the seismogram, as well as the ways in which the total energy content set up by the explosion is distributed along this path. In order to achieve this, it seems necessary to consider:

1. The generation of the elastic vibrations and the phenomena round the shot-point.
2. The behaviour of the elastic vibrations at the interface.
3. The losses of seismic energy.
4. The effect of stratification.

1. The generation of elastic vibrations and the phenomena occurring round the shot-point at the moment of an explosion, were given in some detail in Chapter III. Here is a brief repetition:

The detonation of the explosive placed in a shot-hole produces the chemical change of its components into a small volume of gas of very high pressure and temperature. This high amount of energy released is at once converted into heat and mechanical energy; the first occurring mostly in the form of a chemical change in the adjacent facing of the hole and in the shape of accompanying smoke, the second causing three concentric zones in the adjacent rocks, within which the rock can be discriminated as crushed, shattered, and cracked respectively. In the chemical and mechanical changes of the surrounding rocks a great amount of the generated energy is lost, and only a very small part of it penetrates further and produces the movement of all the particles from their centre, and their temporary compression. This small part of mechanical energy is converted into kinetic energy of the particles which preserve their potential energy in their resistance. The inner radius of the zone of elastic waves, i.e. the distance from the source at which the elastic phenomena occurs is different in different rocks and its size has probably an influence on the amount of energy converted into seismic waves.

Among all the different motions of a single particle there are two movements which predominate. These are longitudinally and transversely to the directions of the propagation of seismic energy. The longitudinal movement is faster and expresses itself in the form of radiating waves which begin from the inner boundary of the elastic zone with sudden compression. The front of this compressed wave is immediately followed by a short series of successive rarefractions and compressions. The other part of the movement of the particle in the transverse direction is slower and of no great importance to present seismic prospecting.

The longitudinal impulse being of a transient nature, as is the whole explosion, the amplitudes of the vibrations decrease in time due to the damping caused by the internal friction between the particles.

The movement of an individual particle in its simplest form may be considered as a sine movement, where the single particle is performing a simple harmonic vibration, which can be represented by the equation

$$y = a . \sin 2\pi \left(\frac{t}{T} - \frac{x}{\lambda} \right) \qquad \text{VII} - 1$$

where y is the displacement of a particle at a distance x from the origin, the wave having travelled this distance in time t, a is the amplitude of the vibration, T the period, λ the wave length. With λ as the path which the particle travelled and returned to the point of origin in space during the period T, the velocity in which this movement has been accomplished is

$$V = \lambda : T = \lambda . f \qquad \text{VII} - 2$$

where f is the number of oscillations per second of the particle. Withall, the velocity of the compressional impulse is expressed in terms of the characteristics of the

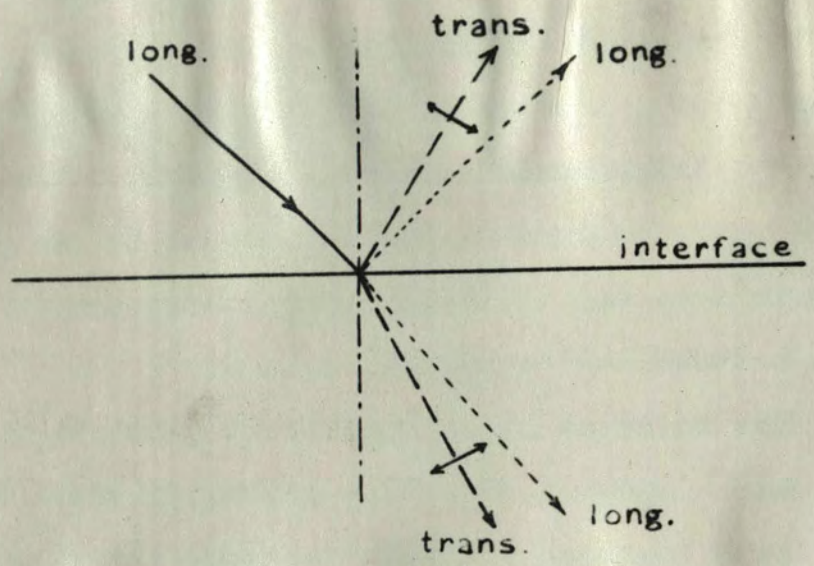
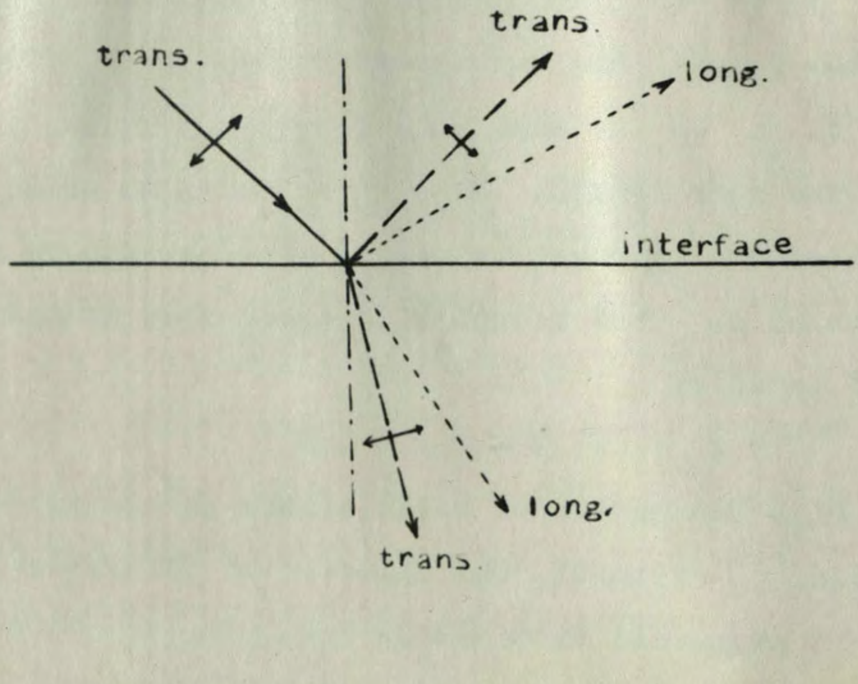

long.
trans.
long.
interface
long.
trans.

Fig VII-1.


trans.
trans.
long.
interface
long.
trans.

medium considered :

$$V = (k \quad \frac{4}{3} n) = d \qquad \text{VII - 3}$$

where k is the bulk modulus, the n rigidity, and d the density of the medium. In a homogenious and isotropic medium this velocity is constant.

1. The behaviour of longitudinal impulses at the interface.

When a beam of longitudinal impulses, penetrating through, a homogeneous and isotropic medium, encounters on its way another medium of a different wave velocity, then according to the geometric and optical laws adapted to elastic vibrations, its further behavious depends on the angle of incidence at which the impulse strikes of the interface.

A longitudinal impulse falling on the interface at an angle between 0° and that of total incidence splits into four different impulses:

transmitted and reflected longitudinal impulses
" " " transverse "

in the way shown in fig. VII-1.

An elaborate study concerning the amplitude of the reflected and transmitted longitudinal and transverse waves, the intensities of these components and the fractions of the incident energy carried away by them is given by M. Muskat and M.W.Meres (Refr: VII-1) .

On the strength of the num~~b~~erous tables given in

FRACTIONS OF THE INCIDENT ENERGY CARRIED AWAY BY THE REFLECTED AND TRANSMITTED WAVES.

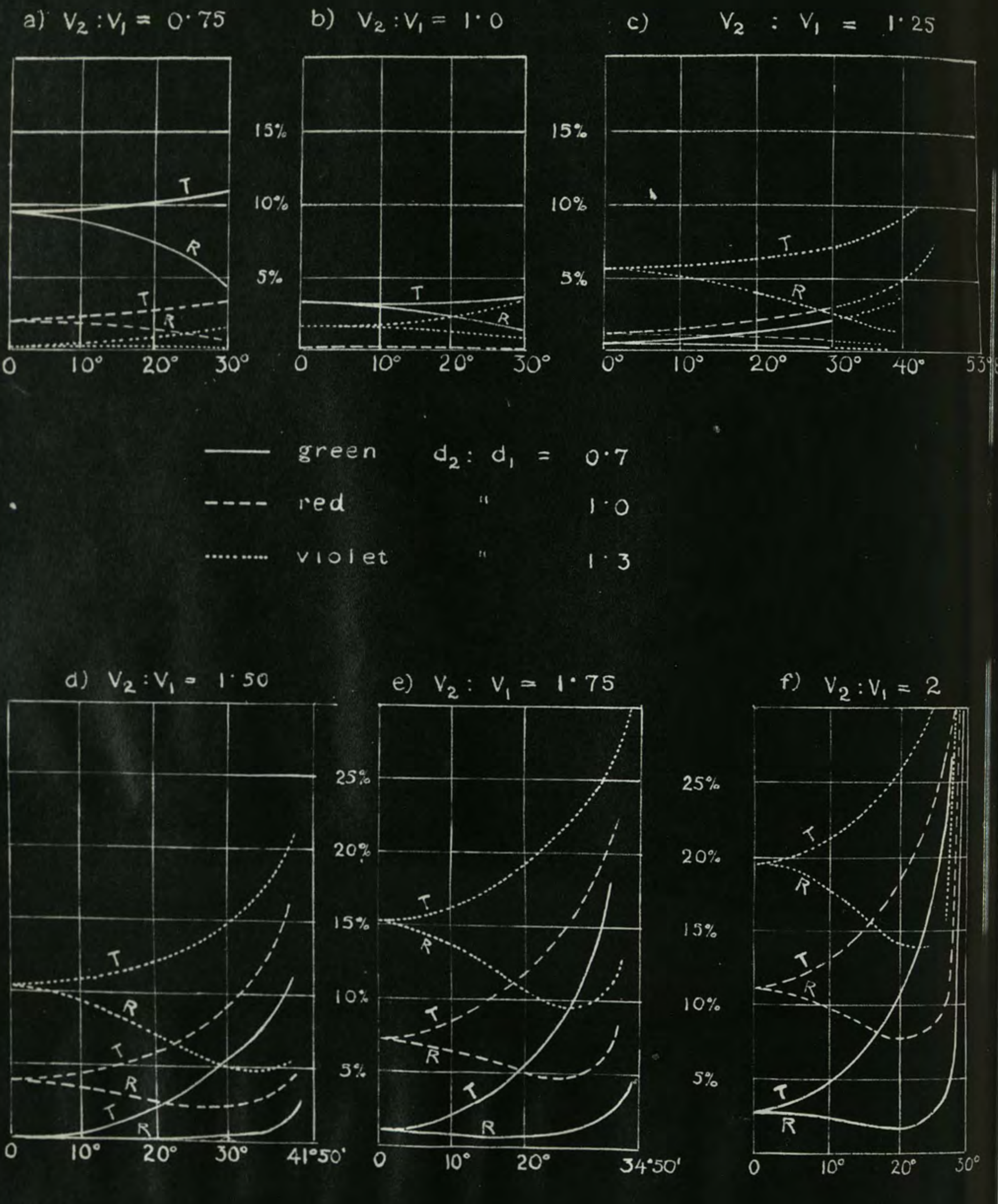


FIG. VII-2.

this article the writer has drawn the graphs shown in fig. VII-2. These graphs refer to the fractions of the incident energy of longitudinal impulses carried away by the longitudinal and transverse reflected and transmitted energy.

In the individual graphs from a. to f. these energy fractions in percentage of that of the incident are plotted against the angles of incidence from 0° to that of total incidence.

Each graph is drawn for specified physical interfacial parameters V_2/V_1 = the ratio of velocities, varying from the value V_2/V_1 = 0,75 in graph a, to the value V_2/V_1 = 2 in graph f.

Besides this, the fractions of incident energy in each group are plotted in colours for three different values of d_2/d_1 = the ratio of the densities of the media on both sides of the interface

blue curve is for value d_2/d_1 = 0,7
red " " " " = 1,0
violet " " " " = 1,3

Before entering into practical inferences, consider graph f and the two violet curves there. The lower of these represents the fractions of the incident energy transformed into the reflected longitudinal wave, the percentage is given in figures on the left side of the graph. The upper violet curves there shows the fractions of the incident energy converted into the transmitted longitudinal wave, these fractions being plotted from the top of the graph downwards (the figures of percentage are on the right side). In this way thesurface between the two violet lines gives the total sum of the fractions of incident energy converted into reflected and transmitted transverse waves.

According to the theory expressed by M. Muskat the total sum of these individual fractions is:

$$L_r + L_t + T_r + T_t = 1$$

in an ideal elastic medium, i.e. non-dispersive and non-absorbent. This relation is expressed in each graph.

The two violet curves in graph f refer to an interface of two media with a ratio of velocities $V_2/V_1 = 2$, the ratio of densities d_2 / d_1 being 1,3. Thus it will correspond to an interface of shale and limestone, the velocities of which are 2500 m/sec and 5000 m/sec respectively. It is evident from the graph that when a longitudinal impulse strikes their interface at the angle of 0°, about 20% of the incident energy is reflected, whereas the rest i.e. about 80% is transmitted to the lower medium. Approaching the angle of 25° the reflected energy decreases to 14% of that of incident and so does the transmitted part which decreases to about 70% in favour of the transverse reflected and transmitted fractions.

In the vicinity of the angle of total incidence, which for the violet curves occurs at 30° ($\sin i_c = V_1/V_2 = 1/2$)

the reflected longitudinal energy increases rapidly to be nearly 90% of that of the incident, whereas the transmitted energy decreases, to become zero at the angle of total incidence, this fact being true in the strict meaning of the word. The impulses striking the interface at angles very near that of the total incidence and at that of total incidence by diffraction at the first interface return to the surface in the form of a refraction wave, and this fact forms the basis of the refraction method of prospecting. This wave is of very low content in seismi energy.

The reflected longitudinal impulse arrives at the surface earlier than the reflected transverse impulse, on account of the difference in their velocities; a geophone, used in seismic prospecting is so designed that it picks up longitudinal impulses rather than transverse ones; finally, the transverse energy is very small at the angle between 0° and that of total incidence; therefore the transverse phenomena can be excluded from the present consideration. Although up till now, transverse energy has not been proved to be of any value to practical prospecting, yet in the future it may yield some hitherto unexplained means of dertermining the surface beds.

Returning to the graphs, one will notice that the same phenomena which are shown in graph f. occur also in instances expressed by graphs c, d , and e, in which the angle of total incidence is 53° 8'; 41° 48'; and 34° 50' respectively. As the tables do not give any corresponding figures for these values, the curves are dotted from 30° onwards.

The graphs a. and b. refer to the instances in which the velocity of the transmitting or feflecting media is smaller than that of the incidence medium. Here the reflected waves returning to the surface encounter beds of successively higher velocities and densities.

Reviewing the graphs from a. to f. for the violet curves that is, for an interface of two media, from which the reflecting medium has a density of 1,3 times greater than that of the incidence and when the ratio of velocities varies from 0,75 to 2, it is evident that the fractions of the reflected energy vary from almost zero for $V_2/ V_1 = 0,75$, to 20% for $V_2/ V_1 = 2$, wheras the shape of the curves, dependent on the angle of incidence, remains almost the same.

1. Example.

Prospecting in the Daszawa gas-field in Poland revealed a reflection horizon at a depth of about 400 m belonging to the Miocene gas-sandstones, overlaid by Miocene sands and clays. The densities of these beds may be assumed to be 2,2 and 2, whereas the velocities are 3000 and 2400 m/sec. respectively. Since the value of the density ratio is 2,2 : 2 = 1,1 and that of the velocity ratio is 3000:2400 = 1,25, this type will correspond with the graph c/ with a curve which can easily be interpolated between the red and violet curves.

Since the distance of the average position of the receiver was 200 m, (the middle geophone on the spread), the angle of incidence at which the fractions of incident energy were reflected back to the surface was $\tan i_0 = 100:400 = 0{,}25$, thus i_0 = about 10°. The reflected longitudinal energy is then, according to the graph, 2% of that of the incident.

2. Example.

In the whole foreland area of the Carpathians a very good reflection was observed from the gypsum-anhydrite beds of the Cretaceous age, which in the region North of Stryj ~~at~~ occurs at a depth of 1200m. This bedrock is covered by a thick mantle of Miocene clays and thin sandstones. The densities of these two formations may be assumed to be 2,9 and 2,3 respectively, whereas the velocities are 4500 and 3000 m/sec respectively. The ratio of the densities is then 2,9:2,3 = 1,3 and that of the velocities 4500:3000 = 1,5. This type is expressed in graph d/ by the violet curve. Here the fractions of the reflected energy are greater than in the previous case, though not surpassing 10% of that of the incident energy. They vary from 10% at 0° to 5% at 30°. The angle of total incidence could be reached at the distance $x = 2.1200.\tan 42° = 2350$ m. from the shot-point. The longest reflection transverse, however, did not exceed the average distance of 500 m, and thus the reflection work was carried out at the angle of incidence varying from 0° to 5°.

From both examples it becomes obvious that the reflected energy is a very small fraction of that of the incident and a great many other precautions must be taken in order to reveal on the seismogram this energy which along with the others, form the integral part of the incident energy.

3. Losses of seismic energy.

The above considerations have been referred to ideal elastic media. In nature, however, the seismic energy, penetrating the subsurface beds and partly returning to the surface by reflection or diffraction, is subjected along its path by a series of factors which change both its intensity and character. To these factors belong:

a) The internal friction between the particles of the medium. It reduces the intensity of seismic energy. This fact is expressed by the known formula:

$$I_r = I_0 \cdot e^{-\alpha \cdot r} \qquad \text{VII - 4}$$

where I_r is the intensity at the distance r from the source where the intensity of the seismic energy is I_0 ; α is the coefficient of absorption and being proportional to the internal friction increases with the second power of frequency (see page 211.). Hence the impulses of higher frequencies are already eliminated near the source, whereas the low frequencies are left over. Observing a reflected impulse near the source, its frequency is higher than that of the impulse observed far from the source. Since the reflected impulses are normally of higher frequency than the others, the former can be more easily detected near the source, than farther away, where their frequency may decrease to the range of the frequencies of other non-useful vibrations. That is one of the reasons why reflections are easier obtained near the shot-point than at the long spreads.

b) <u>The variations of the specific acoustic resistance</u> of the rocks, which is considered to be the product of the velocity and density

$$R = V.\ d \qquad \text{VII - 5}$$

referred to unit dimensions. The intensity of seismic energy I, that is, the amount of energy per unit area normal to the direction of propagation and the character of the impulses i.e. their amplitude A and their frequency f are bound together in a relation

$$I = \frac{\pi}{2} \frac{(A.\ f\ )^2}{r^2} .\ R \qquad \text{VII - 6}$$

for a spherical wave. In homogeneous and isotropic media R is constant and the intensity decreases with the second power of the distance from the source. Thus the deep reflections require to have more seismic energy introduced into the ground than do the shallow ones; also in order to receive the reflections from the same beds of the same magnitude at the long spreads more explosive has to be used than at the short spreads. In heterogeneous media one has to deal too with the factor R, the specific resistance. The intensity decreases with the decreasing acoustic resistance. Rocks of small density and velocity have small acoustic resistance, and the wave penetrating them loses more in intensity. The amplitude of the impulses, however, increases with the decreasing R.

c) In the subsurface of some areas, which consist either of shore line deposits or which were subjected to the action of a shallow sea, there exist many discontinuous beds, or the same beds reveal great changes in their lithology. These factors are responsible for the fact that the same beds are in some places considered to be good reflectors, whereas in other places they are only good transmitters. In some areas where the mantle of Diluvial rocks is rather thick, the scattered Diluvial stones may be of large dimensions and being embedded in the clays in great numbers scattered the seismic energy which is passing by. In areas where faults occur, the vertical or oblique faces of the faults cause a great scattering of seismic energy. Sometimes large boulders are also the cause of that scattering. The scattering of seismic energy is then produced by the outstanding irregularities in the subsurface~~;~~ if the dimensions of these irregularities are at least appreciable fractions of the length of the seismic wave. The larger the dimensions of the encountered body, the greater is the amount of energy scattered by it, and the greater is the loss of useful energy.

The amplitude of the scattered energy is inversely proportional to the square of the wave length, or directly proportional to the square of the frequency. Thus the loss of the energy through scattering is greater for waves of higher frequency than for those of lower frequency.

In areas where the presence of such outstanding irregularities is revealed or can be suspected, the reflections from the subsurface beds,being of higher frequency than those of the other waves, may be difficult to receive unless far away from the source, where the frequency of reflections are smaller, and thus suffer less by scattering. In the latter case, however, other factors will be encountered and will act in a negative way on the reception.

d) Similar to the above phenomenon is the diffraction of seismic energy. It is caused by the subsurface obstacles, the dimensions of which are greater than the length of the impinging wave. It may becaused by subsurface lenses or intercalations, the boundaries of which act as the source of new waves.

In the reflection survey the frequency of reflections is of a range of 30 - 60 cycles per second and thus the length of the wave travelling with an average velocity of 3000 m/sec, e.g., is equal to 3000:60 = 50 m. Then the

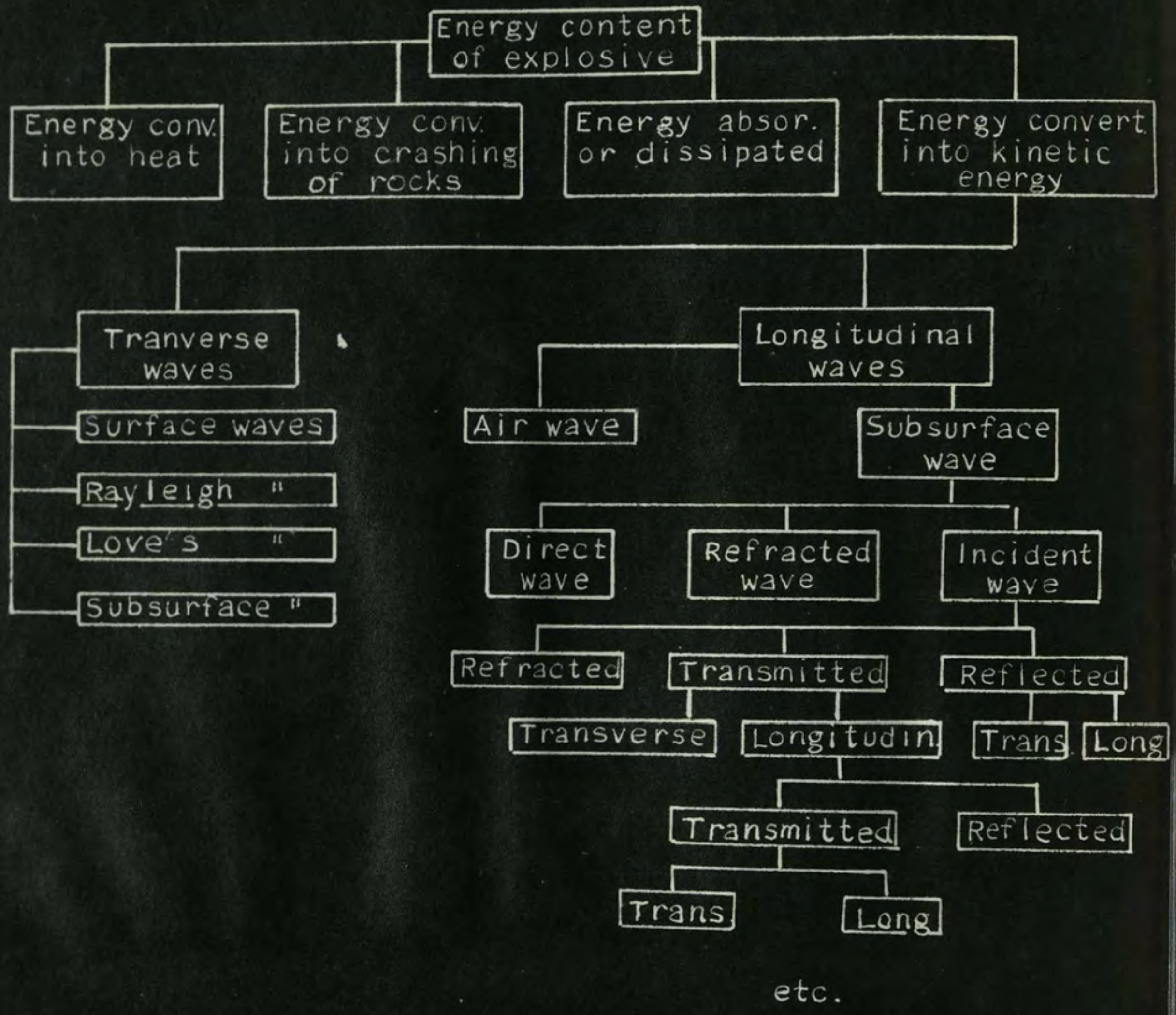


Fig. VII-3.

Schematic plan of the distribution of seimic energy.

subsurface lenses whose dimensions are in that limit, and happen to be in the path of that wave, cause the diffraction of the useful energy by producing additional diffracted waves, which by interfering with the useful energy cause the record to be disturbed or even unreadable.

Resume: Resuming the division of elastic energy together with the generating of the different kinds of waves detailed on page 86, a schematic plan is given in fig. VII-3 Beginning from the energy content in the explosive it is known that only a small part of thisenergy is converted into kinetic energy of longitudinal and transverse elastic vibrations, each of them having different velocities of propagation. The longitudinal part being of greater speed it is upon this that the practical side of seismic prospecting is based. This part, as seen from the plan, is partly converted into sound waves spreading over the surface. The remaining part of this longitudinal energy which is greater is converted into subsurface waves from which that carrying the highest percentage of subsurface energy, arrives as a direct wave at the receiver. This direct wave the velocity of which corresponds to that of compressional waves in the surface layer, is apparent on the seismogram by its great amplitudes following the small and short impulses of the refraction wave. The latter is the result of the second part of the seismic energy which strikes the interface at the angle of total incidence. Being limited to the neighbourhood of this angle, this wave carries with it a very small amount of elastic energy.

The third part which is of great importance in reflection prospecting is that of transmitted and reflected waves. As a whole it may be considered as the incident energy. Both transmitted and reflected energies are split on their part into longitudinal and transverse waves. The former only is of practical importance.

To complete the picture, the transverse part of the kinetic energy which produces the surface waves of small frequency of Rayleigh and Love is eliminated mainly by the instruments; the subsurface waves of the transverse part contains the direct, refracted and incident waves, but carrying a very small amount of energy within the range of the usually applied angle of incidence they do not play any important role meantime in practical surveying.

To conclude the schematic plan for energy - distribution it must be remembered that there exist losses of energy caused by the anistropy and heterogeneity of the conducting media, which absorb, scatter and disperse the useful energy. By "useful energy" in reflection prospecting is to be understood the amount of energy which is carried by the compressional waves of the incident energy.

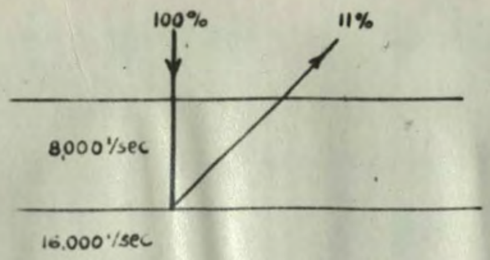


Fig. VII-4.

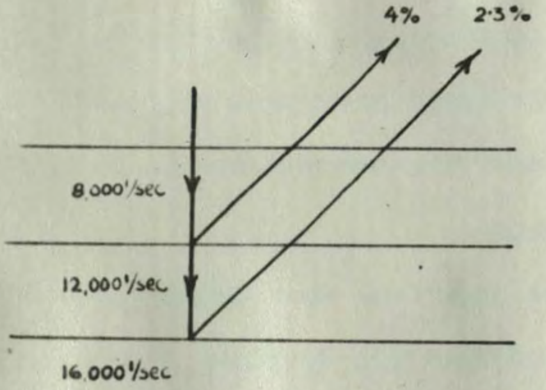


Fig. VII-5.

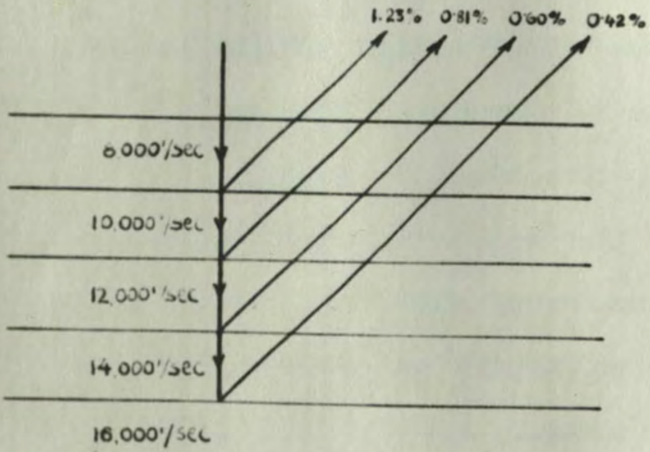


Fig. VII-6.

4. Effects of stratification.

The longitudinal waves, apart from the losses suffefed by the above-mentioned factors, undergo, at each interface they encounter on their way, a splitting into new reflected and transmitted compressional and shear waves, and the deeper the waves penetrate, the deeper are the reflections observed, the smaller is the part of useful energy reflected back to thesurface. Thus the splitting of energy at the successive strata is the effect of the stratification.

This effect has been studied in several examples by M. Muskat and M. Merves, who have shown (Refr. VII - 2) that in the range of the angle of incidence from 0° to 10°, the reflected energy deceases slowly with the increasing angle; this decrease is however, much greater with the increasing number of intermediate interfaces. Some of the more characteristic examples studied by them for $d_2 / d_1 = 1$, and the angle of incidence = 0° are given below:

1. Example : two layers of velocities 8,000 ft/sec and 16,000 ft/sec. The amount of energy reflected back to the surface is 11% of that of the incidence (fig. VII -4) .

2. Example: three layers of velocities 8,000, 12,000, and 16,000 ft/sec. The energy reflected from the first interface is 4%, whereas that reflected from the second interface is only 2,3% of that of the incidence (fig.VII-5).

3. Example: five layers of velocities successively

increasing with depth (fig.VII-6). The energy reflected from the lowest interface is only 0,42% of that of incidence.

It follows from these examples that one intermediate interface makes the energy reflected from the bottom bed, after reaching the surface of the ground, be five times smaller than without this interface (2,3% instead 11%). Further, it follows that three intermediate interfaces cause the energy reflected at the lowest layer, after reaching the surface of the ground, to be only 0,4% of that of incidence; thus a decrease of the reflected energy is 11:0,4 = 27 times bigger than without any intermediate interface.

All these calculations refer to for a non-absorbent and non-dispersive medium, in which case one deals only with stratification, while the change of the angle of incidence and the thickness of the individual beds are not considered.

Examples of distribution of seismic energy.

In order to illustrate the influence of the angle of incidence and that of stratification in absorptive and dispersive media, practical examples from the explored areas in the Carpathian foreland are computed below.

The first example deals with shallow reflections occurring in the area of the suboutcrops of the Podolian Plateau in the region south of Stanislawow. A good reflection from these suboutcrops was obtained, from a depth of 60 m. It was a very rare case of recording a good reflection from such a shallow depth, but it was due chiefly to the outstanding discrimination in the density and velocities of the strata encountered. The surface bed or so-called "Weathering-zone" consisted of sandy clay of Diluvial deposits, of a velocity of V_o - 1000 m/sec, the denisty of which could be assumed to be d_o = 2,2. Under this bed lies a homogeneous bed of clays of Pokucie (V_1 = 2000 m/sec , d_1 = 2,7). These clays are immediately overlying the hard rocks belonging to the Podolian Plateau formation consisting of gypsum, anhydrite, and limestone of the Cretaceous age (V_2= 4000 m/sec, d_2= 2,9).

The calculation will include: -

1. The values of the angles of incidence at the first and second interfaces.

2. The travel-time lines of the direct, refracted and reflected waves.

3. The distribution of incident energy with regard to the angle of incidence and stratification.

4. The distribution of energy with regard to absorption and spreading.

1. The calculation of the angle of incidence.

These angles vary with the distance of the seismograph from the shot-point and depend on the coefficient of refraction n = sin i_o : sin i_1 , where i_o is the angle of incidence at the first interface, i_1 the angle of refraction in the second medium and thus the angle of incidence at

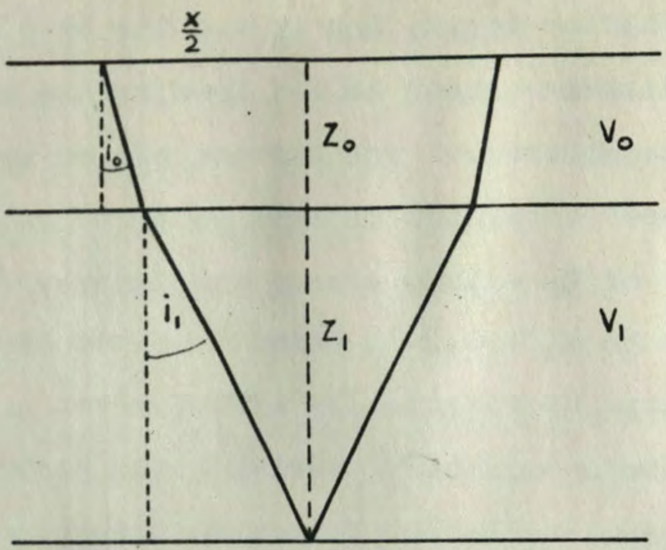


Fig. VII-7.

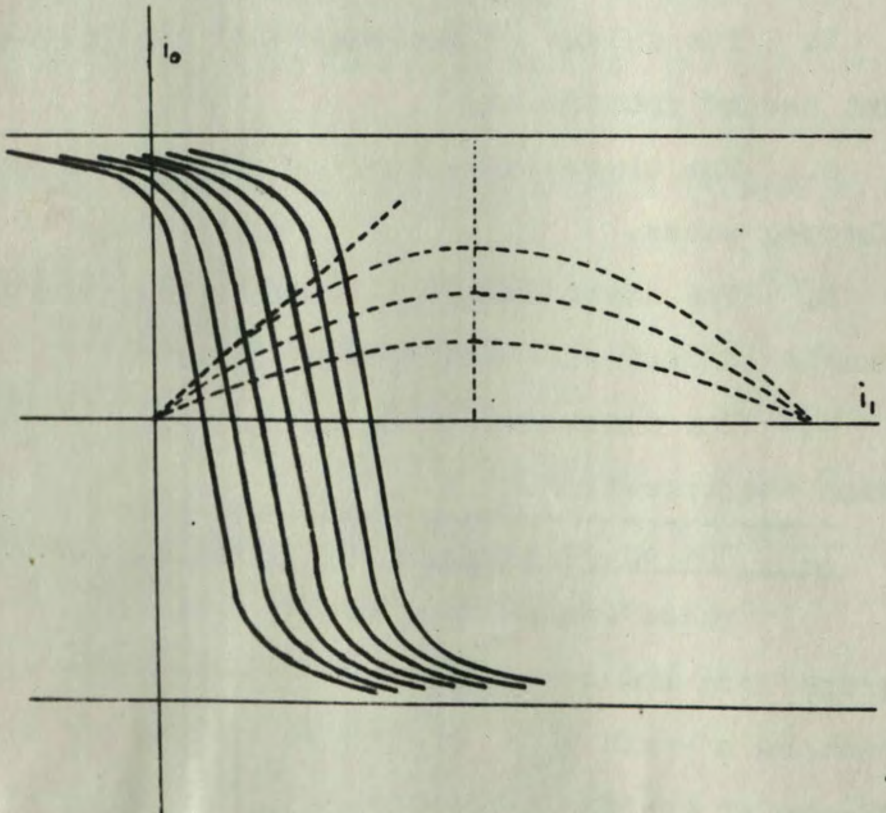


Fig. VII-8.

the second interface. Considering fig.VII - 7 it can be seen that a seismic ray, striking the first interface at the angle i_o, enters the second medium at the angle i_1, and after being reflected at the second interface, before reaching the surface of the ground, is refracted again at the first interface at the angle i_o. To deal with the values of i_o and i_1 one has from the figure the following two relations :

$$Z_o \cdot \tan i_o + Z_1 \cdot \tan i_1 = x/2$$

$$\sin i_o = n \cdot \sin i_1$$

where x - the distance of the receiver from the shot-point

Z_o, Z_1 the thicknesses of the investigated beds, which are equal to 10 m. and 50 m. respectively

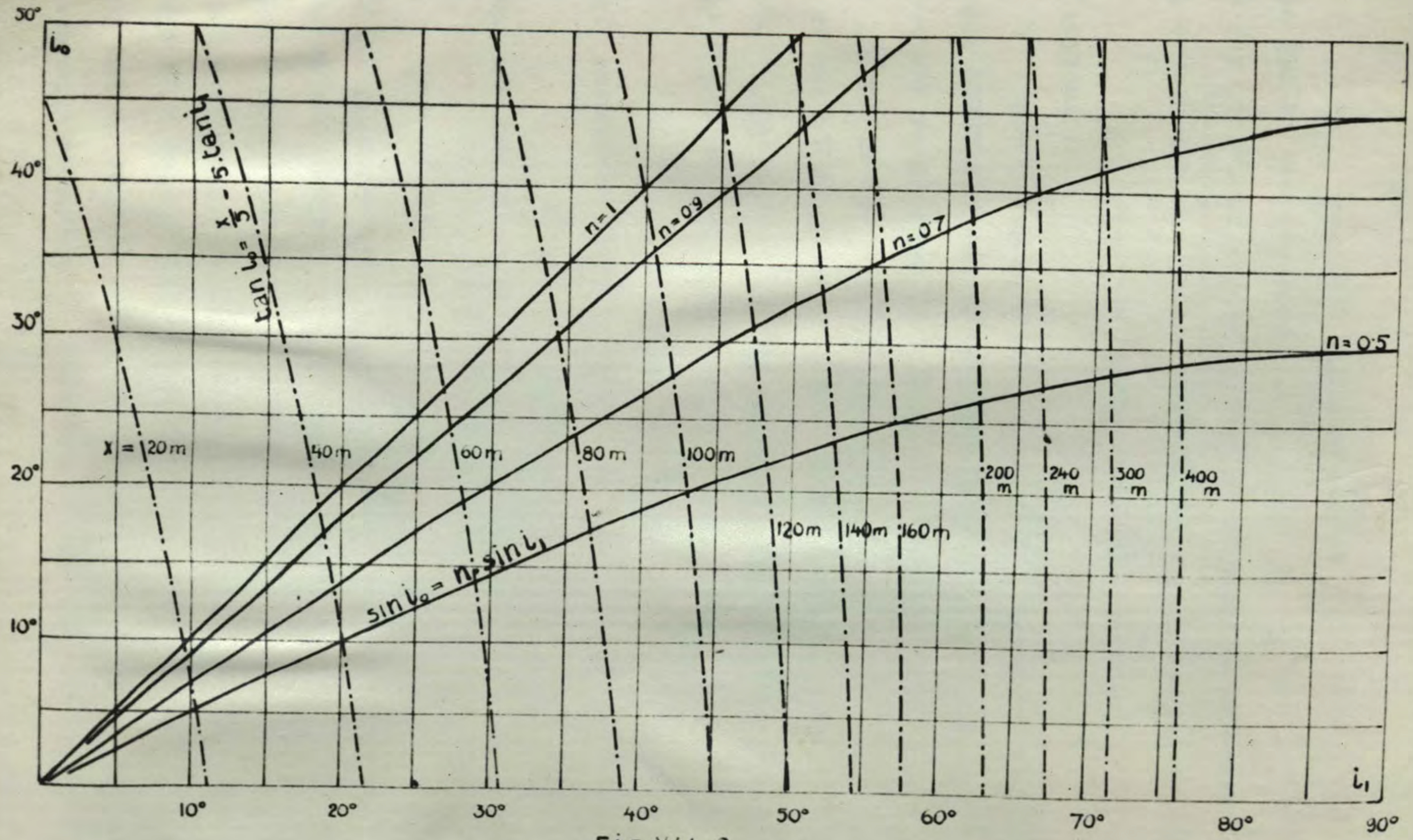
n - the coeff. of refr. = $V_o : V_1 = 1000 : 2000 = 1/2$. One has two equations with two unknown quantities i_o and i_1. By solving these equations one will obtain the values of i_o and i_1 in terms of the ~~u~~ known values of Z_o, Z_1, n and x. Since the solving of these equations in the normal algebraic way would lead to a general form of an equation of the fourth power, it can be much easier achieved graphically.

The first of these two equation cab be transformed as follows :

$$\tan i_o = x/2Z_o - \tan i_1 \cdot Z_1/Z_o$$

and solved for the particular case in which $Z_o = 10$, $Z_1/Z_o = 5$ and for different values of x/2, which will be selected from 0 to 200 m. one has then

$$\tan i_o = x/5 - 5 \cdot \tan i_1$$



i_0
i_1
50°
40°
30°
20°
10°
10°
20°
30°
40°
50°
60°
70°
80°
90°
$\tan i_0 = \frac{x}{5} - 5.\tan i_1$
$\sin i_0 = n.\sin i_1$
n=1
n=0.9
n=0.7
n=0.5
x = 20 m
40 m
60 m
80 m
100 m
120 m
140 m
160 m
200 m
240 m
300 m
400 m

Fig. VII-9.

Introducing into this equation successive values for i_1 varying from 0^o to 90^o, and for x varying from 0 to 400 m, one obtains corresponding values of the angle i_o. Plotting i_o against i_1 one will have a series of tan-curves shown schematically in fig. VII-8. These curves intercept the i_o- axis at distance $\tan^{-1} x/2Z_o$, and the i_1- axis at the distance $\tan^{-1} x/2Z_1$, their asymptotes being parallel to the i_1- axis at the distance $i_1 = \pm 90^o$.

Plotting on the same diagram the second equation $\sin i_o = n. \sin i_1$, for <u>n</u> varying from 0 to 1, one obtains a beam of sinus-curves. The co-ordinates of the points of interception give the solution.

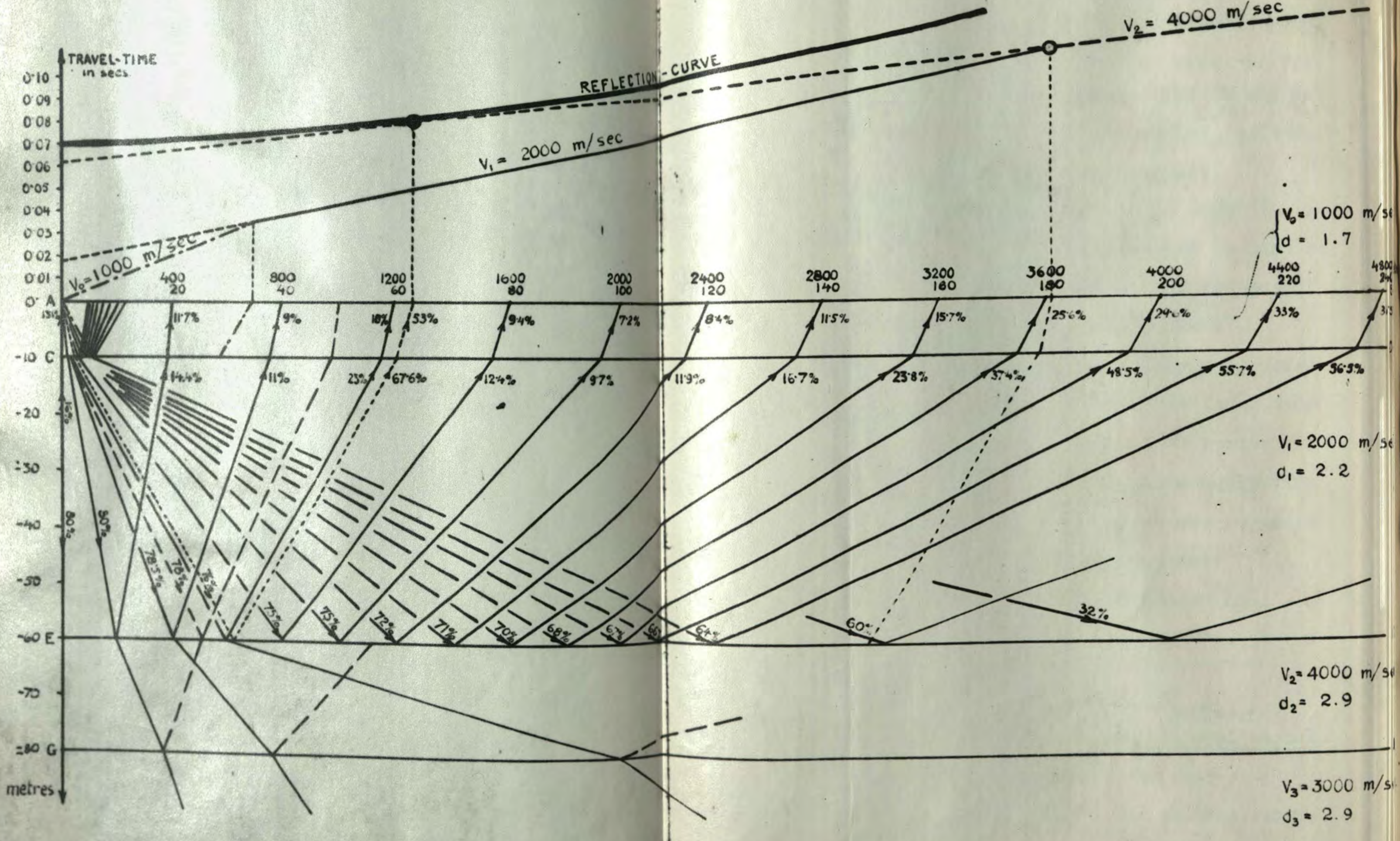
The enlarged part of this diagram which is of importance is shown in the next diagram (fig.VII-9), where the almost parallel curves are the tangent-curves for the successive values of x varying from 20 to 400, whereas the beam of curves spreading from the point 0 represents the beam of sinus-curves for n = 0,5: 0,7: 0,9: 1,0.

The interception of points of the sine-curve of $n = 1/2$ with the tan-curves give the values of i_o and i_1 for $x = 20$, 40, 60, and so on until x = 400 m.

<u>2. The travel-time lines of the direct, refracted and reflected waves.</u>

Let the line AB (fig.VII-10) represent the surface of the ground, and respectively CD the first interface, EF

Fig. VII-10.


TRAVEL-TIME in secs.
0·10
0·09
0·08
0·07
0·06
0·05
0·04
0·03
0·02
0·01
0 A
-10 C
-20
-30
-40
-50
-60 E
-70
-80 G
metres
REFLECTION-CURVE
V₂ = 4000 m/sec
V₁ = 2000 m/sec
V₀ = 1000 m/sec
400 20
800 40
1200 60
1600 80
2000 100
2400 120
2800 140
3200 160
3600 180
4000 200
4400 220
11·7%
9%
18%
53%
9·4%
7·2%
8·4%
11·5%
15·7%
25·6%
24·0%
33%
14·4%
11%
23%
67·6%
12·4%
9·7%
11·9%
16·7%
23·8%
37·4%
48·5%
55·7%
36·3%
80%
80%
78·5%
76%
76%
75%
75%
72%
71%
70%
68%
67%
66
64%
60%
32%
V₀ = 1000 m/s
d = 1.7
V₁ = 2000 m/s
d₁ = 2.2
V₂ = 4000 m/s
d₂ = 2.9
V₃ = 3000 m/s
d₃ = 2.9

the second, and GH the third interface i.e., the bottom of the gypsum bed which in the example considered was 20 m. in thickness. Plotting the positions of successive geophones alongside the line AB, with a displacement of 20 m. (as was true in practicee) and assuming the shot-point to be at O (A-side), one may now, on the strength of the values of i_o and i_1 draw the individual paths of travel of the seismic rays spreading away from the shot-point down and up to the successive geophones.

Besides the reflected wave, one has also to deal here with one direct and two refraction waves. The direct wave spreads way within the first medium with the velocity of $V_o = 1000$ m/sec. The first refraction wave appears when the incident wave strikes the first interface at the angle $i_{o1} = 30^\circ$ (angle of total incidence) . The second refraction wave is produced by that part of energy which strikes the first interface at the angle $i_{o2} = 14^\circ\ 30'$ ($\sin i_{o2} = V_o/V_1 = 1/4$), where it undergoes refraction and transmission into the second medium, and strikes the second interface at the angle of total incidence $i_{12} = 30^\circ$ ($\sin i_{12} = V_1 / V_2 = 1/2$)

The travel-time curves of these three waves are drawn in the upper part of the figure, by plotting the times of arrival against the distances of the geophones from the shot-point. These times of arrival are obtained from the known formulae, which are :

$$T_o = \frac{x}{V_o} = \frac{x}{1000}$$

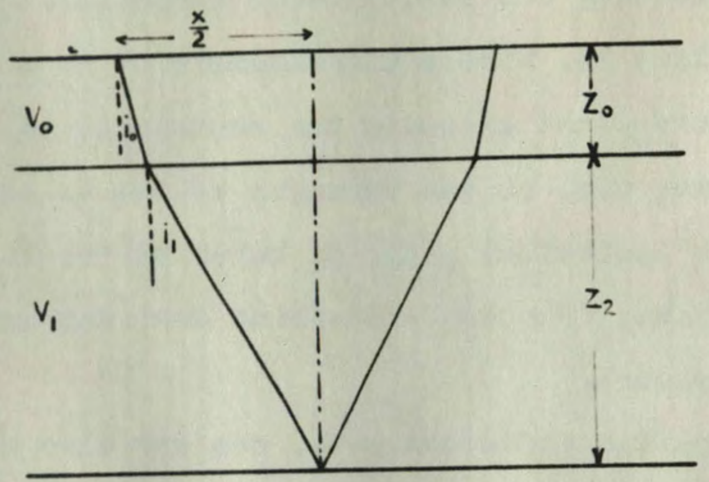


Fig. VII-11.

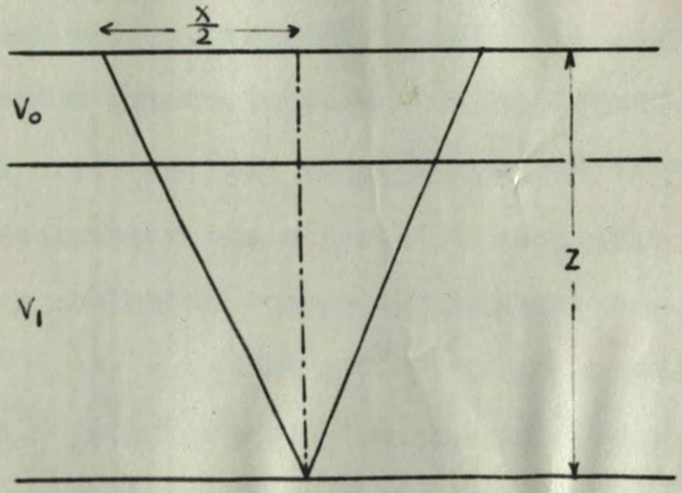


Fig. VII-12.

$$T_1 = \frac{x}{V_1} + \frac{2.Z_o\sqrt{V_1^2 - V_o^2}}{V_o \cdot V_1} = \frac{x}{2000} + 0.0173$$

$$T_2 = \frac{x}{V_2} + \frac{2.Z_o\sqrt{V_2^2 - V_o^2}}{V_o \cdot V_2} + \frac{2.Z_1\sqrt{V_2^2 - V_1^2}}{V_1 \cdot V_2} = \frac{x}{4000} + 0.0626$$

the values of 0.0173 and 0.0626 secs. being the intercept times with the time axis.

The intersection of each pair of the individual travel time-lines can be received by comparing the times $T_o = T_1$, and $T_1 = T_2$. Thus coordinates of these intersections are : $x_{o1} = 34.6$ m, $T_{o1} = 0.0346$ sec, and $x_{12} = 181.2$ m, $T_{12} = 0.1079$ sec respectively.

To obtain the times of arrival or the travel-times for the wave reflected at the gypsum bed, consider two ways of procedure. The first deals with the calculation of the actual or true path of the seismic wave (fig.VII-11), i.e., considering its refraction at the first interface, the wave travelling with its true velocities V_o and V_1 through the corresponding media. The second method (fig.VII-12) assumes the straight route of the seismic energy without its suffering any refraction at the first interface, the velocity of travel being the average of those of the two beds according to the formula $V_a = (Z_o + Z_1) : (Z_o/V_o + Z_1/V_1)$, the general form of it being: (see the next page) :

$$V_a = \Sigma\ Z_n : \Sigma\ Z_n / V_n$$

Thus from fig. VII-11 the true time will be

$$T_r = 2\ (Z_o : [V_o \cdot \cos\ i_o] + Z_1 : [V_1 \cdot \cos\ i_2])$$

whereas from fig. VII-12 the approximative time is

$$T_a = \sqrt{x^2 + 4\ Z^2}\ : V_a$$

Introducing into both equations the corresponding values for $Z_o = 10$ m/ $Z_1 = 50$ m, $V_o = 1000$ m/sec., $V_1 = 2000$ m/sec and $V_a = 1715$ m/sec, one obtains the respective values of T_r and T_a for x the latter varying from 0 to 200 m. These values are collected below:-

x = 0 m	T_r = 0,0700 sec	T_a = 0,0697 sec
20 "	0,0716 "	0,0709 "
40 "	0,0735 "	0,0737 "
60 "	0,0776 "	0,0782 "
80 "	0,0832 "	0,0842 "
100 "	0,0896 "	0,0911 "
120 "	0,0968 "	0,0989 "
140 "	0,1026 "	0,1077 "
160 "		0,1166 "
200 "	0,1297 "	0,1360 "

From this table it is evident that the approximative values of the travel-time T_a differ from those calculated with the T_r formula. Those discrepances are kept within the limit of the seismogram-reading error equal to 0,001 sec, unless the distance x = 120 m from the shot point is crossed.

Plotting the travel times against the distances, one obtains the travel-time curve for the reflected wave, which, as it follows from the formula for T_a or T_r , is a hyperbola. The line V is one of its asymptotes, the line V_2 is a tangent to it at the point where $T_2 - T_r$, and the tangent point obtained from the latter relation is $x_r = 63$ m, $T_r = 0{,}0777$ sec.

3. The distribution of incident energy with regard to the angles of incidence and stratification.

For each of the seismic rays shown in fig. VII-10 the distribution of incident energy can be calculated with the aid of the Muskat tables and the grapsh given in Fig. VII-2. The corresponding ratios of velocities and densities for the example under consideration are collected in the following table:

m/Sec		V_{n+1}/V_n	d_{n+1}/d_n	V_n/V_{n+1}	d_n/d_{n+1}
$V_0 = 1000$	$d_0 = 1{,}7$	2	1,3	0,5	0,8
$V_1 = 2000$	$d_1 = 2{,}2$	2	1,3	0,5	0,8
$V_2 = 4000$	$d_2 = 2{,}9$	0,75	1,0		1,0
$V_3 = 3000$	$d_3 = 2{,}9$				

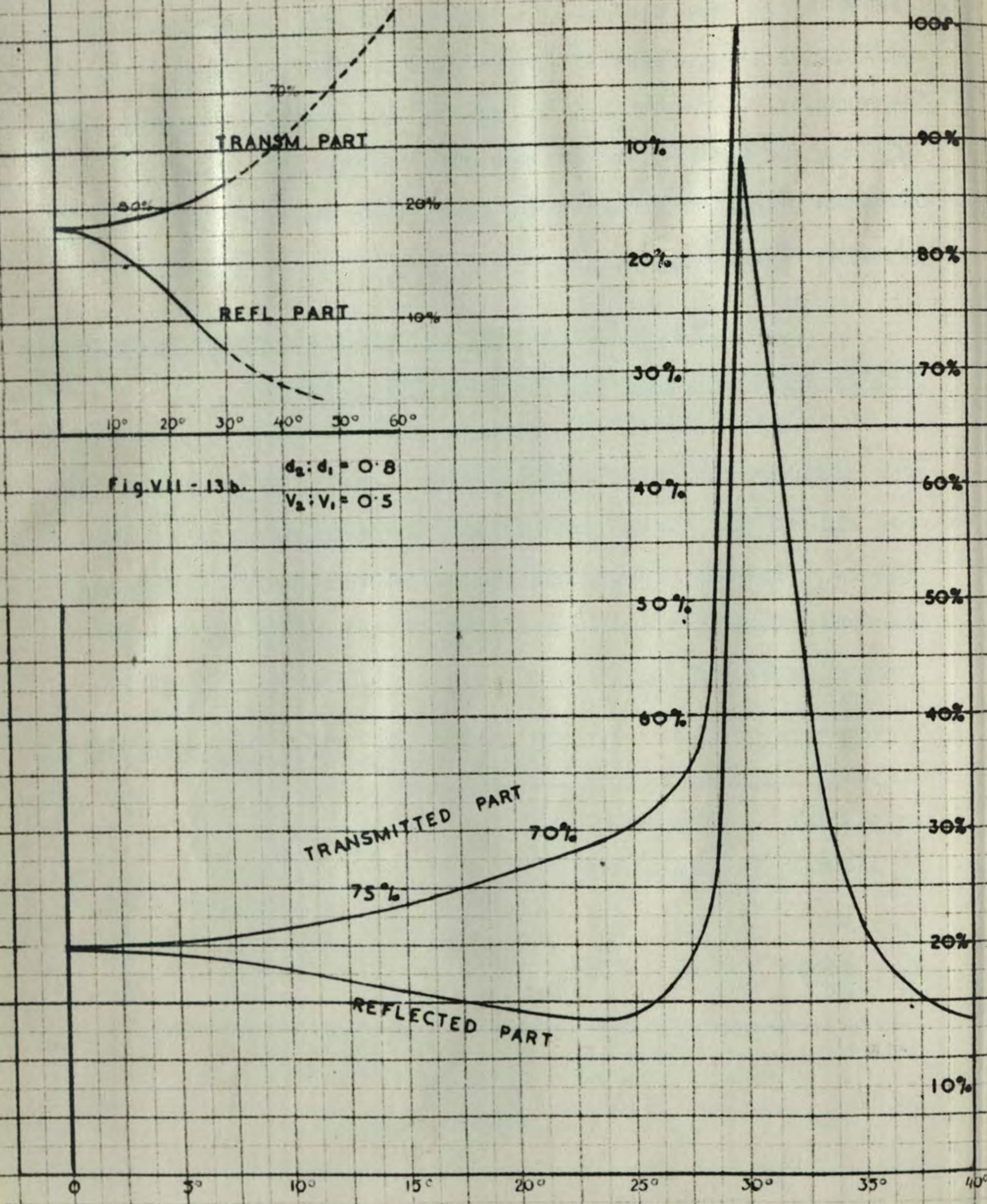


Fig.VII - 13b.

$d_2 : d_1 = 0{\cdot}8$

$V_2 : V_1 = 0{\cdot}5$

Fig VII · 13a.

$d_2 : d_1 = 1{\cdot}3$

$V_2 : V_1 = 2{\cdot}0$

In computing the fractions of the incident energy converted into transmitted and reflected longitudinal waves /useful energy/, with regard to the values expressed in the above table, the case shown in graph f in fig.VII-2 by the violet curve will be applied. For easier handling this is given in an enlarged graph in fig.VII-13a. Dealing, with the reflected waves on their way back to the surface, the case expressed in the graph shown in fig.VII-13b, based on table 3 of Muskat, will be applied.

In the example considered one has also to deal with angles of incidence greater than 30°. Since the corresponding fractions of the incident energy are not given in Muskat's tables, they will be computed below, using the equations of Knott /Refr: VII-3/ for the longitudinal wave striking the interface between two solids. They are:

$$\cdot B_1 + c_1 \cdot Y = \cdot B_2 + c_2 \cdot A_2$$

$$\gamma_1 \cdot B_1 + X = -\gamma_2 \cdot B_2 + \cdot A_2$$

$$-2\gamma_1 \cdot B_1 + (\gamma_1^2 - 1) \cdot X = \frac{2u_2}{u_1} \cdot \gamma_2 \cdot B_2 + \frac{u_2}{u_1}(\gamma_2^2 - 1) \cdot A_2$$

$$(\gamma_1^2 - 1) \cdot B_1 - 2c_1 \cdot Y = \frac{u_2}{u_1} \cdot (\gamma_2^2 - 1) \cdot B_2 - \frac{2u_2}{u_1} \cdot c_2 \cdot A_2$$

where

$$X = A + A_1$$

$$Y = A - A_1$$

and A - the amplitude of the ~~im~~ incident long. wave
A_1 - " " " " reflected " "
A_2 - " " " " transmitted " "
B_1 - " " " " reflected transverse wave
B_2 - " " " " transmitted " "

c_1 - cotan i_1 ; i_1 - angle of incidence)
c_2 - cotan i_2 ; i_2 - " " transmission) long.
γ_1 - cotan ψ_1 ; ψ_1 - " " reflection)
γ_2 - cotan ψ_2 ; ψ_2 - " " transmission) trans.

From the equations of motion, Knott derives: (2)

$$(m_1 + u_1) \cdot (c_1^2 + 1) = d_1 \cdot \omega^2 = u_1(\gamma_1^2 + 1)$$
$$(m_2 - u_2) \cdot (c_2^2 - 1) = d_2 \cdot \omega^2 = u_2(\gamma_2^2 + 1)$$

thus

$$\frac{m_1 + u_1}{d_1} \cdot (c_1^2 + 1) = \frac{u_1}{d_1}(\gamma_1^2 + 1) = \frac{m_2 + u_2}{d_2}(c_2^2 + 1)$$

hence

$$V_1^2 \cdot (c_1^2 + 1) = v_1^2(\gamma_1^2 + 1) = V_2^2 \cdot (c_2^2 + 1)$$

hence

$$(c_1^2 + 1) : (c_2^2 + 1) = V_2^2 : V_1^2 = (\gamma_1^2 - 1) : (\gamma_2^2 - 1)$$

where d - density, u - rigidity, V - long. velocity
$m - \frac{1}{3} u$ = bulk modulus, v - trans. "

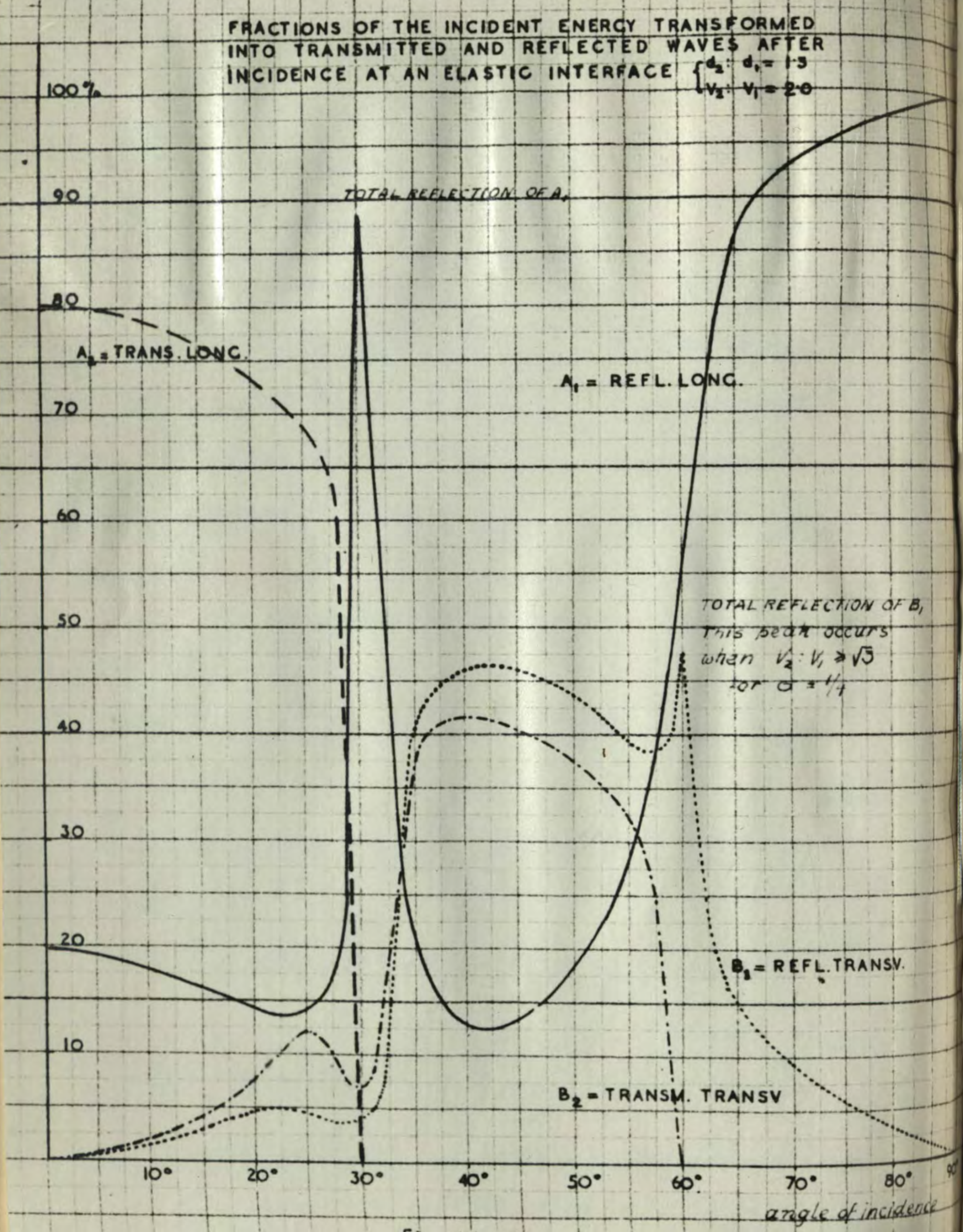

FRACTIONS OF THE INCIDENT ENERGY TRANSFORMED INTO TRANSMITTED AND REFLECTED WAVES AFTER INCIDENCE AT AN ELASTIC INTERFACE
$d_2 : d_1 = 1{\cdot}5$
$V_2 : V_1 = 2{\cdot}0$
100%
90
80
70
60
50
40
30
20
10
TOTAL REFLECTION OF A_1
A_2 = TRANS. LONG.
A_1 = REFL. LONG.
TOTAL REFLECTION OF B_1
This peak occurs when $V_2 : V_1 \geq \sqrt{3}$ for $\sigma = 1/4$
B_1 = REFL. TRANSV.
B_2 = TRANSM. TRANSV
10°
20°
30°
40°
50°
60°
70°
80°
90°
angle of incidence

Fig. VII-13C.

thus:
$$\frac{u_2}{u_1} = \frac{V_2^2}{V_1^2} \cdot \frac{d_2}{d_1}$$

From equations (1) and (2) Knott derives the energy equation

$$c_1 \cdot d_1 \cdot A^2 - c_1 \cdot d_1 \cdot A_1^2 = \gamma_1 \cdot d_1 \cdot B_1^2 + c_2 \cdot d_2 \cdot A_2^2 - \gamma_2 \cdot d_1 \cdot B_2^2$$

or

$$1 = \left[\frac{A_1}{A}\right]^2 + \frac{\gamma_1}{c_1}\left[\frac{B_1}{A_2}\right] + \frac{\gamma_2 d_2}{c_1 d_1}\left[\frac{B_2}{A}\right]^2 + \frac{c_2 d_2}{c_1 d_1}\left[\frac{A_2}{A}\right]^2$$

which is identical with Muskat's equation given on page 191 of his paper (Refr: VII-1).

To obtain the full diagram of the energy distribution all four energies were computed for the angles: 30°, 40°, 45°, 50°46′7″, 55°, 60°, 65°, 70°, for the case $V_2 : V_1 = 2$, $d_2 : d_1 = 1.3$; the energy percentages are plotted against the angles of incidence of the diagram in fig. VII - 13 c. From this diagram it is evident, that within the angle of total incidence, there is an abrupt increase of the reflected energy, confined to a small range of about 5 degrees. At about 43° there is a second minimum of the reflected energy, from which the latter grows steadily to reach its maximum /grazing/ at 90°, which is equal to 1.

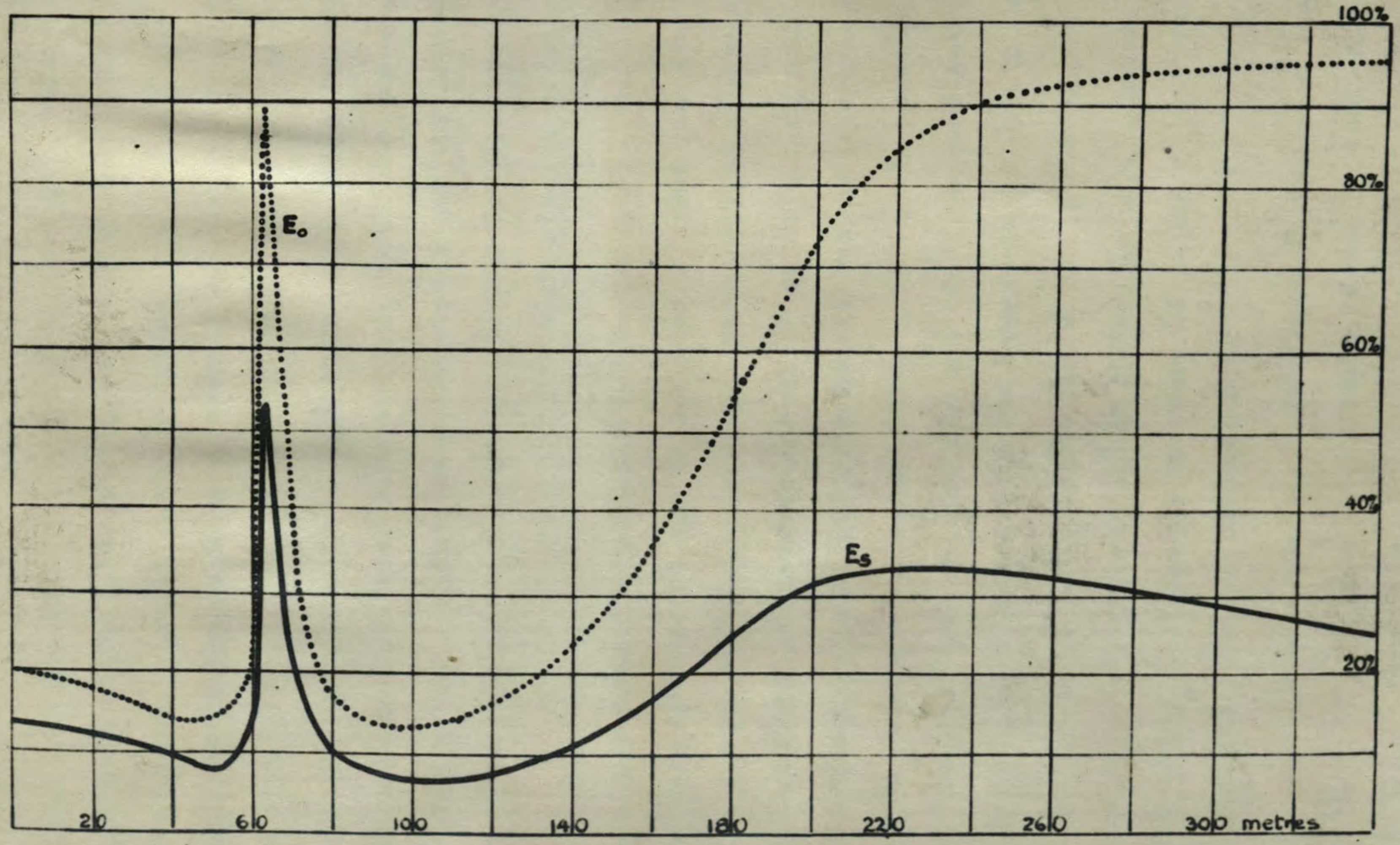
Being now in possession of all the necessary data the division of the incident energy into its component parts at the first, second, and third interfaces with regard to the angle of incidence is calculated in the following way:

Taking the wave recorded by the geophone placed in the neighbourhood of (theoretically at) the shot-point, (the distance $x = 0$ and the angle of incidence equal to 0^{o}), it can be seen from the diagram (fig. VII-13a) that at the first interface 20% of the incident energy is reflected back to the surface and 80% of it transmitted to the second medium. The transmitted part strikes the second interface at the angle of 0^{o}, and 80% of it, i.e. 64% of the original energy, is transmitted to the third medium, whereas 20%, i.e. 16% of the original energy is reflected back to the first interface, as a result of which only 13% of the original energy is picked up by the zero geophone.

Proceeding in the same way with that part of the energy which is recorded by the geophone placed at the distance $x = 40$ m, one sees that, the original energy being 100 , only 78.5% of it is transmitted to the second medium, and 18% reflected back to the surface at the first interface . From the transmitted part striking the second interface, 58% of the original energy is transmitted to the second medium, 18% being reflected to the first interface, through which only 11% is picked up by the second geophone. The part transmitted to the third medium striking the fourth medium or the bottom of the gypsum bed, splits here again and only 0.4% of it returns to the surface. Thus to the geophone placed at the distance x = 40 m, the first interface reflects 18%, the second 9%, the third interface only 0.4% of the original incident energy. By applying the same procedure for the other geophone positions the whole traverse is tested for the distribution of energy , the corresponding percentage of the original energy being marked on the successive rays in fig. VII-10.

Conclusions. - Plotting the percentages of the original energy, received by the successive geophones against the distances of the latter from the shot-point, one obtains the curve E in the diagram in fig.VII - 14. This curve shows the distribution of seismic energy along a traverse 400 m. long over a considered section of the explored bedrock. If one had only to deal with one interface i . e. if the upper bed of velocity V_o = 1000 m/sec, was absent the distribution of useful energy would follow the general line expressed by the lower curve in graph a, fig. VII - 13, which in terms of spread is shown by the curve E_o in fig. VII - 14. This could be achieved by shooting in a deep hole, which penetrates into the second medium (10 m. deep at least) and by placing the geophones in other deep holes on the top of the second medium. Leaving, however,

Fig. VII-14.



the geophones at the surface of the ground, but shooting in the 10 m. deep hole, one would approach the curve E_o . Shooting at the surface, as was assumed in the example, the area betwwen the curves E_o and E_s represents the loss of useful energy due to the existence of the surface layer (the latter also being called the weathering zone).

Considering the curve $E_s$in more detail one would notice that a spread exists from 60 to 100 m where the amount of recorded energy is greatest (53%). Before 60 m, there is a "low" , where the percentage of useful energy falls to 8%, the second "Low" being at 100 m. (7.2%) . From the latter value, as the distance increases, this percentage rises almost uniformly to 33% at the distance $x = 200$ m from which the rate of falling is faster, so that at $x = 400$ m. the energy is only 12% of that of the original,

The total distribution of seismic energy withregard to the angle of incidence and stratification, the result of which is shown in fig. VII - 14, will be best comprehended, when considered in fig. VII - 10. The incident energy spreading away from the shot-point at A impinges on the first interface C-D at different angles varying from 0 - 30° and splits here into the reflected and transmitted parts.

The reflected part consists of from 20% at 0° to 13% at 23°, of the original incident energy and from that angle increases suddenly to reach 87% at which there is no energy transmitted to the second medium. All this part of energy reflected at the first interface is the part lost for practical seismic purposes. At the angle of total incidence diffraction and refraction waves are produced and recorded as "first arrivals " on the seismogram.

The part transmitted into the second medium now plays the role of incident energy against the third medium and is that part which in the example considered may be called useful energy. Its behaviour at the second interface is the same as that of the original incident energy at the first interface. From 0-30° it splits into that transmitted to the third layer, and into the reflected part, which will consist of from 16% at 0° to 8% at 23° of the original energy. At the angle of total incidence no more energy is transmitted to the third medium, all the energy being reflected and again the phenomena of diffraction occur yielding the "second arrivals" on the seismogram. On its way back to the reflected part has yet to pass the first interface, where another loss of energy occurs before it reaches the geophones placed at the surface.

The highest amount of energy reflected, which corresponds to the angle of total incidence for the second interface, will occur in the example considered at the distance $x = 63$ m. This distance coincides with the point of the earliest possible refraction impulse diffracted at the second interface. Thus as seen from the figure, it is the point of tangency between the travel-time line V and the travel-time curve of the reflections.

Were it not for the absorption and dispersion of energy, which will later be shown to have a great influence on the distribution of seismic energy, the most favourable spread for the geophones, as far as the amount of seismic energy is concerned, would, according to the diagram, be from about 60 - 100 m. and 180 - 300 m.

When carrying out the experiment along the above mentioned traverse , the reflection at the gypsum bed was reeorded clearly on the seismogram. It might be objected, that what was recorded as the reflection at the gypsum bed, might have been the refracted wave, the travel-time line of which, as seen in fig. VII - 10, differs in this range very little in time from the travel-time curve of the reflection wave. Further more it might also be the secondary effects of the wave diffracted at the first interface, the travel-time line of which is within this range almost parallel to the travel-time curve of the reflection wave. Against this assumption is the fact that the diffracted waves carry with them only a very small amount of seismic energy and being of smaller frequency than that of the reflection wave can be sufficiently suppressed by the filters, as was the case in the experiment in question, the reflected impulses being therefore fairly clear. However, this reflection was also recorded at the spread 0 - 60 , where practically no diffraction wave occurs, at the second interface. There are, however, other factors, which prevent this case being generalised. The subsurface of the area investigated is the least disturbed. The clays of "Pokucie" overlying the gypsum bed are not affected by any lithological changes, and the gypsum bed is almost homogeneous and horizontal. Practice has shown that in any other similar area, the reflection could quite easily be obtained from a depth of about 100 m. but in any other more disturbed area, where the clays consist of series of monotonous bands, differing slightly in density and velocity, the reflection could be only obtained beginning from a depth of 200 m. This is because the refraction and direct waves cannot be so sharply separated from the wave reflected at the first interface, which being again reflected at the boundary between the ground and the air, spreads along the surface bed and interferes greatly with the reflections arriving from the deeper beds.

On the basis of the example considered above, one may approach another more general case. Considering the fundamental equations of the previous example

$$\tan i_o = x/{}^2Z_o + Z_1/Z_o \cdot \tan i_1$$

$$\sin i_o == n. \sin i_1$$

one may assume a case to be dealt with, in which the quantities x, Z_o, Z_1, V_o, V_1, and V_2 vary freely, but their ratios $x/2Z_o$, Z_1/Z_o and $n = V_o/V_1 = V_1/V_2$ remain the same as in the first example.

One may consider then the case of

$$x/2Z_o = x/20 = = 10\ x/200$$

$$Z_1/Z_o = 50/10 = 1000/200$$

$$n = 1000/2000 = 1200/2400 = 2400/4800$$

Thus one has a second example where $Z_o = 200$, $Z_1 = 1000$, $V_o = 1200$, $V_1 = 2400$, $V_2 = 4800$, which approaches the actual conditions prevailing in the larger part of the eastern foreland area of the Carpathians.

Substituting in fig. VII - 10, the distances x = 40, 60, etc. by the corresponding figures 800, 1200, 1600, etc., and the depth of the first interface 10 m. by 200 m. and that of the second by 1200 m, the distribution of seismic energy will remain the same as that marked in fig. VII - 10, and the diagram in fig. VII - 14. The travel-time lines will not be the same however, as the velocities to be dealt with are different from those in the previous case. All other considerations concerning the distribution of seismic energy remain the same.

4. Distribution of seismic energy along a reflection traverse allowing for losses due to stratification, absorption

and spreading.

Losses caused by the absorption and spreading for a spherical wave can be expressed by (Ref: VII - 4) :

$$I_r = I_o \cdot e^{-\alpha . r} : 4 . \pi . r^2$$

where I_r - the intensity of seismic energy at a distance r

from the source where the intensity is I_o ,

α - the coefficient of absorption, which according to Stoke's formula for a compressional wave of frequency f in a medium of viscosity η , density d and a longididudinal velocity V , is equal to

$$\alpha = 8 . \pi^2 . \eta . f^2 : 3 . d . V^3$$

There has been very little published regarding the coefficient of absorption of solids and especially of rocks. To calculate it one has to rely upon the above equation and thus first of all, to consider η and f.

The viscosity has recently been determined by N. Ricker (Ref: VII - 5) . It refers to the shales of the Cretaceous age in the Pierra Shale of Eastern Colorado. This shale is several thousand feet thick and the viscosity has been calculated for two extreme cases (values), and one from near the surface studies and one from deep studies.

For the near surface density a value 2 grs. per c.c. has been used. The velocity determined byrefraction was 5850ft / sec = 1.78×10^5 cm/sec and the value obtained for viscosity was:

$= 2.7 \times 10^7$ grs. per cm. per sec.

For deep density a value 2.3 grs. per c.c. has been used. The velocity determined was

$= 2.23 \times 10^5$ cm/sec. and the calculated viscosity was of the value

$= 4.9 \times 10^7$ grs. per cm. per sec.

The average of these extreme values is

$= 3.8 \times 10^7$ grs. per cm. per sec.

In both examples of the Carpathian foreland considered on previous pages (shallow bedrock and deep bedrock) one deals with surface clays of a density 1.7 and Miocene clays of a density 2.2. With some approximation one may consider these beds as a single medium of a density:

$d = \sum Z_n \cdot d_n : \sum Z_n =$

1. example:

$d = (10 \times 1.7 + 50 \times 2.2) : 60 = 2.1$

2. example:

$d = (200 \times 1.7 - 1000 \times 2.2) : 1200 = 2.1$

and of the average velocity

$V = \sum Z_n : \sum Z_n/V_n =$

1. example:

$V = 60 : (10/1000 + 50/2000) = 1715$ m/sec

2. example:

$V = 1200 : (200/1200 + 1000/2400) = 2200$ m/sec

To find the value of η for both examples one will relay on Ricker's formula.

$$\eta = d.V^2/16 \cdot b^2/T,$$

in which

b - = the wavelet breath , T - time of its arrival.

b^2/T for the two values of η computed by Ricker was equal to 0.0067 sec and 0:0068 respectively.

It is evident, that assuming b^2/T to be nearly constant, η is in direct proportion to the density d and varies proportionally with the square of velocity V.

Since the values of d and V in the examples under consideration do not deviate too much from those used by Ricker, one may assume that $b^2/T - 0.00675$ and the reliable values of η will be in the 1st example =

$$2.1 \times 1715^2/16 \times 0.00675 = 2.6 \times 10^7$$

2nd example

$$= 2.1 \times 2200^2/16 \times 0.00675 = 4.3 \times 10^7.$$

The frequency f which is required to calculate the coefficient of absorption may be obtained directly from the seismograms, recorded in the field work. They have shown that the frequency of reflections for the very shallow structures ranged from 70 to 90 cycles per second, whereas for the deep structures it dropped to a range of from 40 to

50 cycles per second.

To verify this assumption one may base it on the experiment described by N. Haskell (Refr: VII - 6). This experiment, carried out in San Joachim Valley in California, has shown that with an increasing depth of the reflection horizon from 1300' to 4400', the frequency of the reflections decreases from 60 cycles per second to 40 cycles per second, which agrees within 10% with a general formula of Gutenberg:

$$T^2 = T_o^2 + a.D$$

assuming $T_o^2 = 120$, $a = 0.05$, and expressing D in feet as a double depth; here "T" is the period of a wave at the distance D from the source, in thousandths of a second, "T_o" is the period of a wave near the source, "a" a constant depending on the elastic characteristics of the rocks and on the internal friction.

Applying the latter formula to the examples one will have

for the 1.example $T^2_{60} = 120 + 0.05 \times 2.60 \times 3.28 = 140$

for the 2.example $T^2_{1200} = 120 + 0.05 \times 2.1200 \times 3.28 = 514$

where 3.28 ft is the equivalent of 1 m.

One has then

$$T_{60} = 0.118 \text{ sec}$$

$$T_{1200} = 0.228 \text{ sec}$$

hence the frequences

$$f_{60} = 1/T_{60} = 85 \text{ cycles/sec}$$

$$f_{1200} = 1/T_{1200} = 44 \text{ cycles/sec}$$

are in the range observed in practive.

One can now calculate the coefficient of absorption for both examples

$$\alpha = 8 . \pi^2 . \eta . f^2 : 3 . d . v^3$$

the corresponding values entering this formula and expressed in a gr. cm. sec. system being as follows:-

Bedrock	$\eta:10^7$	f	f^2	d	$V:10^5$	$V^3:10^{15}$	$\alpha.10^5$
1.Shallow	2.6	85	7230	2.1	1.715	5.05	46.5
2. Deep	4.3	44	1940	2.1	2.200	10.65	9.8

To compute the values of seismic energy in both examples, making allowance for losses due to stratification, absorption and spreading (dispersion) along the reflection traverses, a general formula, deduced from that given on page 211 may be applied:-

$$E_r = E.R/100 . e^{-\alpha r} . 1/4\pi r^2 = E. A. B .C$$

where

E_r - the resultant reflected energy at a travel-distance "r" from the source, where the energy

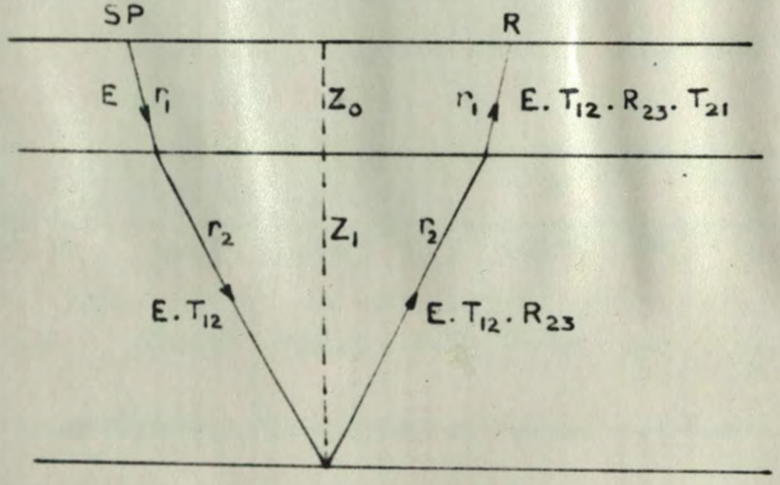

SP
R
E
r_1
Z_0
r_1
$E \cdot T_{12} \cdot R_{23} \cdot T_{21}$
r_2
Z_1
r_2
$E \cdot T_{12}$
$E \cdot T_{12} \cdot R_{23}$

Fig. VII-15.

is E (incident energy)

R - the fractions of incident energy split by stratif.

α - the coefficient of absorption

A - the stratification factor

B - the absorption factor

C - the dispersion factor

To find out these three factors consider fig. VII - 15. The incident energy E, after being transmitted to the second medium, is given a value $E.T_{12}$, where T_{12} = the fraction of incident energy transmitted from medium 1 to 2. This energy, after suffering reflection at the second interface, reaches a value $E.T_{12}.R_{23}$, where R_{23} is equal to the fraction of incident transmitted energy reflected at the second interface. When reaching the surface, the energy will have a value $E.T_{12} \cdot R_{23} \cdot T_{21}$, where T_{21} is that fraction of energy which is transmitted from medium 2 to 1 . Hence the stratification factor

$$A = T_{12} \cdot R_{23} \cdot T_{21}$$

In the same way, the absorption factor will be the product of the successive values of $e^{-\alpha r}$

$$B = e^{-\alpha r_1} \cdot e^{-\alpha r_2} . e^{-\alpha r_2} . e^{-\alpha r_1} = e^{-\alpha}(2r1 - 2r2)$$

where

$2r_1$ - the route of the seismic wave in medium 1 = D_1
$2r_2$ - " " " " " " " " 2 = D_2

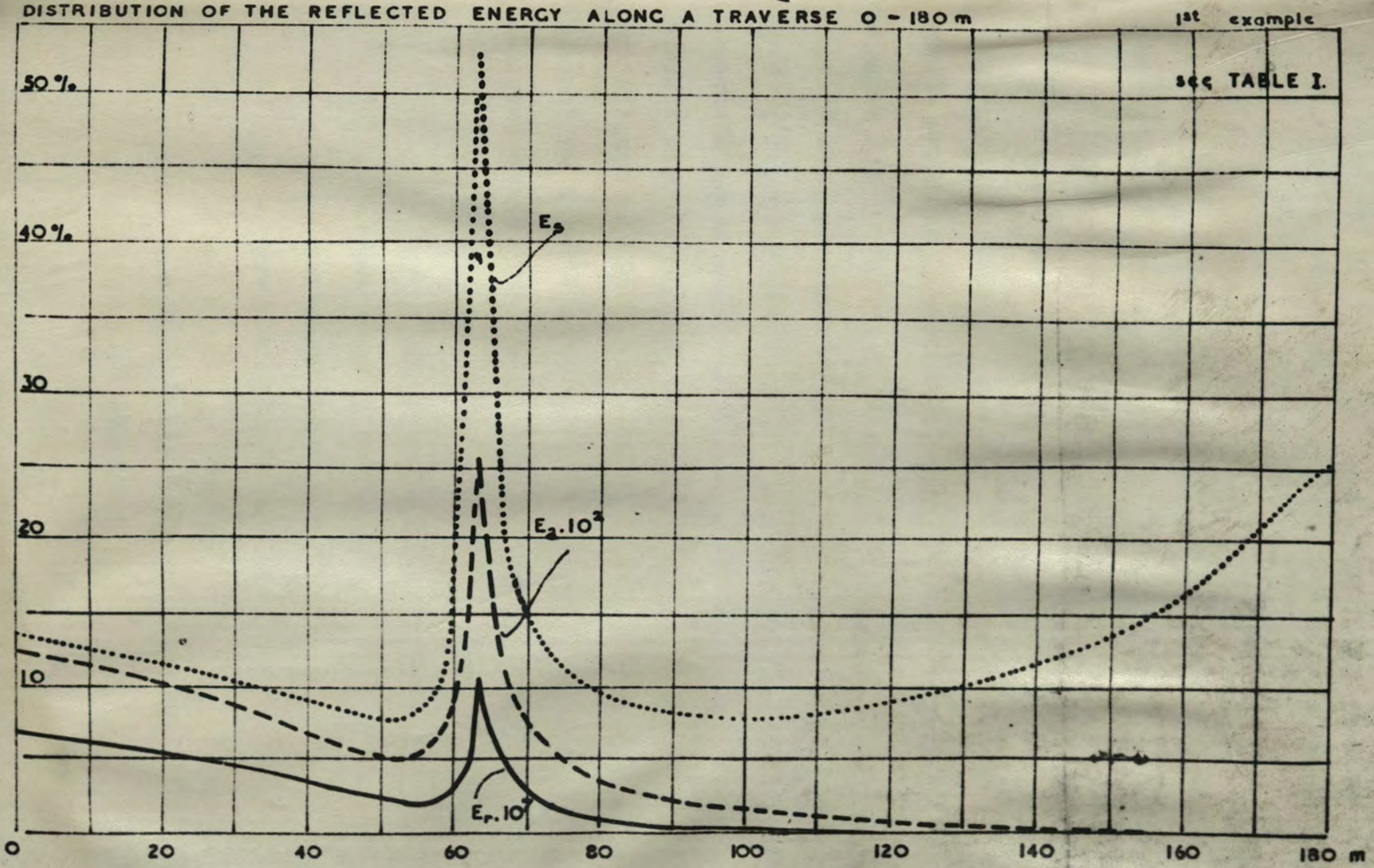

DISTRIBUTION OF THE REFLECTED ENERGY ALONG A TRAVERSE 0 - 180 m
1st example
see TABLE I.
50 %
40 %
30
20
10
0
20
40
60
80
100
120
140
160
180 m
E_s
$E_2.10^2$
$E_r.10^2$

Fig. VII-16.

thus the absorption factor

$$B = e^{-\alpha(D_1 - D_2)}$$

The dispersion factor may be assumed with sufficient approximation to be:

$$C = \frac{1}{4\pi \cdot (D_1 + D_2)^2}$$

Thus finally

$$E_r = E \cdot T_{12} \cdot R_{23} \cdot T_{21} \cdot e^{-\alpha(D_1+D_2)} \frac{1}{4\pi(D_1+D_2)^2}$$

Assuming $E = 100$, one has

$E_s = E \cdot T_{12} \cdot R_{23} \cdot T_{21}$ - the energy in a nonabsorption and nondispersive medium

$E_a = E_s \cdot e^{-\alpha(D_1+D_2)}$ - the energy in an absorptive but nondispersive medium

$E_r = E_a \cdot \frac{1}{4\pi(D_1+D_2)^2}$ the energy in a medium both -absorptive and dispersive.

E_s is independent of the distance travelled by the seismic wave and its value depends only on the angle of incidence. These angles are assumed to remain the same for both examples. Therefore, with regard to the original incident energy E, E_s is equal in both cases and its diagram remains the same for both examples (fig. VII - 14)

To calculate E_a and E_r, D_1 and D_2 (fig. VII - 15) are computed first from the relations given below:-

$$D_1/2 = r_1 = Z_0/\cos i_0$$

$$D_2/2 = r_2 = Z_1/\cos i_1$$

DISTRIBUTION OF REFLECTED ENERGY ALONG A TRAVERSE 0-3600 m.

2nd example.

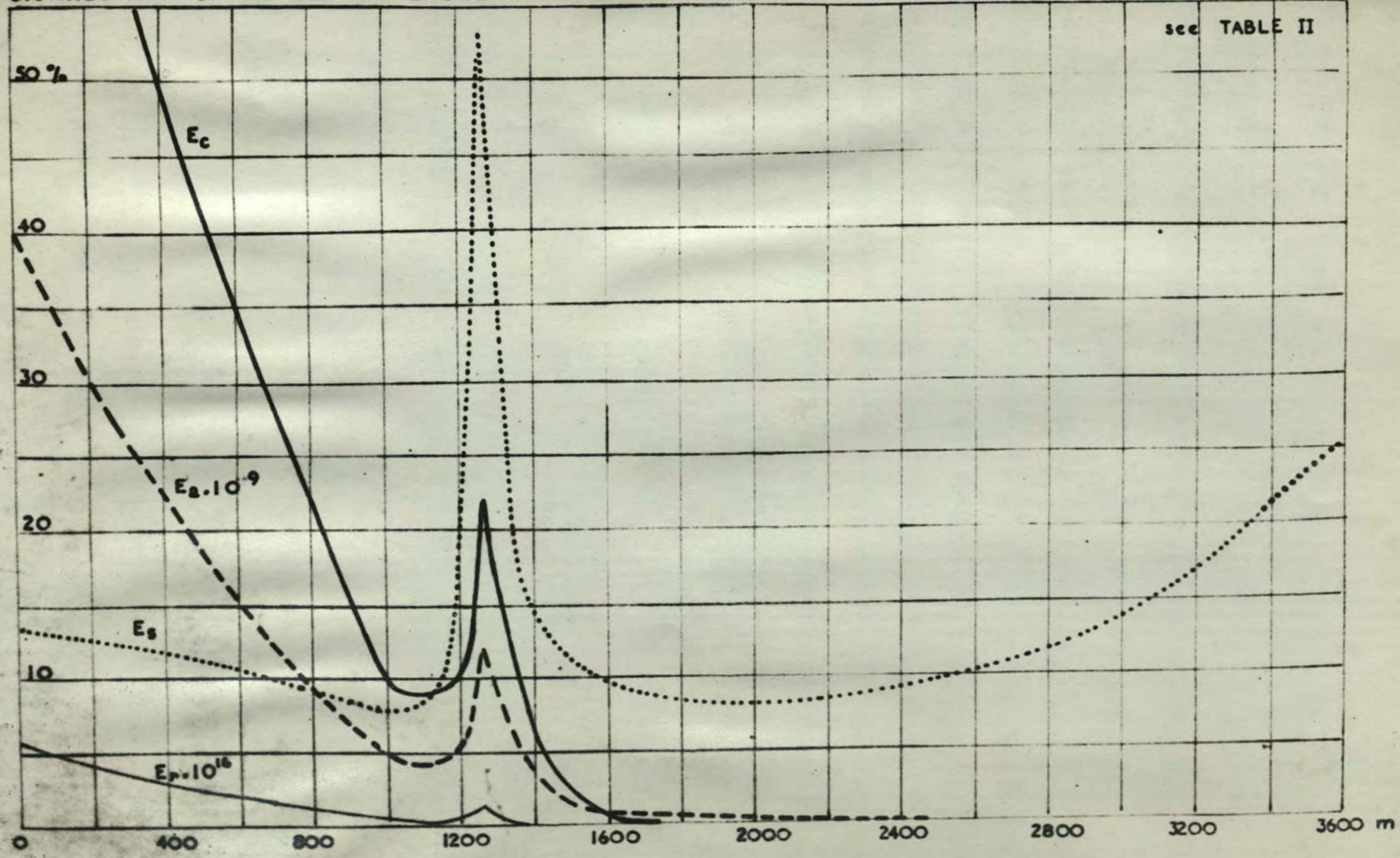


Fig. VII-17.

Then with the aid of the coefficient of absorption the absorption and dispersive factors are computed. All these calculations along the entire traverse in question are given for the first and second examples in table I and II (p.p. 221, 222.).

Plotting the values of E_a and E_r against the individual positions of the geophones in each example, one obtains besides the curve known for E_s , two new diagrams fig. VII - 16 and VII - 17, each having three curves E_s , E_a and E_r.

It is impossible to compare the absolute values of individual fractions of seismic energy obtained at different distances from the shot-point on account of the unknown quantity of energy content in the explosive which spreads away in the ground. On the other hand, this would not have any special value in the case considered because here one observes the indirect effect of this energy along the surface of the ground. It may however, be of interest to compare its amount with the energy registered at the shot-point; the latter energy is denoted by $E_c = 100$. Thus the last column in table I and II gives the percentage of E_c at the different distances from the shot-point. These values are plotted in both diagrams by the black curves, which thereby reveal the most probably distribution of seismic energy along the prospected traverse.

Both diagrams reveal that the highest energy is recorded at the shot-point. In the first example the most favourable spread for the reception of the reflected energy will be from 0 to 100 m. Beyond that distance, the reflected energy becomes very small, and observation would require much bigger quantities of explosives than near the shot-point. The "high" so outstanding in the two previous curves, is much reduced in the black curve and the distribution of energy is more uniform.

In the second diagram, the rate of fading of the reflected energy is much greater, and the "high" occurring at the angle of total incidence is much more attenuated than in the first diagram. The most uniform distribution of energy is for the spread between 900 and 1200 m. from the shot-point. The amount of energy here being, however, fairly small, one would either use great charges or a large amplification, which would simultaneously amplify other waves and render reception rather troublesome. Thus it is more valuable to use the spreads nearer the shot-point since they not only require less explosive, but also simplify later calculations, (using the simplified formula for determining the depth - page 199).

The spread beyond 2000 m. in the second example is, as the diagram shows, very unfavourable as far as the amount of the reflected energy is concerned, the latter dropping exponentially to very small fractions of the energy observed at the shot-point.

REFERENCES

Refr: VII - 1: M. Muskat & W. Meves, "Reflection and Transmission Coefficients for Plane Waves inElastic Media" - Geophysics, vol. V. 1940. No. 2. pp.115 - 148.

Refr: VII - 2 N. Muskat & W. Meves, " The Seismic Wave Energy reflected from various types of stratified horizons" - Geophysics, vol. v. 1940. No. 2

Refr: VII - 3 C. G. Knott "

Phil. Mag. S.5. Vol.48. No.29,July 1899.

Refr: VII - 4 C. Heiland " Geophysical Exploration" 1940 . p. 486

Refr: VII - 5 N. Ricker " A Note on the Determination of the Viscosity of Shales from the measurement of the Wavelet Breadth" - Geophysics 1941 Vol. VI. No. 3.

Refr: VII - 6 N. Haskell, " The Change in Frequency of the Reflection from Basement as this Reflection Horizon Increases in Dpeth" - Geophysics 1940. Vol. V No. 2.

TABLE I. Energy distribution. 1-st example.

x	i_0	i_1	$T_{12}.R_{23}.T_{21}$	E_s	D_1	D_2	D_1+D_2
0	0	0	80. 20. 82	13.1	20	100	120
20	5°	10°15′	80. 18. 81	11.7	20	102	122
40	10°	20°	78. 14. 80	8.9	20	106	126
48	11°20′	23°	78. 13. 79	8.0	20	110	130
60	14°	28°45′	77. 30. 78	18.0	21	114	135
63	14°30	30°	76. 89. 78	53.0	21	116	137
80	17°20′	36°30′	75. 17. 76	9.4	21	123	144
100	20°	43°	75. 13. 74	7.2	21	134	155
120	22°	48°45′	72. 17. 71	8.4	21	148	169
14 0	23°30′	52°45′	71. 24. 69	11.5	22	164	186
160	24°40′	56°30′	70. 34. 66	15.7	22	180	202
180	25°40′	60°	68. 55. 63	25.6	22	196	218
200	26°15′	62°15′	67. 73. 61	29.6	22	214	236
220	26°40′	64°30′	66. 85. 59	33	23	232	255
240	27°20′	66°20′	64. 88. 56	31.5	23	250	273
300	28°15′	71°	60. 93. 51	28.5	23	308	331
400	29°15′	75°30′	32. 96. 40	12.2	24	405	429

E_s - fractions of the incident energy = 100, transmitted into longitudinal waves ~~due to~~ with regard to the angles of incidence i_o and i_1 and stratification.

$\alpha/D_1+D_2/$	E_a	$4./D_1-D_2/^2.\pi$	E_r	E_c
1.07×10^2	12.25×10^{-2}	18.1×10^4	6.77×10^{-7}	100
1.15	10.35	18.70	5.53	81.5
1.32	6.75	19.97	3.48	51.5
1.57	5.13	21.24	2.42	35.8
1.91	9.47	22.88	4.14	61.2
2.04	26.00	23.60	11.10	163.0
2.60	3.50	26.05	1.34	19.8
4.17	1.72	30.20	0.57	8.4
7.08	1.13	36.00	0.31	4.6
13.81	0.83	43.50	0.19	2.8
25.59	0.63	51.30	0.12	1.8
53.79	0.43	59.70	0.07	1.0
95.50	0.31	70.00	0.045	0.7
209.00	0.157	81.50	0.02	0.3
407.00	0.077	93.50	0.008	0.1
222.00	0.009			
120.00				

E_a - fractions of the energy which remain after absorption

E_r - " " " " after absorption and dispersion

$E_c = /E_r:E_r^o/ . 100$ where $E_r^o = 6.77 \times 10^{-7}$

TABLE II. Energy distribution. 2nd example.

x	E_s	D_1	D_2	D_1+D_2	$e^{\alpha/D_1+D_2/}$
0	13.7	400	2000	2400	3.26×10^{8}
400	11.7	402	2060	2462	5.5
800	8.9	406	2140	2546	10.72
960	8.0	410	2180	2590	15.14
1200	18.0	412	2280	2692	35.50
1260	53.0	414	2310	2724	43.66
1600	9.4	418	2480	2898	190.60
2000	7.2	426	2740	3166	1700.00
2400	8.4	432	2950	3382	10.20×10^{11}
2800	11.5	436	3300	3736	18.2×10^{12}
3200	15.7	440	3620	4060	25.7×10^{13}
3600	25.6	444	4000	4444	57.6×10^{14}
4000	29.6	448	4300	4748	67.6×10^{15}
4400	33.0	449	4640	5089	118.0×10^{16}
4800	31.5	450	5000	5450	219.0×10^{17}
6000	28.5	454	6160	6614	339.0×10^{21}
8000	12.2	458	8100	8558	240.0×10^{28}

E_s, E_a, E_r, and E_c with the same meaning as in Table I,

$$E_r^o = 5.56 \times 10^{-16}$$

E_a	$4.\pi./D_1+D_2/^2$	E_r	E_c
402.00×10^{-10}	72.40×10^{6}	5.56×10^{-16}	100
213	76.4	2.79	50.2
98	81.6	1.20	21.6
53	84.4	0.63	11.3
50.7	91.2	0.56	10.0
121.5	93.4	1.23	22.1
4.9	105.5	0.47×10^{-17}	0.85
0.4	126.1	0.33×10^{-18}	0.06
0.8×10^{-11}	144.0	0.57×10^{-19}	0.01
0.6×10^{-12}	175.3	0.36×10^{-20}	
0.6×10^{-13}	204.0	0.30×10^{-21}	
0.4×10^{-14}	248.0	0.16×10^{-22}	
0.44×10^{-15}	282.0	0.15×10^{-23}	
0.28×10^{-16}	324.0	0.09×10^{-24}	
0.14×10^{-17}	373.0		
0.08×10^{-21}	548.0		
0.05×10^{-28}	921.0		

Fig. VIII - 1.

CHAPTER VIII.

REFLECTION - SEISMOGRAM.

A seismogram, resulting from both reflection and refraction prospection , gives important evidence on which the whole procedure of calculation and interpretation depends. Therefore it is worth considering the conditions under which the seismogram is recorded in field work and the factors which influence its character and quality.

Before entering into a detailed consideration of the above, some of the typical seismograms available will be discussed. Fig. VIII-1 shows two seismograms from reflection work in the foreland area of the Carpathians in the region north of Stryj. The first is from the Daszawa gas-field area, the second from the profile along the Stryj-Rozdol road near the village of Dobrzany. The first is typical for a shallow reflection, the second for a deep reflection.

The vibrations of the ground caused by explosion are recorded on a strip of sensitized paper, in this case about 2" wide and about one to two feet long. On each of the seismograms one can distinguish:-

1. Time-lines which cross the paper at a constant interval corresponding to 0.01 sec. These lines are produced by synchronized diaphragm arrangements controlled by an electrically driven tuning fork.

2. Recorded traces of the galvanometer-mirrors, which represent the enlarged and filtered vibrations of the respective geophones strung along a traverse, the corresponding spreads being 280 - 360 m. and 180 - 280 m. respectively.

3. The shot-instant, marked by one of the galvanometer mirrors is seen in both seismograms on the undisturbed part of the lowest trace.

All the waves which have been previously discussed are, as has been stated, of different velocities and therefore arrive at the receiver at different times, being recorded successively on the seismogram.

The actual phenomenon of the explosion is of a transient nature. It has been proved by different experiments that where there is a very short distance between the receiver and the shot-points, the total wave train passes in about 1/100 of a second. R. Beers (Ref: VIII - 1) gives the duration of an impulse at the shot-point as from 0.02 to 0.04 secs and shows the various ways in which it may be controlled and regulated.

As the distance between the receiver and the shot-point increases, this seismic impulse, on account of the heterogeneous and anisotropic nature of the media through which it passes, splits into waves of different shape and behaviour, so that the impulse received cannot be considered as a single unit, and none of its parts can be completely separated from the others.

As for the reflected impulse, which is of the greatest importance, it is influenced by the other vibrations and vice-versa, and therefore it is very difficult or even impossible to determine the absolute characteristics of the returning reflection and only the relative character of the reflections obtained from the same bed could be compared. The individual impulses originating from a single shot-impulse cannot be sufficiently distinguished on the best record obtainable.

On the typical seismograms given in fig. VIII - 1 one can observe the following, to a certain extent individual, impulses:-

1. The traces of the galvanometer-mirrors are first of all disturbed along an oblique line. These first impulses belong to the refraction wave and outdistance the direct wave arriving shortly after. The refraction wave, also called "the shortest time-path wave" or "the first arrival", is produced by that part of incident energy, which strikes the corresponding interface at the angle of total

incidence and slides along the lower side of the interface. By diffraction on the upper side these impulses return to the surface at the same angle of total incidence. This wave theoretically carries no seismic energy, but is of appreciative amplitude and being confined to the angle of total incidence forms the basis of the refraction method. In reflection shooting, however, since the depth from which it comes is rather small (on account of the very short traverses) this wave denotes the existence of the nearest unweathered bed under the surface. The first impulses serve in this case to calculate the depth of the weathered zone, which plays an important role in the exact calculation of the depth and dip of the reflection horizons.

The velocities of the first unweathered layer computed from both seismograms are 1900 m/sec. and 2200 m/sec. respectively. If one assumes the velocity of the weathered zone to be 650 m/sec. (prevailing in the area concerned) then the depths of the weathering zone will be 5 m. and 7. m respectively. The shot-hole in the first instance was 10.6 m. deep passing through the clays down to the top of the gravels. In the second instance the gravels occurred at a depth of 4 m. From the comparison of the computed depths and the depths of the surface clays, it is obvious that the seismic section does not coincide in either case with the lithological changes in the material of the beds, the cause being mainly attributed to the depth of the underground water-level.

2. In both seismograms the direct wave produces several cycles of rapidly increasing amplitudes. These afterwards decrease within a certain period, different in each case and dependent mostly on the distance from the source. From the first seismogram, where the average distance from the shot-point was 320 m. (the middle geophone) it is seen that the direct wave ceased to interfere within 0.1 secs, while in the second case, where the average distance was 220 m, the influence of the direct wave is still in evidence after 0.25 secs.

If the direct wave at the moment of reception were of the simple compression type as it comes out from the shot-point, then it would appear on the seismogram in a much simpler form of one or two cycles. As this is not the case, one has to assume that it is a conglomeration of a direct wave and secondary vibrations produced by the direct wave in the surface zone, and composed mainly of reflections of the direct wave between the surface of the ground and the next interface.

3. The next characteristic vibration which is of great importance for the prospecting of deep structures, is

the reflection. This vibration is well seen on the first seismogram at all traces at the time 0.36-0.38 sec. When the direct wave dies repidly and the recorded oscillations quieten, a new and strong impulse appears along an almost vertical line across the seismogram. The small range of time in which this impulse appears is due to the small difference in the paths of the individual reflected impulses which reach the geophones. It is known that the slope of the reflection arrival varies in amount in accordance with the slope of the reflected bed. On the second seismogram, the same phenomenon is evident much later, namely between 0.8 and 0.9 secs, when, after a certain period of relative quietness, a new, sharp, deep impulse occurs almost simultaneously at all traces.

Both reflections are typical, and since they were recorded over a large area, they were easily used for correlation purposes.

Both reflections are characterised by a sudden influx of seismic energy arriving with great apparent velocity at all the geophones, their first impulses being of the same phase. According to this rule several other traces of reflections can be picked up on both seismograms. Such is the case of an impulse occurring at 0.27 secs. on the first seismogram. This impulse is indistinct being under the influence of the direct wave and to receive it more clearly the spread should have been altered. On the second seismogram one can pick up reflections at 0.42 secs., 0.47 secs. and 0.52 secs., all affected either by the direct wave, which on account of a shallow hole and larger charge lasted longer or by the so called "ground roll".

4. Ground rolls belong to the fourth type of waves which can be observed on the seismogram. They are of two kinds:-

There is the so-called "High speed ground roll", which is a transverse wave along the interface between the weathered and unweathered zones, which sends off secondary compression waves to reach the surface. It can be observed on the first seismogram (first geophone trace) at 0.54 secs., and also at the second geophone trace at 0.582 secs., and some slight traces of it on the subsequent geophones. The first two are very similar in character and therefore easily recognised. The horizontal component of travel of this roll is, as read from the seismogram, around 520 m/sec. This roll, as seen from the first seismogram (first geophone trace) is followed at 0.61 secs. by

b) the so called "normal ground roll" of large amplitude and a small frequency of about 15 cycles (in the case considered). This wave is probably of the transverse Rayleigh type, which travels along the surface of the ground and as its vibrations are transverse to the ground surface and of large amplitude it can be directly felt by an observer. Its velocity is here about 460 m/sec. In less firm ground it has a velocity which varies from 240 to 360 m/sec. and a frequency of from 8 to 15 cycles per sec. This normal ground roll carries a great amount of energy being the result of the direct wave after its reaching the surface of the ground. Its main effect on the seismograms is, fortunately, suppressed by the filtering system.

5. Sound waves travelling along the surface of the ground through the air can also be detected by the geophones. They may also influence the vibrations of the seismic channel. Some parts of this wave can be seen in the second seismogram on the sixth trace at 0.866 sec., on the fifth trace at 0.806 sec., on the fourth trace at 0.742 sec., and on the third at 0.68 sec. The wave in the case considered is too weak to affect the reflections, since the hole was probably well tamped.

Conditions of observations.

It seems of value to give an account of the conditions and factors which influence the quality of seismic records.

A good reflection record, in the terrain where reflections occur, should reveal these reflections in a most definite way i.e. as far as possible the reflections should not be affected by refraction, by direct and sound waves or by ground-rolls and they should be clearly marked at least 5 geophone traces when using a 6 geophone set. In Chapter VII it has been shown, that the wave radiating from the shot-hole has its energy diverted at each new interface. A small part of this energy appears as a reflected longitudinal wave and is detected by a geophone at the surface of the ground. That part of the energy which is transmitted further down, encountering a new surface, will produce new reflections and in the case of multiplied strata a geophone is actuated by a series of reflected waves from successively deeper reflections. It might be expected that the superimposing of other energies on the reflected energy may outweigh the desired effect and produce an effect which is unreadable. Owing to the present-day instrumental and field techniques, however, all the useless energy can be kept below the noise-level so that the reflections can be recorded in a readable way.

Now the aim will be to discuss some more important conditions and factors which have their influence on the intensity, quality and other characteristics of the seismic records, especially on the character of the observed reflections. Under the word "character of a reflections" one will understand the onset, amplitude,frequency, number of cycles and damping factor of a reflection.

From the point of view of field technique these conditions and factors fall into two groups namely, those dependent on the observer and those independent of him.

To the first group will belong:-

1. The depth of the shot-hole; the size of the charge; the method of tamping, and the shot-number.
2. The direction of the traverse with regard to the dip of the reflecting horizon.
3. The distance of the geophones from the shot-point (the length of the spread; the conditions of their location in the ground.
4. Characteristics of the instruments used and the methods of working.

To the second group will belong:-

1. The depth of the reflecting horizon.
2. The thickness of the reflecting horizon.
3. The coefficient of reflection of this horizon.
4. The stratification conditions, that is the number of discontinuities over the reflecting horizon.

The above specified problems form the basis of field technique, and their solution being based principally on the experiments carried out in the terrain, is far from being complete. Tn ere is a large number of publications on this subject partly theoretically, and partly descriptive, based on experiments performed in the terrain, but in the scientific meaning of the word there is still a great deal to be done. The main handicap is the direct inaccessibility of the object., i.e., of the subsurface of the earth and its components, and also a large variety of media, the latter fact causing all vibrations of natural or artificial origin passing through these media as seismic waves, to be very complicated. In such a medium as air, sound waves and their behaviour have been the subject of study and scientific experments for a few centuries. Seismology is a young science, and therefore exploration by seismic waves, which is based on the principles of seismology, being almost from the beginning a practical proposition, has not been able to observe all the phenomena involved, especially since this observation has to be carried out from the surface of the ground. A seismogram is the final record of all that happens to the wave produced at the shot-point. If one were able to place the recording instruments in the medium through which the waves pass in the same way as one can in the medium of sound waves, such as air or water, the work of observation would be much aided and the problem of wave propagation would be more easily solved. Since, however, one has to carry out the observations from the surface of the ground and check the results in a very few instances by means of wells, then the work of a geophysicist must be based not only on his knowledge of physical, mathematical, and geological principles but also on his field experience. An efficient operator should be not only a mechanica who knows the instruments and can manipulate them, but also one who "senses" from the seismogram with what kind of terrain he has to deal. The first shots give him an indication of what he may expect to obtain and how he may expect to obtain a good seismogram in the shortest time and at the least possible expense. Besides, he should be able to decide when he should stop shooting in the explored shot-hole, i.e. he should know the margin of valuable efficiency beyond which it is not profitable to proceed.

It is easy to choose the best record from several of those received at the same spread and in the same direction, this record differing only by a different charge and the filtration applied. But it is a matter of experience to know whether this record chosen is the best which a given instrument could produce at the spot explored. In order to state this fact with the greatest possible accuracy an inefficient observer would change the direction of the traverse explored and the spread used. If, however, at each new position he fires a certain number of shots, the state of the shot-hole itself becomes an important factor. Normally, a shot-hole may be broken when the first shots are fires, i.e. the hole no longer retains water used for tamping, fills up with broken facing or the facing falls in and this fact means that a long time may be required to clear and prepare the hole for the next shooting, if not a new hole may require to be drilled. Time is a precious factor and therefore here the experience of an observer is of great value. In a new terrain, with which the observer is not acquainted, a few holes must be tried in order to supply satisfactory answers as to whether the reflection method would be able to give sufficient data for interpretation.

A field record, or a group of records from the same hole, are the basis of future calculation and interpretation. The office work is much easier if the field work is properly done. A good interpreter should be a geophysicist, who has the practice of an observer and a calculator, besides being well acquainted with physics and geology in order to control the work of both of them and to interpret well the phenomena occurring in the ground.

Neither when exploring a terrain with magnetic methods nor when using gravimetric methods, is the efficiency of the observer so important with regard to the results obtained, as when applying the seismic reflection method. The magnetic and gravimetric data observed with the usual care and skill in the field are nothing but figures which become significant to the interpreter only when compared with data from the other stations and after a certain amount of corrections which very often completely changes the value of the figures observed.

Such is not the case with seismic data which are read from the record. In the reflection method of correlation an observer is able to follow the behaviour of the obse rved layer in the terrain and in this way may considerably help the future work of interpretation. Present day instrumental and field techniques make it possible to receive good seismograms, in a terrain where reflections occur, in the shortest time and with the least expense, but still the efficiency of the observer plays its fole.

With the present knowledge of the behaviour of seismic energy propagated in the ground, it is difficult or seldom reliable to base the interpretation on anything but the times of arrival of the individual impulses. The character of these impulses is the subject of continuous study, but knowledge of these has not yet progressed sufficiently to tell the character of the bed from the characterof a reflected impulse. One does not yet know the quantitative distribution of seismic energy round the shot-hole and the different frequencies involved. One does not know the quantity of energy absorbed by different rocks and earth materials. One does not know the amount of influence of the various media on the spreading and dispersion of the seismic energy, and besides it is difficult to state the direct effect of the instruments used on the amplitudes observed.

It is a proved fact that if at one traverse a good reflection is observed, and the observer moves to the next traverse applying the same amplification and filtration, then he is not able to obtain a reflection of exactly the same amplitude, frequency and number of cycles even if the prospected bed and the overburden disclose no changes in position and lithology. The fact is that one will never find the same conditions in the next shot-hole and one will never encounter the same conditions for the location of the geophones.

It seems worth while to mention briefly the conditions under which a medium is able to yield reflections and first of all to discuss these factors which are independent of the observer, i.e., the coefficient of reflection and the thickness of a bed. The two remaining factors i.e. the effects of the depth and stratification have been the subject of study discussed in Chapter VII.

The Coefficient of Reflection.

Consider a single interface of two nonabsorptive and nondispersive media of velocities V_1 and V_2, and densities d_1 and d_2. The incident longitudinal wave impinging upon the interface suffers splitting into reflected and transmitted parts. The record would reveal the reflected impulse as a reflection of a given frequency, amplitude and the numbers of cycles.

The reflection ability of the interface considered is, according to the theory already put forward by Lord Rayleigh, dependent not only on the contrast between the wave-velocities of both media, but on the contrast between their densities, and is expressed by the coefficients of reflection and transmission. Denoting the amplitude of the function of the reflected wave by A_1, that of the transmitted wave by A_2, and that of the incident wave by A, and assuming the normal boundary conditions, the continuity of pressure and the continuity of displacement at the boundary, one obtains $d_2 . A_2 = (A - A_1)$; $a_2 . A_2 = a_1 (A - A_1)$, where $a_1 = k_1 . \cos \theta_1$; $k_1 = \omega/V_1 = 2\pi/\lambda_1$; $a_2 = k_2 . \cos \theta_2$; $k_2 = \omega/V_2 = \cancel{/V_2} = 2\pi/\lambda_2$; θ_1 and θ_2 being the angles of incidence and transmission respectively, (ω = angular frequency, λ = wave length). From these two equations the coefficients of reflection and transmission are as follows:- (Refr:VIII - 2):

$$\frac{A_1}{A} = \frac{d_2/d_1 - V_1/V_2 \times (\cos \theta_2/\cos \theta_1)}{d_2/d_1 + V_1/V_2 \times (\cos \theta_2/\cos \theta_1)}$$

$$\frac{A_2}{A} = \frac{2}{d_2/d_1 + V_1/V_2 \times (\cos - \theta_2/\cos \theta_1)}$$

In order to obtain these coefficients in terms of the amplitudes of the displacement of the particles, one has to multiply the amplitudes of the function of the individual waves by ω/V, and thus A_1 and A by ω/V_1, and A_2 by ω/V_2. The value of the reflection coefficient remaining the same, the value of the transmission coefficient becomes :-

$$\frac{A_2}{A} = \frac{2.\ V_1/V_2}{d_2/d_1 + V_1/V_2 .\cos\theta_2/\cos\theta_1}$$

multiplying by V_2/V_1 one obtains : for both coefficients:-

$$\frac{A_1}{A} = \frac{d_2V_2/d_1V_1 - \cos\theta_2/\cos\theta_1}{d_2V_2/d_1V_1 + \cos\theta_2/\cos\theta_1}$$

$$\frac{A_2}{A} = \frac{2}{d_2V_2/d_1V_1 + \cos\theta_2/\cos\theta_1}$$

The product d.V is known as the specific acoustic resistance of the medium and is denoted by R. Determinging the ratio of $R_2/R_1 = r_{21}$, one obtains:-

$$\frac{A_1}{A} = \frac{r_{21} - \cos\theta_2/\cos\theta_1}{r_{21} + \cos\theta_2/\cos\theta_1}$$

$$\frac{A_2}{A} = \frac{2}{r_{21} + \cos\theta_2/\cos\theta_1}$$

which for a vertical incidence $\theta_1 = \theta_2 = 0$ become:

$$\frac{A_1}{A} = \frac{r_{21} - 1}{r_{21} + 1}\ ;\quad \frac{A_2}{A} = \frac{2}{r_{21} + 1}$$

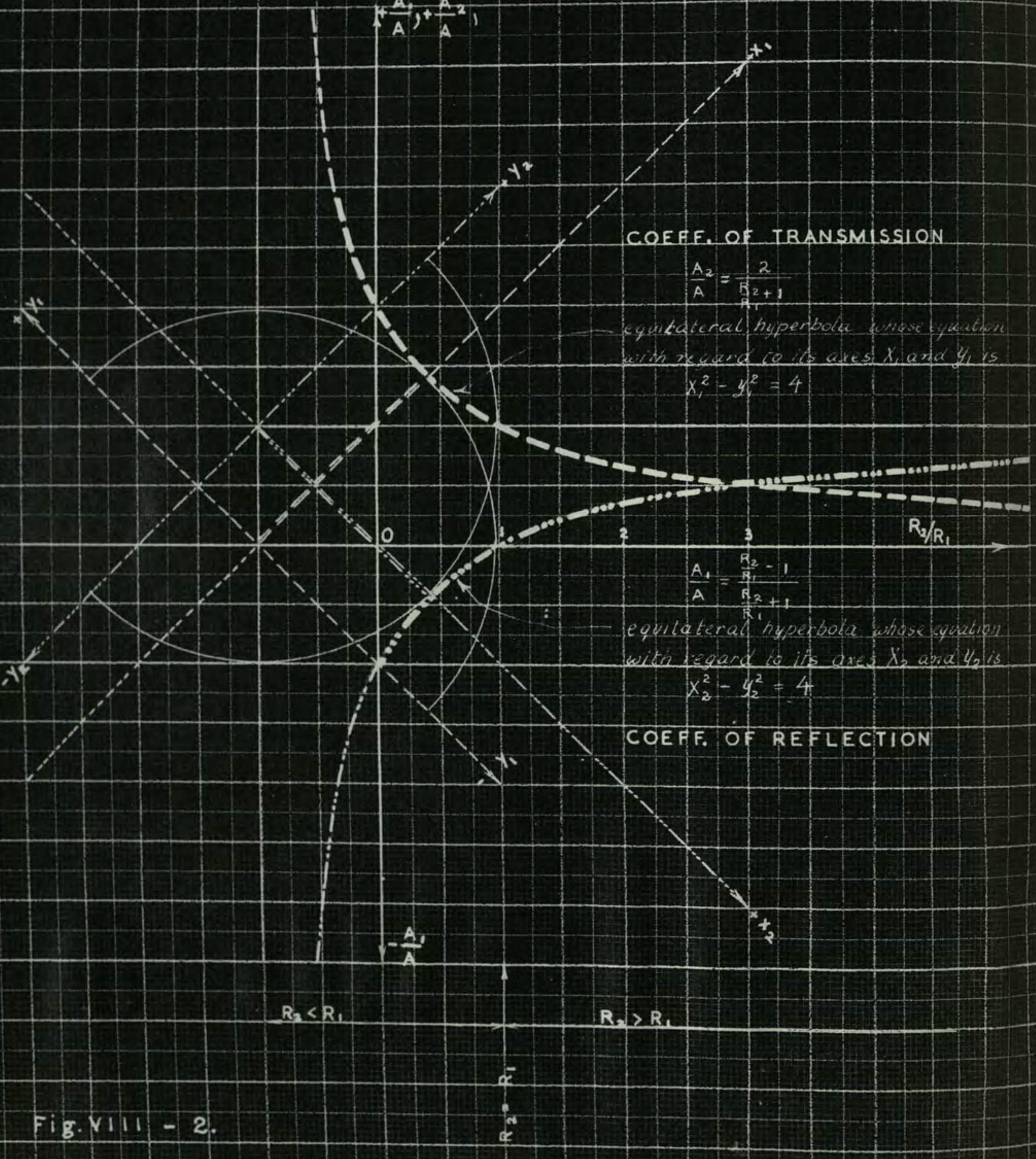

$+\frac{A_1}{A}, +\frac{A_2}{A}$
$+X_1$
$+Y_2$
$+Y_1$
$-Y_2$
$-Y_1$
$+X_2$
0
1
2
3
R_2/R_1
$-\frac{A_1}{A}$
COEFF. OF TRANSMISSION
$\frac{A_2}{A} = \frac{2}{\frac{R_2}{R_1}+1}$
equilateral hyperbola whose equation with regard to its axes X_1 and Y_1 is
$X_1^2 - Y_1^2 = 4$
$\frac{A_1}{A} = \frac{\frac{R_2}{R_1} - 1}{\frac{R_2}{R_1}+1}$
equilateral hyperbola whose equation with regard to its axes X_2 and Y_2 is
$X_2^2 - Y_2^2 = 4$
COEFF. OF REFLECTION
$R_2 < R_1$
$R_2 > R_1$
$R_2 = R_1$

Fig. VIII - 2.

hence :

$$A_2/A + A_1/A = 1 \quad \text{or} \quad A_2 + A_1 = A$$

It is thus evident that in the case of vertical incidence the sum of the displacement amplitudes of the transmitted and reflected waves is equal to the displacement amplitude of the incident wave. Since it is impossible to determine the absolute value of the displacement amplitude of the incident wave for the same reason which prevents the absolute value of the incident energy being determined, therefore the relative values of these amplitudes expressed by the above given coefficients of reflection and transmission become of certain importance.

Plotting A_1/A and A_2/A against the values of r_{21} in a normal co-ordinate system (x,y), two equilateral hyperbolae are obtained (Fig. VIII-2) , the lower for A_1/A , the upper for A_2/A. For each value of $x = R_2/R_1$ one value of A_1/A and one value of A_2/A are obtained, the sum of which is equal to unity. Since in practice one is interested only in the positive values of R_2 and R_1 which are the products of the real values of V and d, therefore these hyperbolae have a practical significance only on the positive side of y-axis excluding $x = 0$. The hyperbola for the reflected wave has negative values for $0 < x < 1$, which means that if the acoustic resistance of the reflecting bed is lower than that of the incidence medium, the reflected impulse suffers a change of phase of 180°. For $R_2 = R_1$ there is no reflection. For $R_2 > R_1$ the reflected wave is in phase with the incident wave. For a rapidly growing R_2 the amplitude of the reflected wave increases slowly and reaches a value equal to that of the incidence when R_2 = infinity or $R_1 = 0$. These instances have no practical appliaation.

The hyperbola for the transmitted wave has within practical limits, i.e. $R_2 / R_1 > 0$, always positive values irrespective of whether the wave is transmitted into a denser or rarer medium. In other words the transmitted wave is always in phase with the incident wave.

When $R_2 = R_1$ the whole incident wave is transmitted into the second medium. For the increasing value of R_2 the amplitude of the transmitted wave decreases slowly to reach a value of zero when R_2 = infinity.

In conclusion, there are two characteristic points which are worth considering:-

1. As it is evident from the first equation on p. 238. the reflection will not occur for $d_2 / d_1 = \dfrac{V_1 \cdot \cos \theta_2}{V_2 \cdot \cos \theta_1} =$

$= \sin \theta_1 \cdot \cos \theta_2 : \sin \theta_2 \cdot \cos \theta_1 = \cot \theta_2 / \cot \theta_1$

This means that for certain values of d_1, d_2, V_1, and V_2 an angle will exist which will satisfy this equation. The value of this angle can be shown to be equal to

$$\cot^2 \theta_1 = \left\{1 - \left[\frac{V1}{V_2}\right]^2\right\} : \left\{\left[\frac{V_1}{V_2}\right]^2 - \left[\frac{d_2}{d_1}\right]^2\right\}$$

from which it follows that if V_1/V_2 (the so called "refraction coefficient") is confined to the values between unity and d_2/d_1 (the so called "density constrast") then there will always exist an angle at which the reflection wave vanishes.

In the examples considered in Chapter VII, where $V_1/V_2 = 1/2$ and $d_2/d_1 = 1.3$, the reflection will always occur, since the refraction coefficient does not satisfy the above mentioned condition.

In the Kosow area the "marker horizon" as revealed by well drilling (see Chapter XIII) consisted of a salt layer embedded in gypsum. Assuming the velocity and density for gypsum to be equal to 4000 m/sec. and 2.8 respectively, and those for salt to beequal to 5000 m/sec. and 2.15 respectively, the refraction coefficient 4000:5000 = 0.8 will lie between unity and 0.758 (the density contrast 2.15:2.8). Thus there will exist an angle such as 20° 50' for which theoretically no reflection will be revealed. Nevertheless, in this case the incident wave will be reflected from the top of the thin gypsum bed overlaid by the Tortonian overburden because between the latter and the gypsum bed the values $V_1/V_2 = 1/2$ and $d_2/d_1 = 1.3$ can be assumed. On account of this thin reflecting bed of gypsum, the reflections received however, were not so outstanding in the Kosow area as in the Stryj area (see Chapter XI) where the gypsum bed is from 15 to 50 m. thick and has no salt layers interbedded with it.

2. From the same equation on. p.   it is further evident that when $\theta_2 = 90^\circ$ or more , then $\cot\theta_2 = 0$ or is imaginary, and $A_1/A = 1$ and the phenomenon of total reflection takes place.

Since $\cot\theta_2/\cot\theta_1 = V_1/V_2 \cdot \sqrt{(1 - \sin^2\theta_2) : \cos^2\theta_1}$

$$= \frac{V_1/V_2}{1} \cdot \frac{\sqrt{(1 - V_1^2/V_2^2).\sin^2\theta_1 :}}{\cos \theta_1}$$

therefore $\cot\theta_2 = 0$ or is imaginary when

$$(1 - V_1^2/V_2^2).\sin^2\theta_1 = 0 \text{ or less than } 0$$

and thus $\sin\theta_1 = V_1/V_2$, which is the value of the angle of total incidence.

Below three examples are given for the conditions existing in the Foreland area of the Carpathians. In these examples the coefficients of reflection are computed for different angles of incidence :-

a/ Stryj area

$V_1 = 2400$ m/sec; $d_1 = 2.2$ - Tortonian clays

$V_2 = 4800$ " $d_2 = 2.9$ - Gypsum bedrock

thus $V_1/V_2 = 1/2$; $d_2/d_1 = 1.3$

and for $\theta_1 =$ 0° , 10° , 20° , 30°

$A_1/A =$ 0.447 , 0.466 , 0.542 , 1

b) Kosow area

$V_1 = 2400$ m/sec; $d_1 = 2.2$ - Tortonian clays

$V_2 = 4800$ " $d_2 = 2.15$ - Salt bedrock embedded in very thin gypsum beds

thus $V_1/V_2 = 0.48$; $d_2/d_1 = 0.98$

and for $\theta_1 =$ 0° , 10° , 20° , 30° , $28^\circ 45'$

$A_1/A =$ 0.35, 0.375, 0.472, 0.6, 1

c) Kosow area (considering the interface between the gypsum and salt beds) and Pomorze area, where gypsum beds cover the salt domes.

$V_1 =$ 4000 m/sec; $d_1 = 2.8$ - gypsum cover (cap)

$V_2 =$ 5000 " $d_2 = 2.15$ - salt (interbedded) or in domes

thus $V_1/V_2 = 0.8$; $d_2/d_1 = 0.77$

and for $\theta_1 =$ 0° , 10° , 20° , $20^\circ 50'$, 30° , 50°, 53°

$A_1/A =$ -.021, -.016, -.003, 0 , . 031, .30, 1,

From these examples it is evident, that the smaller

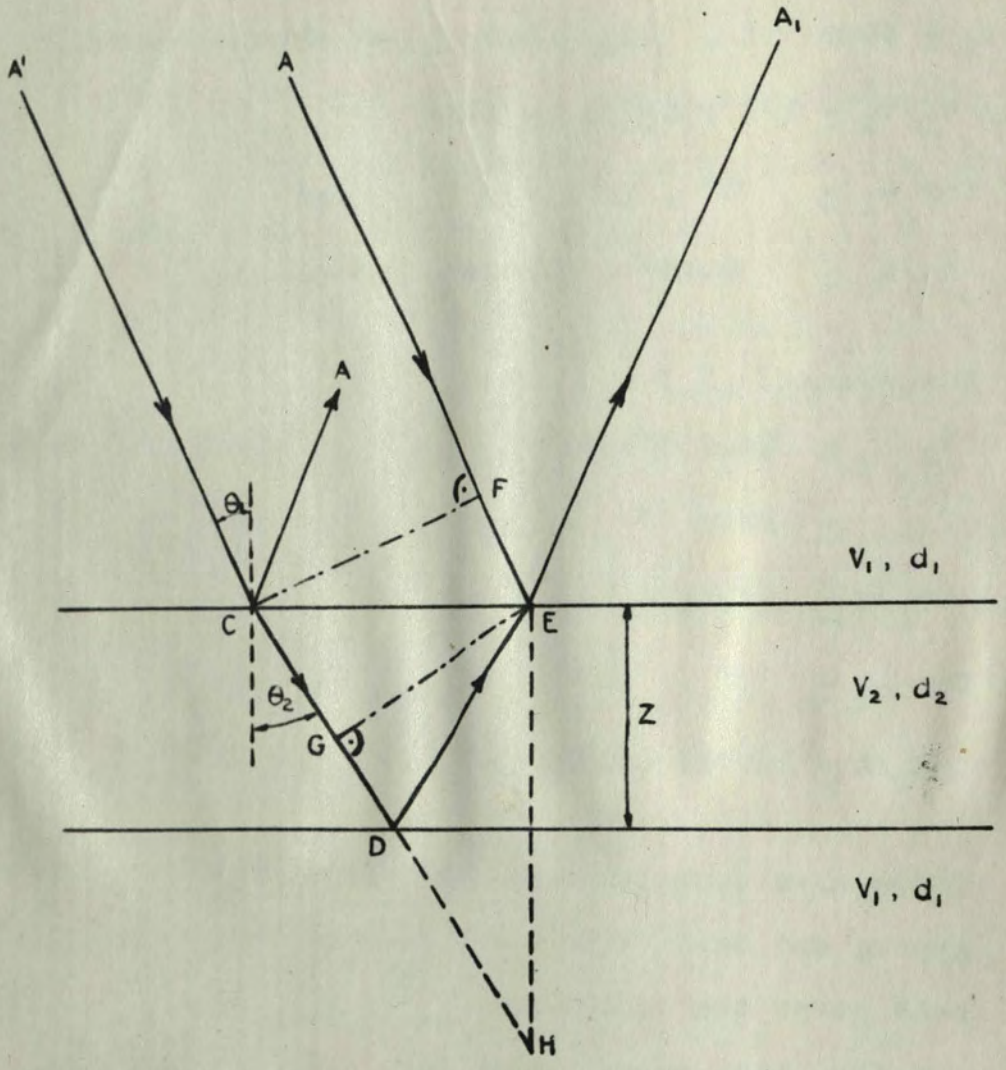


Fig. VIII-3.

the acoustic resistance contrast $(V_2d_2 : V_1d_1)$ the smaller the coefficient of reflection for the same angle of incidence and the smaller is the amplitude of the reflections observed. The third example shows that in the case of the salt domes covered by thick gypsum beds, very weak impulses or none at all, may be reflected from the interface. This was the case when prospecting the salt domes in the area of Pomorze (Pomerania).

Some further examples concerning the coefficient of reflection are given in Chapters X and XI.

The thickness of the reflecting medium.

Assuming a layer of velocity V_2 , density d_2 and of thickness Z, embedded in a medium of velocity V_1 less than V_2 and of density d_1 less than d_2 , and considering, in ideal elastic conditions, only the longitudinal reflected and transmitted effects, the picture as shown in fig. VIII - 3 will be obtained. Confining one's attention to the ray-paths $A'CDEA_1$ and AEA_1 , CF and GE will represent the fronts of the incident and the transmitted waves respectively, contained between the two rays considered. Thus the portions of the paths CG and FE are equal (in travel time) , and the path difference

$$GD + DE = GH = 2Z.\cos \theta_2$$

An impulse reflected at the surface of a denser medium (at point E) suffers no change in phase, while the transmitted impulse passing the point C without phase change, suffers a phase change of 180° at the point D when being reflected from the less dense medium below. This phase change is equivalent to a path difference of half a wave length so that the total retardation along the paths A'CDEA, in comparison with AEA, is caused by the difference in phase along the path GDE and is equal to $2Z.\cos\theta_2 + \frac{1}{2}\lambda$ If this retardation is equal to an even number of wave lengths, or, in other words, if $2Z.\cos\theta_2$ is equal to an odd number of half wave lengths, the intensity of the composite reflected ray A_1 will be at a maximum. It will be a minimum when $2Z.\cos\theta_2$ is equal to an even number of half wave lengths. If follows then that the maximum of intensity will be obtained when

$$Z.\cos\theta_2 = (2N+1)\,.\frac{\lambda}{4}\ ,$$

and the minimum of intensity when

$$Z.\cos\theta_2 = N.\ \frac{\lambda}{2}\ ,$$ where N is an integer

As follows from theory, the maximum of intensity is extremely strong. The first minimum and the first maximum of intensity are obtained for N = 0, and for Z = 0 and $Z = \frac{\lambda}{4}\,.\sec\theta_2$ respectively. The second minimum of intensity is reached for N = 1, and for $Z = \frac{\lambda}{2}\,.\sec\theta_2$.

In application of this principle to the particular case of a gypsum layer embedded in the Tortonian clays (Chapter VII), consider the first maximum of intensity for $Z = \frac{\lambda}{4} \cdot \sec \theta_2$. Since $\lambda = V_2/f$, where f is thefrequency, therefore $Z = V_2 : 4.f.\cos \theta_2$. It is evident that for the same lithological conditions (V_2 constant, depth constant) Z will vary with the angle of incidence; while for the same angle of incidence and V_2 constant, Z will vary with the depth since f varies with the depth. This is shown in the table given below:-

Depth in ft	Frequency	Thicknesses of the reflecting bed for the 1st maximum of intensity for the following $\theta_1 (\sin \theta_1 : \sin \theta_2 = 1 : 2)$						
$H = \frac{D}{2}$	f	0°	5°	10°	15°	20°	25°	
500	76,5	15.8	15.9	16.7	18.3	21.6	29.4	m
900	69	17.4	17.7	18.5	20.4	24	32.6	m
1400	62	19.3	19.7	20.6	22.6	26.6	36.2	m
2800	50	24	24.2	25.6	28	33	45	m
4000	44	27.2	27.7	29	32	37.4	51	m

(The value of f in this table was computed from the formula of Gutenberg, considered in this paper on p.214; $V_2 = 4800$ m/sec , $V_1 : V_2 = 1:2$).

The condition for the first minimum of intensity (apart from $Z = 0$) will be obtained from the above table by

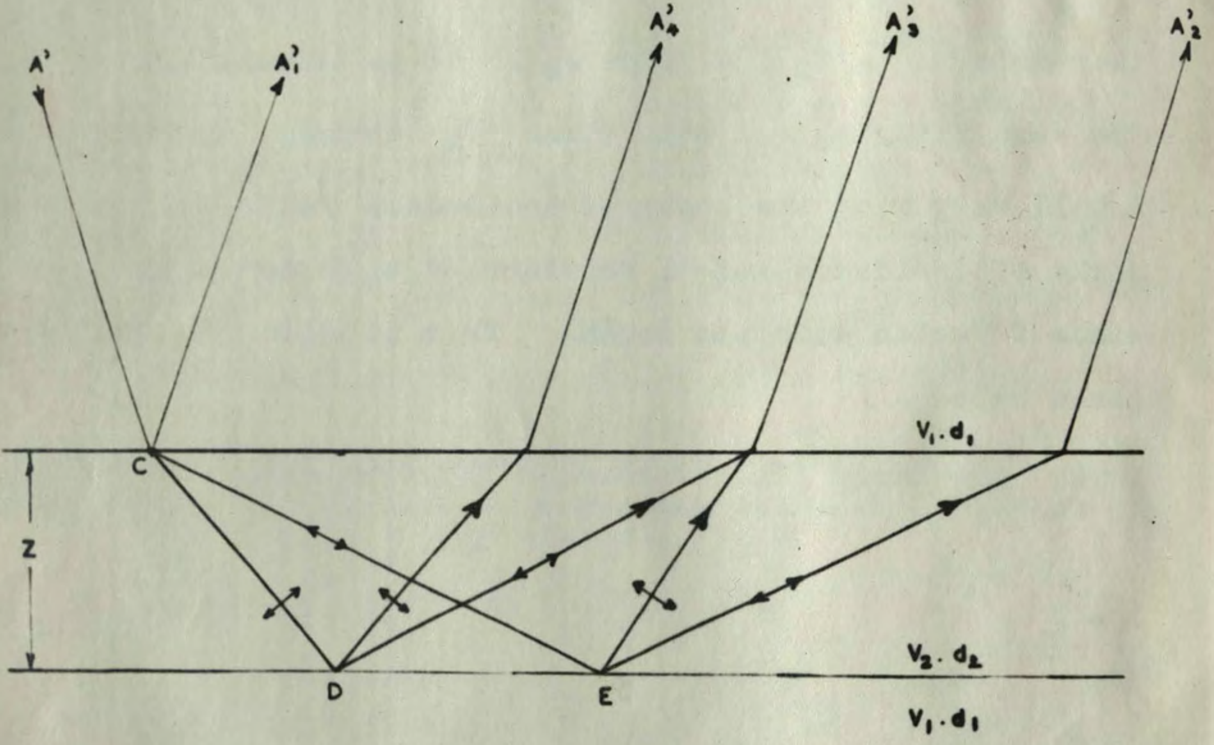


Fig. VIII - 4.

doubling the given value of thickness, and that of the second maximum of intensity is obtained by multiplying the given value by 3.

From the table it can be seen that, if other factors are not considered, the reflecting gypsum bed which was found at a depth of about 4000 ft. in the Stryj area, being about 30 m. thick, should have yielded very good reflections at a distance of 300 - 400 m., corresponding to an angle of incidence of about 5° . This in fact was the case.

It seems worth noting here, that when the medium underlying the considered bed is of higher velocity than the bed, the wave reflected from the bottom of the bed does not suffer phase change and therefore the maximum of intensity of reflection will occur for those values of Z for which, in previous cases, one would expect the minimum of intensity; and vice-versa.

The case is less simple if both longitudinal and transverse reflected and transmitted impulses, produced by the incidence of a longitudinal wave, are taken into account.

A single longitudinal impulse A' (Fig. VIII - 4) impinging on the surface of a layer of thickness Z, (acoustic resistance $V_2.d_2$) , embedded in a medium of smaller acoustic resistance, is partly reflected, producing the longitudinal impulse A'_1, and a transverse impulse, not marked on the figure, and partly transmitted, yielding the longitudinal impulse CE and the transverse impulse CD. Each of them suffers reflection and transmission at the bottom of the bed. The reflected part will consist again of two impulses, transverse and longitudinal, as shown in the fig., and each of them will be partly transmitted into the upper medium giving here the longitudinal impulses A'_2 , A'_3 , and A'_4 which will follow in this order the direct reflection A'_1 .

M. Muskat (Refr: VIII - 3) considers the latter case in greater detail and gives theoretical examples showing the way in which the waves A'_2 , A'_3 , A'_4 might affect the direct reflection A'_1 when the thickness of the layer changes. Considering three particular instances in which $Z = \frac{\lambda}{2}$, λ , 2λ , when intensity is at a minimum he shows how the impulse A'_2 , being always of the opposite phase, affects the direct reflection A'_1 , It follows from those examples that good reflected effects can be expected from beds, the thickness of which is greater than half a wave length. This seems contrary to the expectation that there will be a maximum of intensity when $Z = \frac{\lambda}{4}$, but as was mentioned before, this maximum, like the others, is reached very repidly as the value of Z approaches $(2N \pm 1) \cdot \frac{\lambda}{4}$. Therefore it cannot be considered to invalidate the general case.

The direction of shooting traverses with regard

to the dip of the reflecting horizon.

This is one of the more important factors which affect the quality of the reception of reflections and which can be to a considerable degree controlled by the observer.

One of the predominant phenomena which play their rolè in this case, is that of the distribution of the reflected energy. A particular example for a horizontal bed was given in Chapter VII. This distribution, it will be shown, differs considerably when dealing with inclined beds. According to the considerations in Chapter VII., the longitudinal reflected energy received in an absorptive medium is equal to

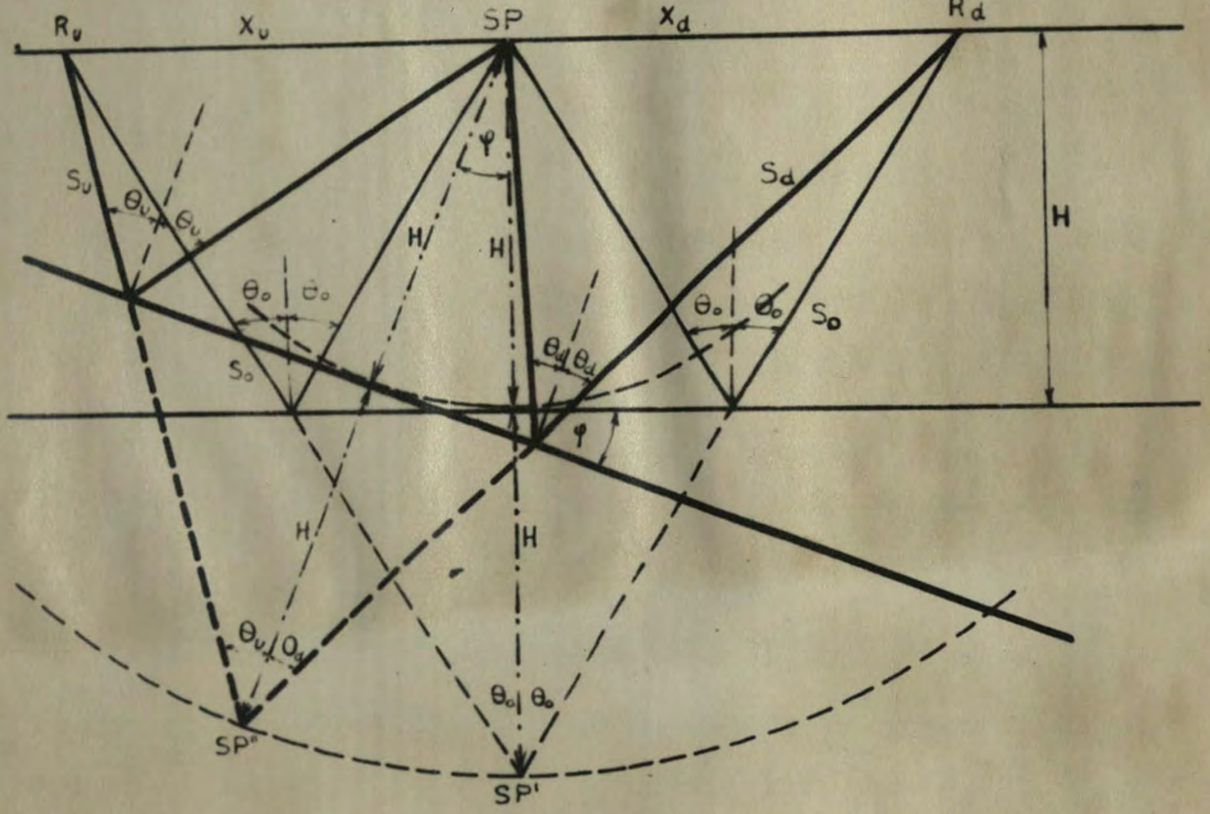
$$E_a = E_o \cdot R_{12} \cdot e^{-\alpha S}$$

and in a medium both absorptive and dispersive is equal to

$$E_r = E_a : 4\pi S^2$$

where E_o = the incident energy, R - fractions of the incident energy transformed into longitudinal waves after the incidence of a longitudinal wave at an elastic interface; It is called the stratification factor. $e^{-\alpha S}$ = the absorption factor, in which α - the coefficient of absorption, S = the travel distance of the wave. $\frac{1}{4\pi S^2}$ = the dispersion factor.

In order to compute this energy it seems necessary to consider first the relation between the angle of incid-



R_u
X_u
SP
X_d
R_d
S_u
θ_u
θ_u
φ
H
H
H
S_d
θ_o
θ_o
θ_o
θ_o
S_o
S_o
θ_d
θ_d
φ
H
H
θ_u
θ_d
θ_o
θ_o
SP''
SP'

Fig.VIII - 5.

ence and the dip-angle, and then the relation between the travel-distance S and the dip-angle.

Consider a horizontal interface between two media (fig.VIII - 5) at a depth equal to H. On equal distances from the S.P. are placed the receiving stations R_d and R_u; the travel-distances of the impinging and reflected waves are shown in ~~red~~ thin lines.; S.P$'$. is the image of the S.P., θ_o the angle of incidence, S_o the travel distance of the wave from the S.P. to R_d as well as to R_u .

Imagine now an inclined bed , of dip-angle φ , at the same depth under the S.P. Then S.P.$''$ being the image of S.P. for this interface, θ_d and θ_u are the angles of incidence for the down-dip station and the up-dip station respectively, while S_d and S_u are the travel-distances of the waves from the S.P. to R_d and from the S.P. to R_u respectively (in thick lines).

From the figure the following relations can be established:

$$S_o^2 = X^2 + 4H^2$$

$$S_d^2 = S_o^2 + 4XH.\sin\varphi$$

$$S_u^2 = S_o^2 - 4XH.\sin\varphi$$

$$\frac{X}{2H} = \frac{\sin\theta_d}{\cos(\theta_d + \varphi)} = \frac{\sin\theta_u}{\cos(\theta_u - \varphi)} \quad \text{hence}$$

$$\tan\theta_d = \frac{\cos\varphi}{2H/X + \sin\varphi} \qquad \tan\theta_u = \frac{\cos\varphi}{2H/X - \sin\varphi}$$

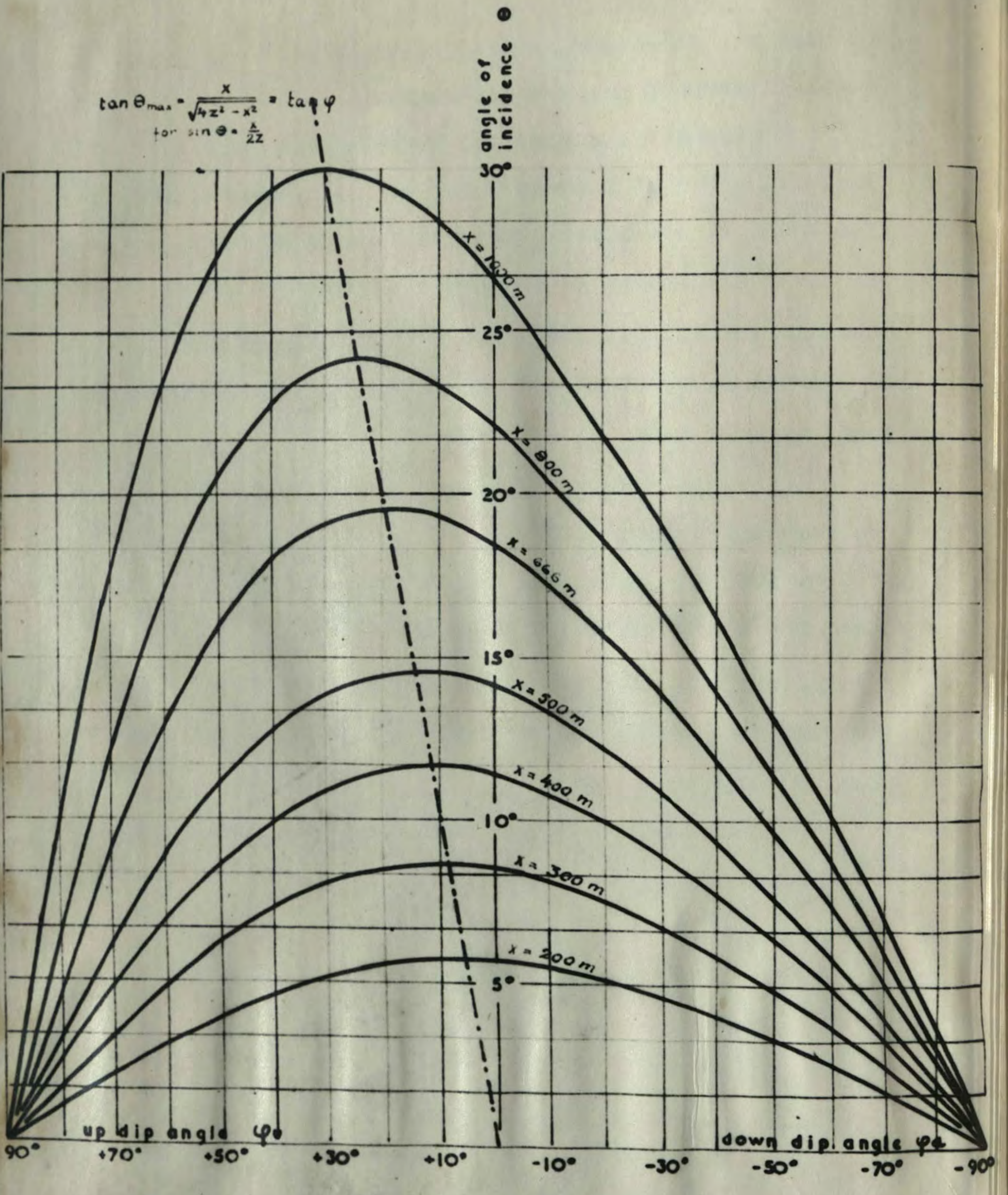

$\tan \theta_{max} = \frac{x}{\sqrt{4z^2 - x^2}} = \tan \varphi$
for $\sin \theta = \frac{x}{2z}$
angle of incidence θ
30°
25°
20°
15°
10°
5°
x = 1000 m
x = 800 m
x = 666 m
x = 500 m
x = 400 m
x = 300 m
x = 200 m
up dip angle φ°
down dip angle φ°
90°
+70°
+50°
+30°
+10°
-10°
-30°
-50°
-70°
-90°

Fig. VIII - 6.

For X constant, θ_u is maximum and equal to φ, equal to $\sin^{-1} \frac{X}{2H}$. As φ increases, S_d increases and when $\varphi = 90^\circ$ (vertical interface) S_d is maximum and equal to $[2H + X]$; while S_u decreases and when $\varphi = 90^\circ$, Su is at a minimum and equal to $[2H - X]$.

The values of X for which the phenomenon of total incidence occurs (θ_i) are different for each slope and can be determined by the formulae:-

$$X_{di} = \frac{2H}{\cot \theta_i . \cos\varphi - \sin\varphi}; \quad X_{ui} = \frac{2H}{\cot \theta_i . \cos\varphi + \sin\varphi}$$

Assuming now a simple case of a gypsum bedrock at a depth of $H = 1000$ m, overlaid by the Tortonian clays, the following data can be assumed :- $V_1/V_2 = 1/2$; $d_2/d_1 = 1.3$.

Fig. VIII - 6 shows the variations of the angle of incidence with the dip-angle for different values of X, for a particular case of an interface between two media of $V_1/V_2 = 1/2$ at the invariable depth of 1000 m. under the S.P.

To show the variations of S_u and S_d with x variable consider that the equation

$$S^2 = X^2 + 4H^2 + 4HX.\sin\varphi$$

gives S_u when X varies from - infinity to zero,

and S_d " " " " + " to zero

and can be transformed into an equation such as

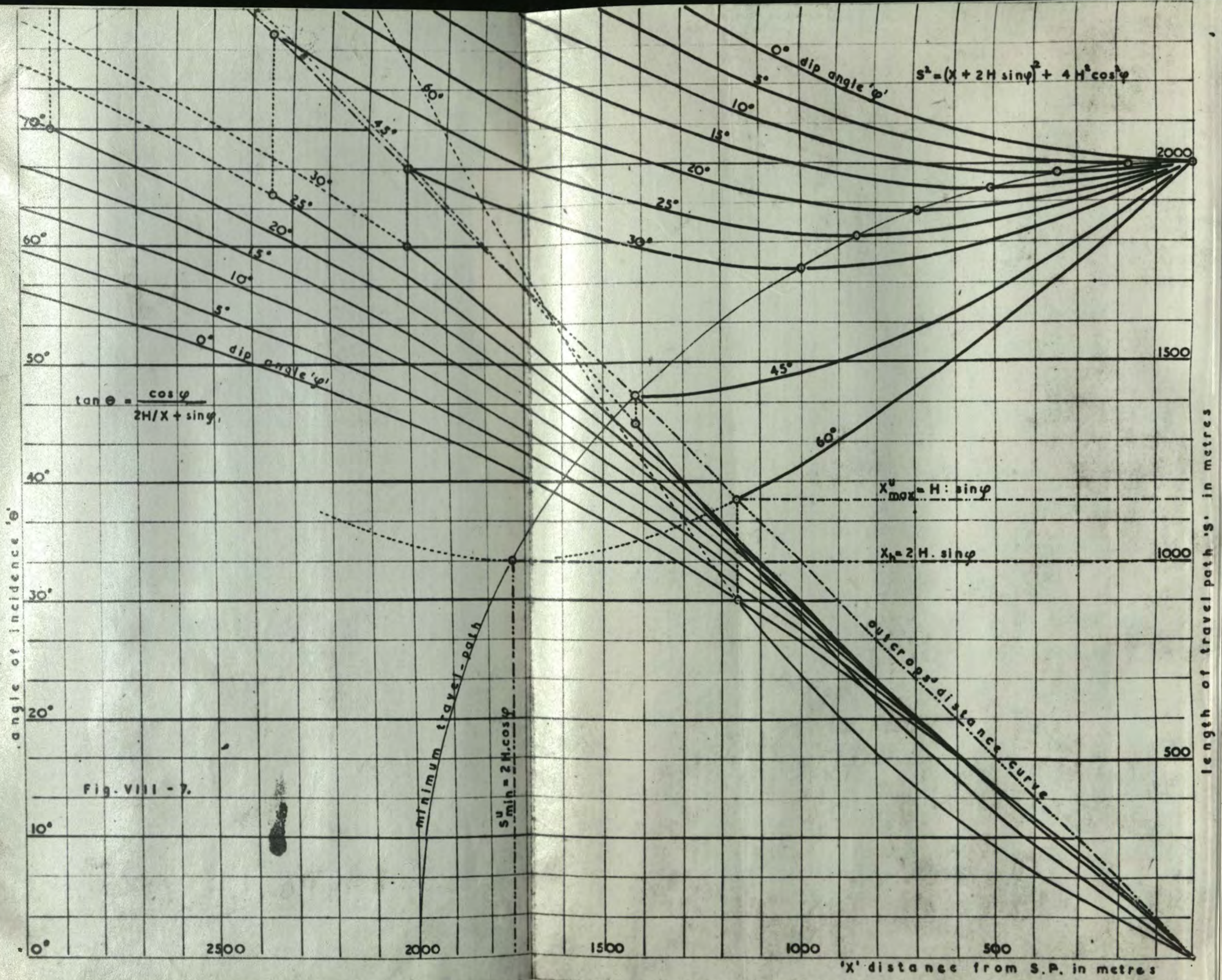

angle of incidence 'θ'
0°
10°
20°
30°
40°
50°
60°
70°
length of travel path 'S' in metres
500
1000
1500
2000
'X' distance from S.P. in metres
2500
2000
1500
1000
500
$\tan\theta = \frac{\cos\varphi}{2H/X + \sin\varphi}$
0° dip angle 'φ'
5°
10°
15°
20°
25°
30°
45°
60°
$S^2 = (X + 2H\sin\varphi)^2 + 4H^2\cos^2\varphi$
0° dip angle 'φ'
5°
10°
15°
20°
25°
30°
45°
60°
$X^u_{max} = H : \sin\varphi$
$X_h = 2H.\sin\varphi$
$S^u_{min} = 2H.\cos\varphi$
minimum travel-path
outcrops' distance curve

Fig. VIII - 7.

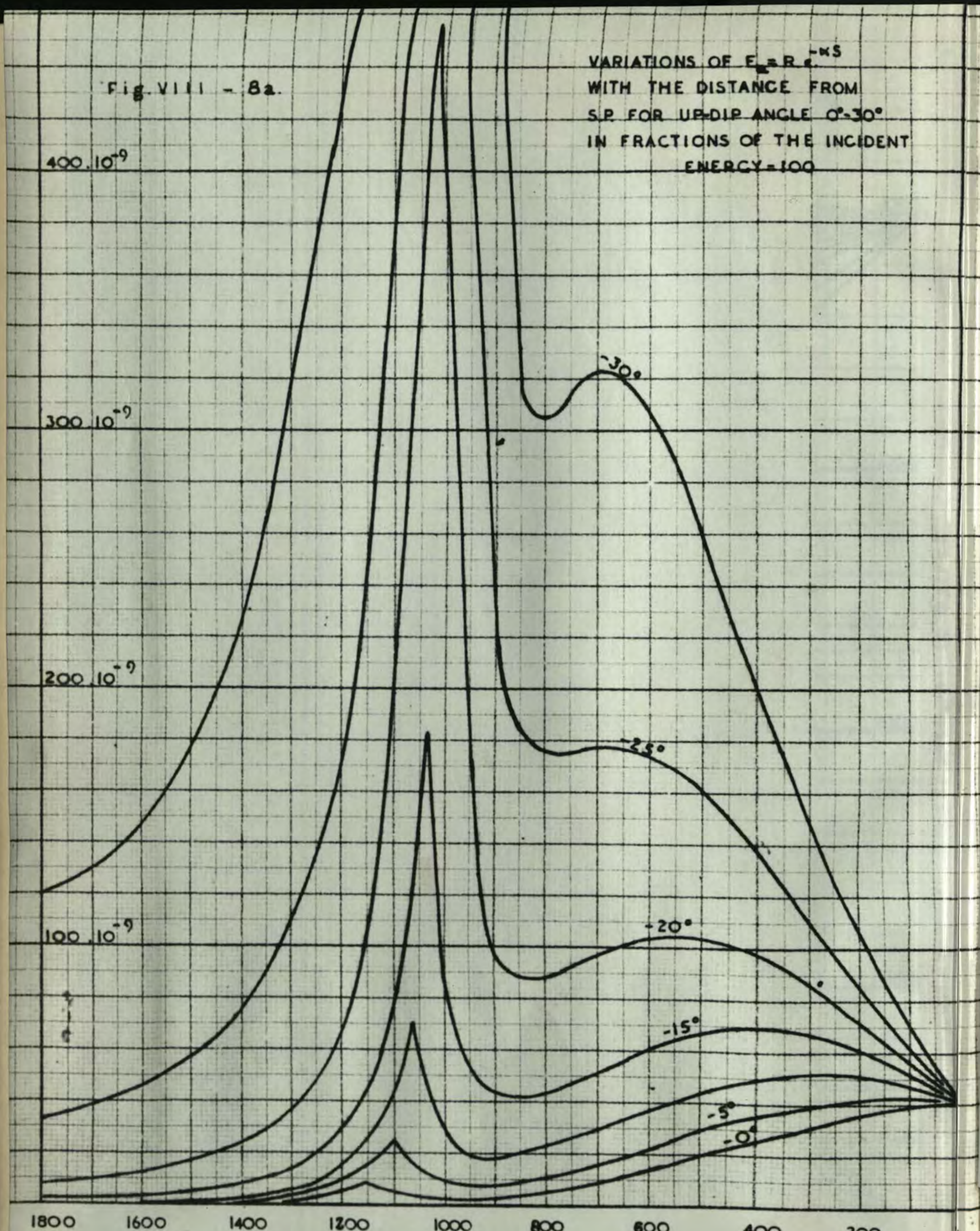


Fig. VIII - 8a.

VARIATIONS OF $E_R = R\,e^{-\alpha S}$ WITH THE DISTANCE FROM S.P. FOR UP-DIP ANGLE 0°-30° IN FRACTIONS OF THE INCIDENT ENERGY = 100

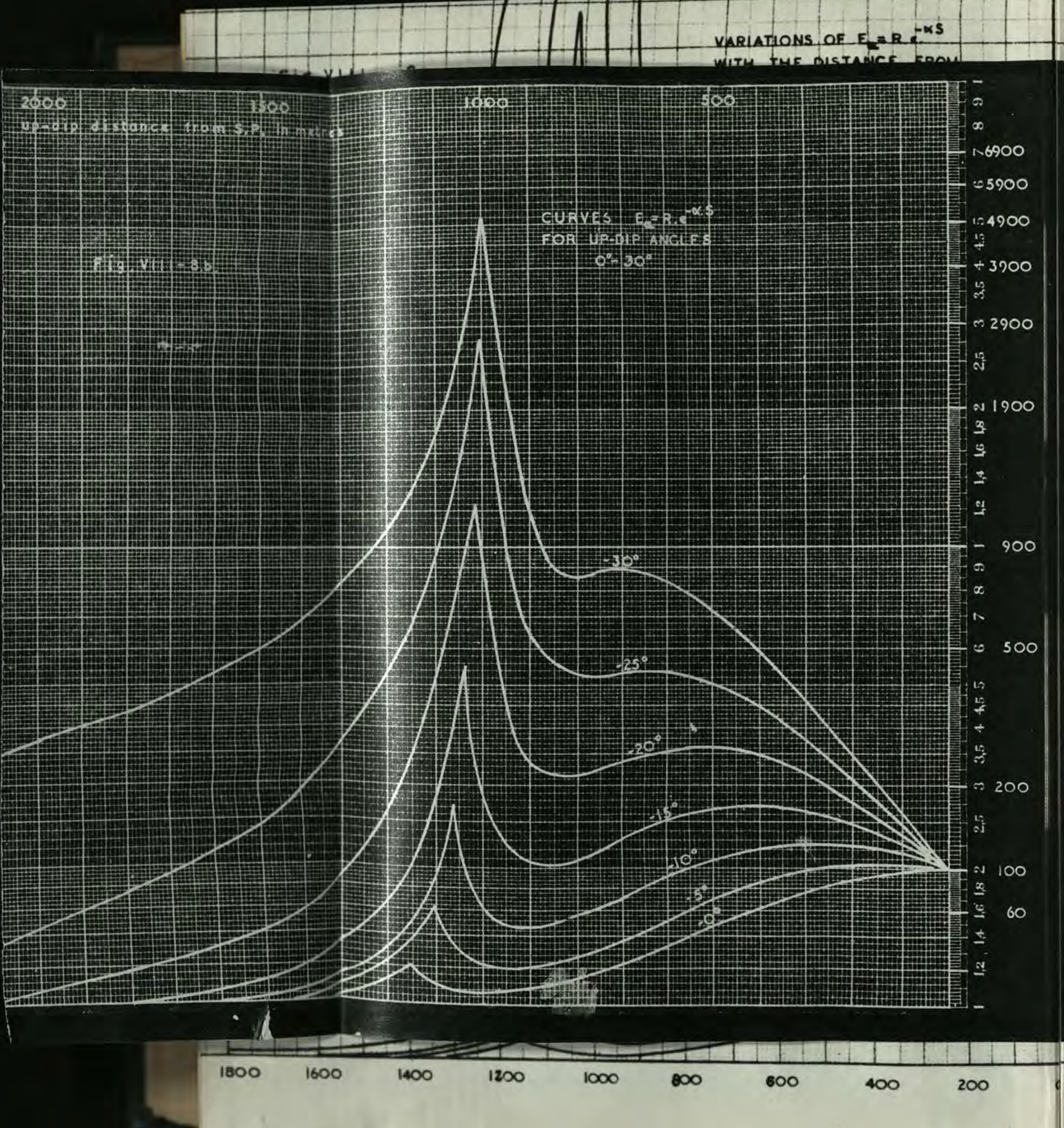

VARIATIONS OF $E_{\alpha} = R.e^{-\alpha S}$
WITH THE DISTANCE FROM
2000
1500
1000
500
up-dip distance from S.P. in metres
CURVES $E_{\alpha} = R.e^{-\alpha.S}$
FOR UP-DIP ANGLES
0°- 30°
-30°
-25°
-20°
-15°
-10°
-5°
-0°
6900
5900
4900
3900
2900
1900
900
500
200
100
60
1800
1600
1400
1200
1000
800
600
400
200

Fig. VIII-8.b.

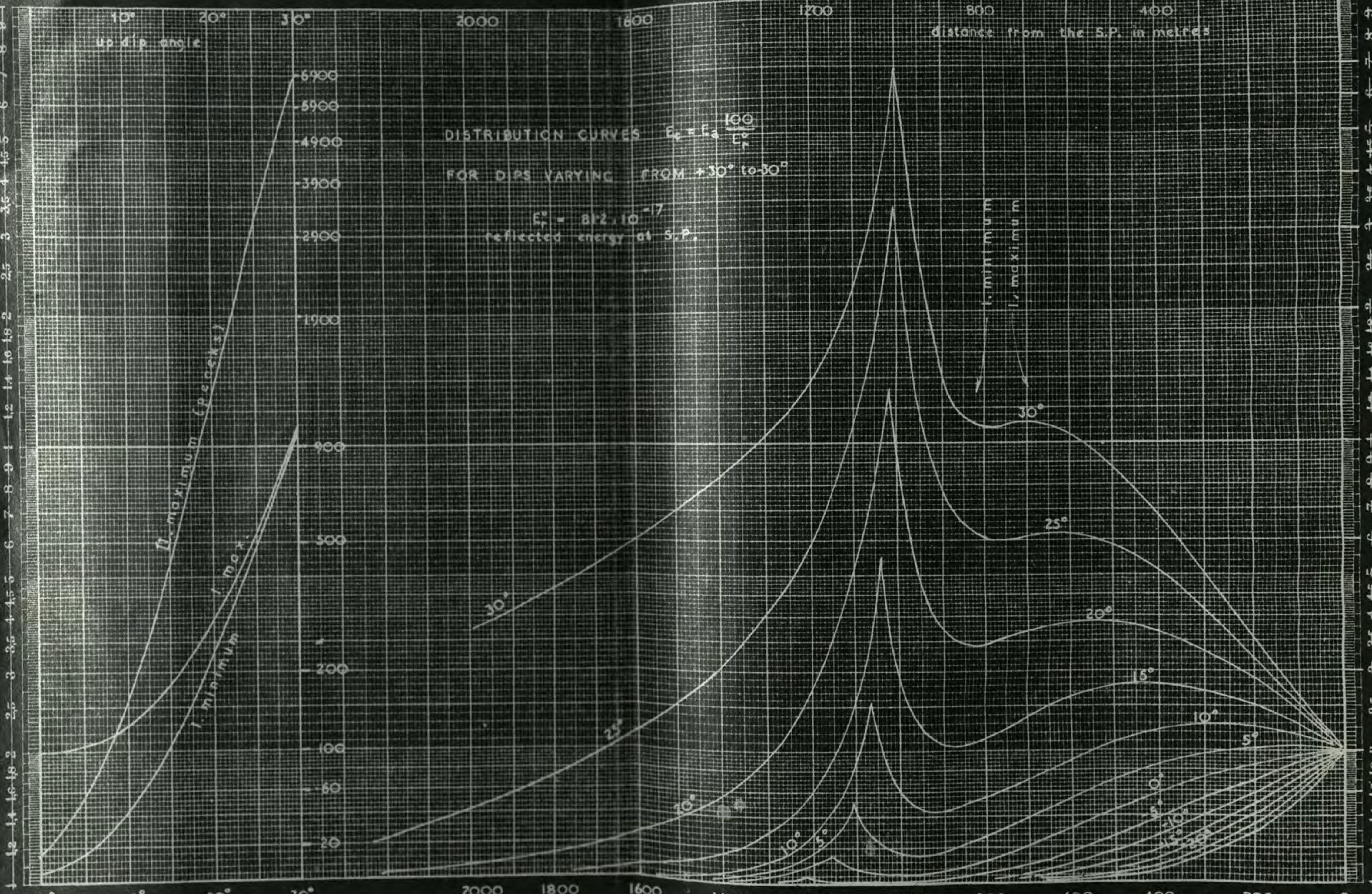

DISTRIBUTION CURVES $E_c = E_a \frac{100}{E_r^0}$
FOR DIPS VARYING FROM +30° to -30°
$E_r^0 = 812 . 10^{-17}$
reflected energy at S.P.
up dip angle
10° 20° 30°
II. maximum (peacks)
I max.
I minimum
6900
5900
4900
3900
2900
1900
900
500
200
100
60
20
2000 1600 1200 800 400
distance from the S.P. in metres
I. minimum
I, maximum
30°
25°
20°
15°
10°
5°
0°
-5°
-10°
0° 10° 20° 30°
2000 1800 1600 1400 1200 1000 800 600 400 200 0

Fig. VIII - 9.

$$S^2 - (X + 2H.\sin\varphi)^2 = 4H^2 . \cos^2\varphi$$

which represents an equilateral hyperbola, the origin of which has co-ordinates $[-2H.\sin\varphi, 0]$, while the co-ordinates of its cusp are : $X = -2H.\sin\varphi$, $S_{min} = 2H.\cos\varphi$.

These hyperbolae for $\varphi = 0°, 5°, 10°, 15°, 20°, 25°, 30°, 45°$, and $60°$ are shown in fig. VIII - 7, their ordinates give S_u for X variable from zero to the value of $X_u = H:\sin\varphi$, i.e., where the bed outcrops at the surface. The values of S_d can also be read from this figure, owing to the symmetry of these hyperbolae with regard to their vertical axes.

To compute the values of E_a and E_r , the coefficient of absorption is assumed to be equal approx. to 10^{-4} if S is expressed in cm. (see p. 215.). The stratification factor R_{12} is interpolated from the diagram fig. VII - 13c.

The values of E_a and E_r calculated in this way are plotted on the log-diagrams (fig. VIII - 8 a,b, and 9) for up and down-dip traverses. The down-dip traverses are considered from 0-1000 m. in length, the up-dip traverses from zero to $X_u^{max} = H:\sin\varphi$, which corresponds with the outcrops distance from the shot-point.

The values of E_a and E_r are expressed with regard to those observed at the shot-point, where they are assumed to be equal 100.

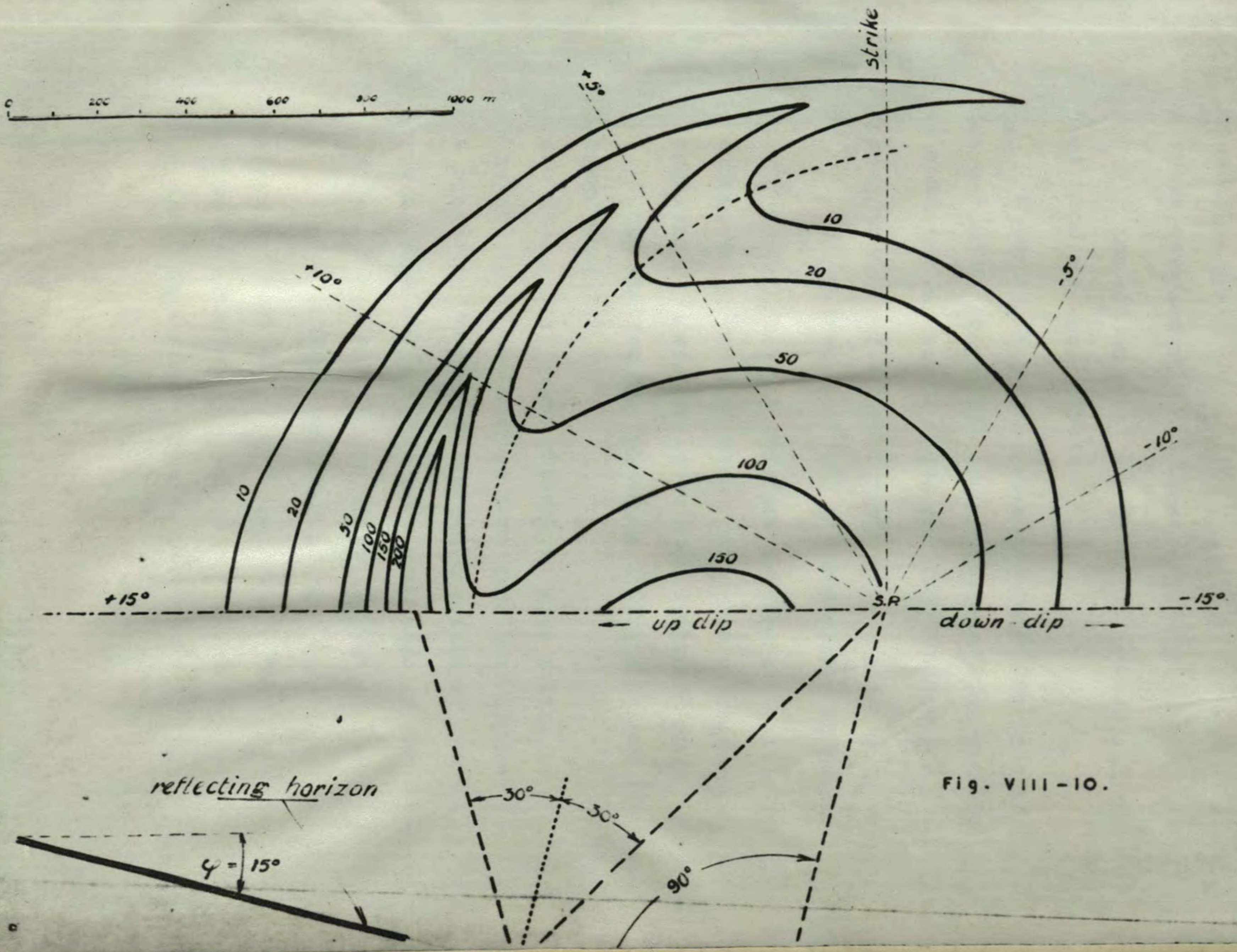

0
200
400
600
800
1000 m
strike
+5°
+10°
-5°
-10°
+15°
-15°
10
20
50
100
150
200
S.R
up dip
down dip
reflecting horizon
φ = 15°
30°
30°
90°

Fig. VIII-10.

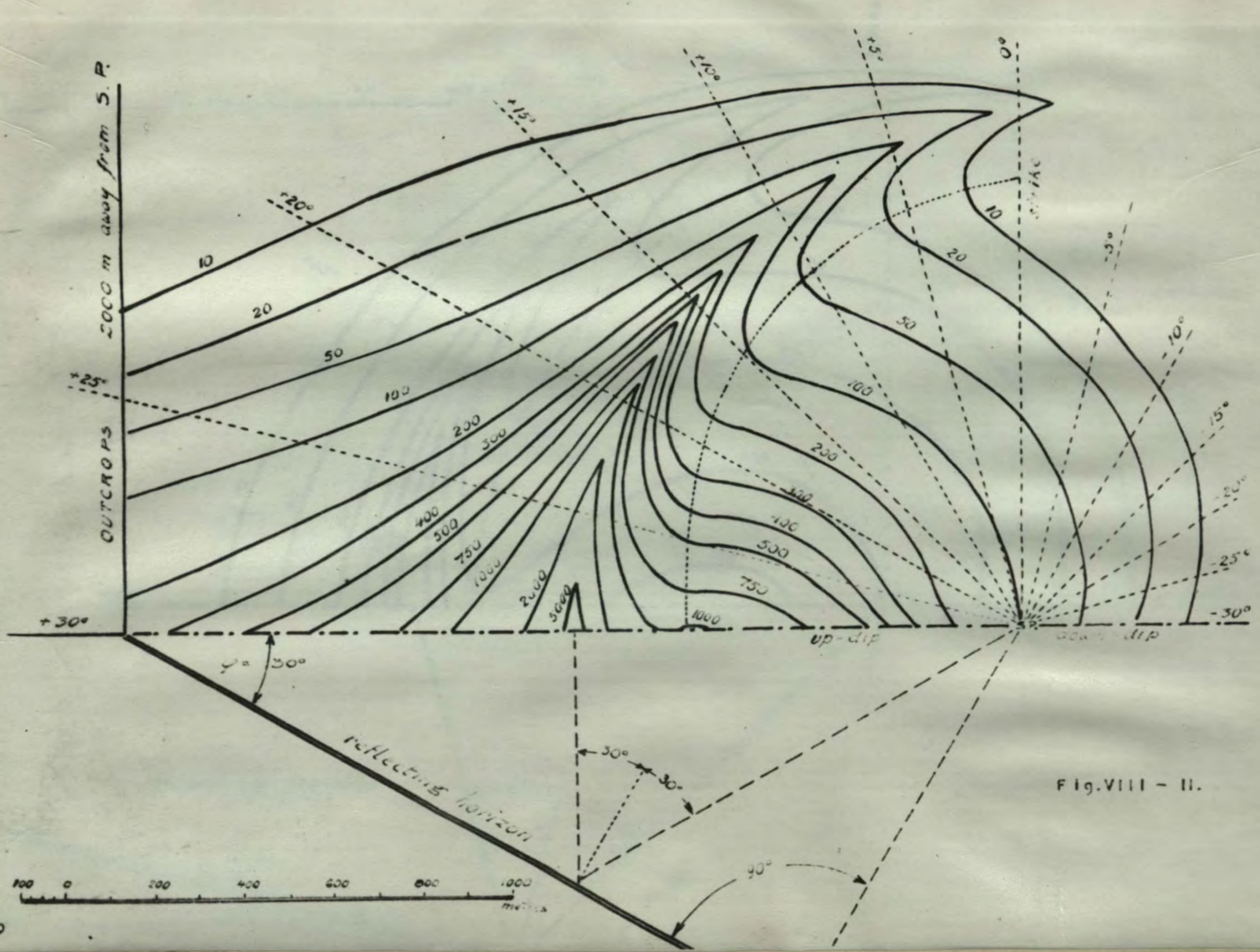

OUTCROPS 2000 m away from S.P.
+30°
+25°
+20°
+15°
+10°
+5°
0°
strike
-5°
-10°
-15°
-20°
-25°
-30°
10
20
50
100
200
300
400
500
750
1000
2000
3000
up-dip
down-dip
φ = 30°
reflecting horizon
30°
30°
90°
100
0
200
400
600
800
1000
metres

Fig. VIII - II.

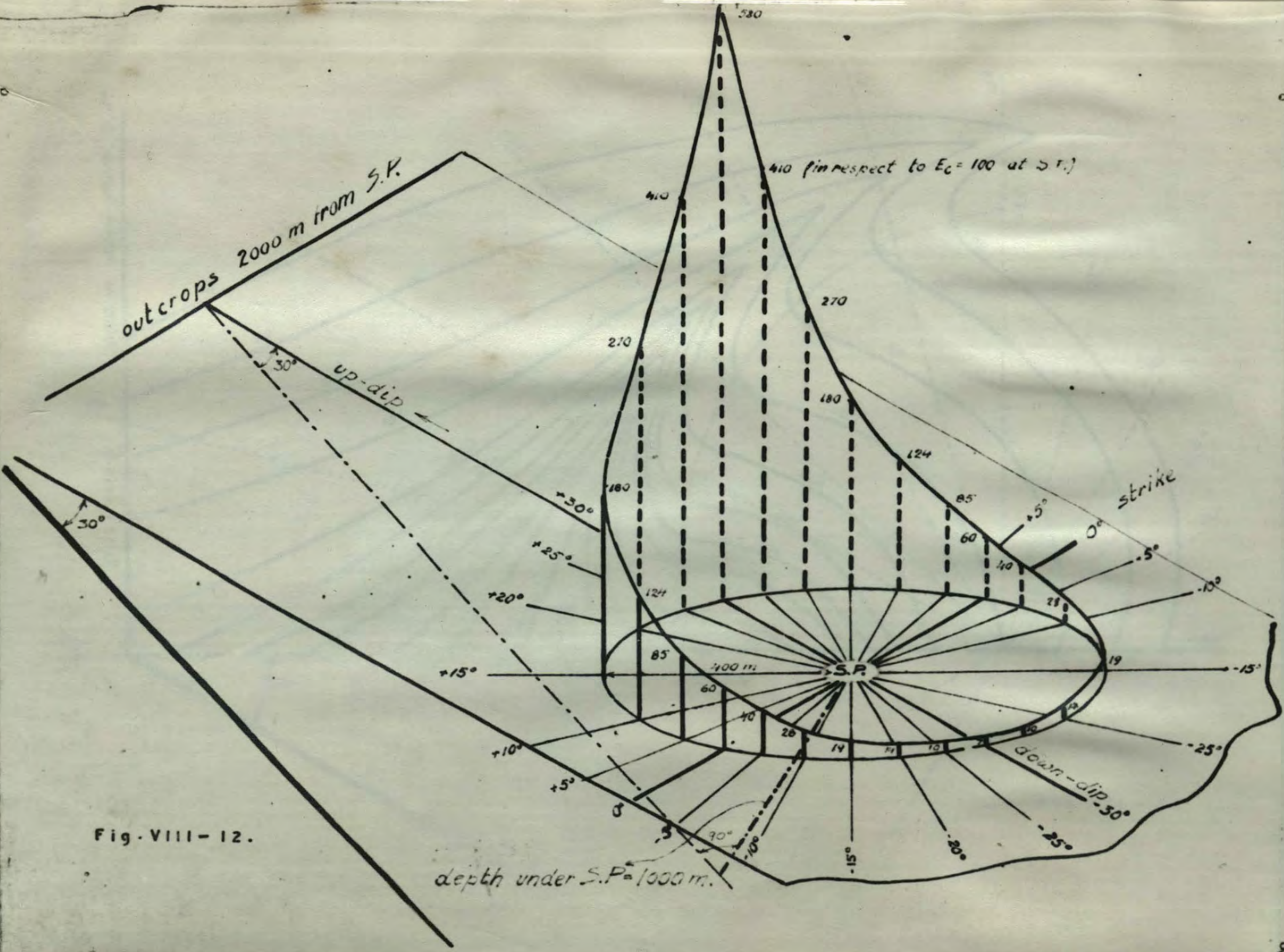

outcrops 2000 m from S.P.
up-dip
30°
30°
580
410 (in respect to E_c = 100 at S.P.)
410
270
270
210
180
180
124
124
85
85
60
60
40
40
28
28
14
11
10
19
400 m
S.P.
+30°
+25°
+20°
+15°
+10°
+5°
0°
-5
90°
-10°
-15°
-20°
-25°
-30°
down-dip
+5°
0°
-5°
-10°
-15°
-25°
strike
depth under S.P.= 1000 m.

Fig. VIII-12.

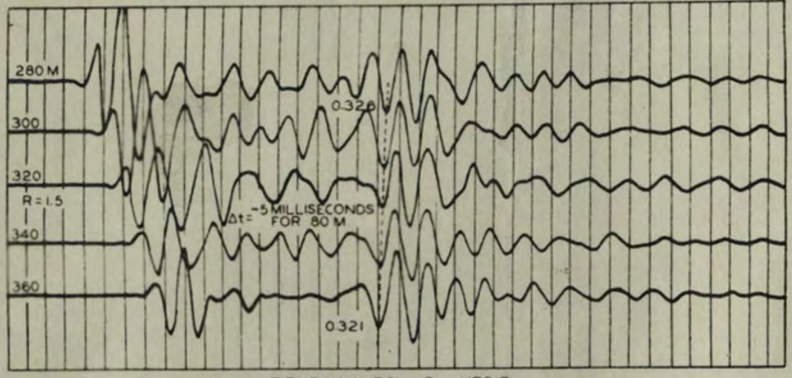
It is evident from these figures that for inclined beds the reflected energy received is no longer greatest at the S.P. as it is for a horizontal bed, but the maximum, before the angle of total incidence is reached, moves in the up-dip direction as the dip-angle increases.

Assuming the interface under consideration to have a constant dip towards the east equal to 15°, contours of equal energy distribution on the surface of the ground can be drawn as shown in fig. VIII - 10. The radii from the S.P. towards these contours give the distance at which the same amount of reflected energy is to be expected. The amount of energy registered at points on short down-dip traverses is equal to that registered on up-dip traverses at points several times more distant. Fig.VIII - 11 shows this distribution for a bed dipping at 30° towards the right.

If receiving stations are located around the S.P. for instance, on a circle of 400 m. radius, and if the amount of reflected energy is plotted on the verticals to the radii from the S.P. the developing line will show the amount of energy registered at points on a circle of radius 400 m. about the S.P. as centre; fig. VIII - 12 ~~and VIII - 13~~ shows this enveloping line for a bed inclined at 30°.

From these figures it is fairly evident how important for the amount of useful energy registered is the direction in which the traverse is made.

To conclude this paragraph, fig. VIII - 13. shows a



TRUSKAWIEC — S — UPDIP

Z = 1467'; Φ = −30° FOR V_a = 8,000' SEC^{-1}, Δt = − 4.9 MILLISECONDS FOR 80 M.

Fig. VIII - 13.

seismogram received in the Truskawiec area, when investigating the behaviour of the conglomerates. A sketch of the geological conditions there, was given in Chapter IV. p. 115. No good reflections were registered, but at one spread in up-dip shooting from 280 - 360 m. a very good shallow reflection was obtained, characterised by a verystrong influx of the reflected energy, stronger than the direct wave which followed the first arrivals. Registering this reflection in an area where the coefficient of reflection is relative~~l~~ly small (the overburden consists of a Salt Formation, the velocity of which was almost equal to that of the conglomerates, altho' it can be assumed that its density was lower than that of the conglomerates) is a typical example of the success of finding by trial the most favourable position along the up-dip traverse, where the reflected energy was the largest. It has to be noted, that neither at a nearer spread nor at a spread further away could this reflection be freed from the non-useful energy.

Other factors listed on p. 232. which can be controlled by the observer, will not be considered in this chapter, since no records are available; lacking these, the writer would be confined to a description only; although as a matter of fact this would be backed by his own observations as well as by a considerable number of publications which have appeared lately in "Geophysics" and other papers.

Nevertheless it would occupy much space and, to a certain extent, might be a repetition of published articles.

Several examples concerning these factors, i.e., the size of the charge, the depth of the shot-hole, the location conditions of the geophones, will be given in later chapters when dealing with the methods of the field work.

REFERENCES

Ref: VIII - 1 R.Beers, "Resolution Control in Seismic Survey". Geoph. 1941. Vol. VI. N. 1.

Ref: VIII - 2 G.Stewart and R. Lindsay, "Acoustics", 1930.

Ref: VIII - 3 M. Muskat "The reflection of longitudinal Wave Pulses from Plane Parallel Plates", Geophysics 1938. Vol. VII. No.3.

[redacted]

Ph.D. THESIS — G. J. [illegible]