REPORT
ON
SEISMIC PROSPECTING ON WESTERN TAIWAN
REPUBLIC OF CHINA

MARCH 1969

GOVERNMENT OF JAPAN

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国際協力事業団

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PREFACE

The Government of Japan, in response to the request of the Republic of China, had decided to undertake a mineral resources survey for the western area of the Taiwan Province and entrusted the execution of this task to the Overseas Technical Cooperation Agency.

The chief objective of the survey is to carry out geological surveys in the northern, central and southern areas with seismic refraction traverses along four traverse lines, two in the northern area, one in the central area and one in the southern area, covering a total distance of approximately 154km and to undertake soil investigations along these traverses lines.

Also included in the project are the analysis of the survey result to be performed in Japan and the preparation of a report on geological structure of the said area.

The survey team, comprising nine members and headed by Mr. Junji Suyama, Chief, Technical Development Section, Physical Exploration Department, Geological Survey Institute, Industrial Science and Technology Agency, Ministry of International Trade and Industry, remained in the Republic of China for 71 days from June 3 to August 12, 1968, carrying out field surveys. Upon returning to Japan the team continued their effort for the analysis of the survey results and the report of the survey has just been completed.

It is my sincere desire that the report thus prepared will contribute to the promotion of development of mineral resources in Taiwan and to the growth of economies in the Republic of China and at the same time to further promote friendship and good-will between the two countries.

Finally, I would like to take this opportunity to express my sincere appreciation and gratitude to the Government of the Republic of China and their officials for the full cooperation and support extended to the team in the course of this survey.

March 1969

S. Shibusawa

Shinichi Shibusawa
Director General
Overseas Technical Cooperation Agency

CONTENTS

I Introduction

I Introduction

1 - 1 Background

In Taiwan Province, Republic of China, the production of petroleum and natural gas is becoming increasingly important because of the rise in energy demand caused by the rapid economic growth. Oil and gas have been the object of prospecting during the last hundred years since the discovery of oil seepage at the producing area of Miaoli in 1861, it has become increasingly active since the establishment of Taiwan Petroleum Exploration Division of Chinese Petroleum Corporation in 1964. The production increased notably after the discovery of deep producing strata at Well No. 38, Chinshui in 1958 and the discovery in Well No. 1, Tienchenshan of the strata correlated to strata No. 13, Chinshui in 1962. During 1967, 11.7% of the consumption was supplied by the production within Taiwan. Prospecting is actively pursued with the objective of increasing production. Geological and geophysical prospecting is being carried out for the whole western Taiwan area including the Taiwan Straits, with drilling as deep as 6,000 m. Some basic survey projects are planned with the purpose of the investigation of the oil productivity, of obtaining basic geological information for effective deep drilling, and of clarifying the deep geologic structure including the basement of the sedimentary basins. These projects were discussed at the Fourth Session of the Committee for Co-ordination of Joint Prospecting for Mineral Resources in Asian Offshore Areas (CCOP) which was held in Taipei in 1967. At that meeting, refraction seismic survey on land area of western Taiwan was proposed as one of these projects. The Japanese Government offered to undertake this project in response to the request from the Government of the Republic of China, and the project was confirmed by a note of the Japanese Government dated February 8, 1968 and that of the Chinese Government dated April 15, 1968.

The Japanese Government assigned the Overseas Technical Cooperation Agency, to implement the project. The Agency organized a Mineral Resources Survey Team for Offshore Area of China and dispatched it to the Republic of China.

The survey was planned for northern, central and southern areas of western Taiwan, with two seismic refraction traverses in northern area and one each for central and southern parts. The total length of traverses amounted to 160 km, and geological survey of the vicinity was also planned.

The duration of the survey was 68 days from June 3 to August 9, 1968, of which 48 days were spent for seismic survey, 30 for geological survey and a member of the team was dispatched to Taiwan for 20 days before and after the survey for preparations and withdrawal.

Also the present work was proposed as a cooperative project of the two countries, and 33 scientists and technicians of the Chinese Pretroleum Corporation joined the team together with nine Japanese members, and the necessary personnel and material for the work such as many workers, vehicles, explosives and other expendable items were furnished by the Chinese Government.

The analysis of the survey results were done in Japan, but Mr. Hsiao, Chief, Seismic Section, Geologic Department Taiwan Exploration Division, C. P. C. joined the interpretation work and also the preparation of the report.

The survey team is greatly indebted to the unfailing support and the most active and warm cooperation from the Chinese members of the team, without these assistance the survey would not have been possible, the Japanese members hereby express their sincere gratitude.

1 - 2 Organization of the Japanese team

Leader:	Junji Suyama	Geological Survey of Japan
	Shigetoshi Kurihara	Ube Kosan Co., Ltd.
	Hirosuke Obayashi	" "
	Seikichi Kamata	Geological Survey of Japan
	Eiji Inoue	" "
	Akira Aribe	Ube Kosan Co., Ltd.
	Nobuo Ito	" "
	Shinya Masuda	Trade and Development Bureau, Ministry of International Trade and Industry
	Morimasa Hamano	Ube Kosan Co., Ltd.

The following Chinese technical personnel of CPC joined the team and cooperated during the function.

Messrs. Hsiao PaO Tsung, Chen Fui Shiang, Huang Chin, Yen Tian Hai, Chiang Hsin Chun and 28 men from Geologic Department, CPC, for geophysical work; and Hsu, of Geologic Department, CPC, for geological survey;

Yung Fang and members of the survey team for topographic survey; Lin Wen Hui and members of drilling team for drilling;

1 - 3 Objective of the survey and surveyed area

The surveyed area is bounded to the east by the Central Ranges which extend in north-south direction and to the west by the Taiwan Straits. The area consists of foothills, tablelands, and coastal plains where Neogene Tertiary formations are developed, and the productive areas of oil and natural gas are all included in this area. The foothills consist of hills of 200 - 1000 m in height (above sea-level) at the western side of the Central Ranges and all the traverse lines pass through a part of this area.

Traverse Line 2 extends in north-south direction through the tablelands developed between the foothills and the north-western coast of Taiwan with the total length of 33. 7 km. It runs in N. N. W. - S. S. E. direction from 2 km east-northeast of Kuanyin through west of Yangmei to a point 5 km south of Kuanhsi. This traverse line was selected for determining the depth variation and lithelogy of the Miocene basement. At near the northern end of the traverse there is an area called Kuanyin Shelf where the basement is considered to be shallow.

Traversa Line 1 extends parallel to the coast from a point approximately 5. 5 km southeast of Hsinchu in N. E. -S. W. direction to about 2. 5 km east of Yuanli with the total length of 42. 7 km. Most of the traverse is in the foothill areas. There is Tienchenshan-Tunghsiao Anticline near the traverse which is known for natural gas production, and there are many data from gravimetric and reflection seismic surveys and also from deep wells. Thus the geology is fairly well known to the depth of 5, 000 m. This traverse was selected for the purpose of obtaining information on the depth variation of the basement which will serve as basic data for the future exploration of Taiwan Straits and also for correlating the seismic wave velocity with the geologic strata using the existing data.

Traverse Line 3 runs from a point approximately 4 km west of Wufeng in southern Taichung Basin extending in N. E. -S. W. direction across Pakuanshan Hills, and Hsilo-Chi reaching south of Hsilo with the total of 45. 1 km. This is from the center to the margin of the sedimentary basin. Peikang Shelf where the Mesozoic basement is confirmed is located to the south of the traverse and thus the basement can be located with certainty. This profile was selected for the purpose of obtaining information on the manner of subsidence of the basement and also the form of the Pakuanshan Anticline in the deeper parts.

Traverse Line 4 extends from 5 km N. N. W. of Chishan across the foothills, pass approximately 1 km north of Kuanmiao and into the coastal plains with the total length of 32. 2 km. It intersects at right angles the Chingchou Anticline, Tainan Anticline and other major structures. Drilling at the axial parts of the above anticlines shows that mudstone is distributed to depths of 4, 000 m, and the basement has not yet been reached. The traverse was selected in order to investigate the thickness of these abnormally thick mudstone formation and the structure under it.

II Topography and Geology

II Topography and Geology

2 - 1 General outline

Taiwan is an island of 385 km north-south, 143 km east-west with an area of 35, 960 km^2. It is located at the eastern margin of the continental shelf extending from continental China and separated by the Taiwan Straits with water depth of 50 - 100 m.

Taiwan is located in the arc folding zone of the Western Pacific Orogenic Belt, lies at the intersection of between the Ryukyu Island Arc and the Philippine Island Arc. Thus the geology shows complex folded structure.

2 - 1 - 1 Topography (Fig. 1)

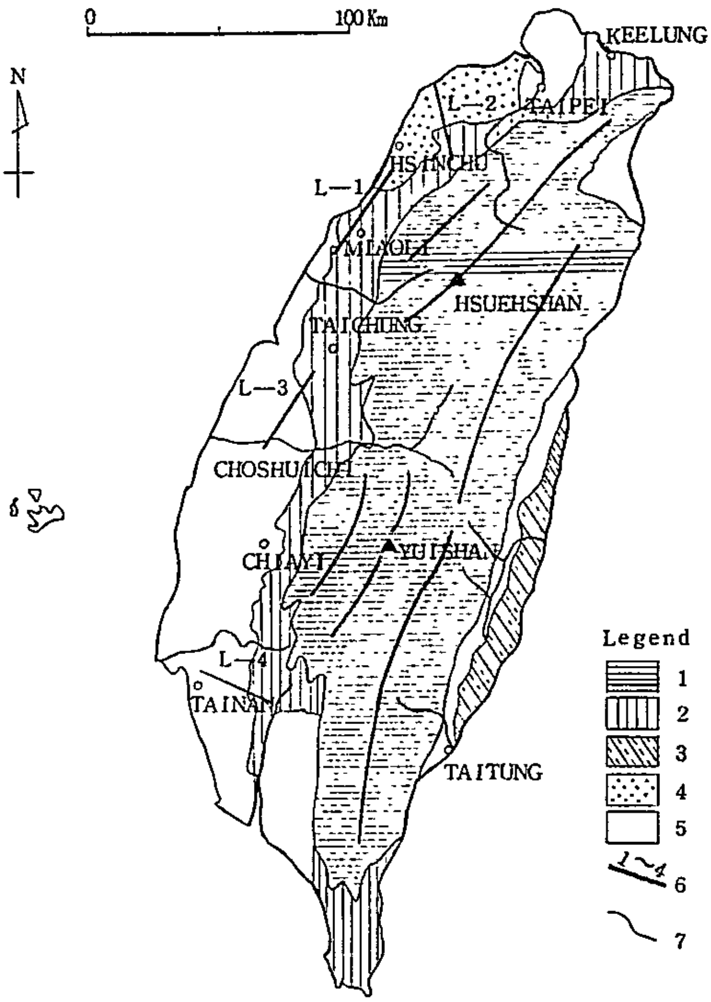
In central Taiwan, there are high precipitous folded ranges extending in north-south direction. These ranges divide the island to the east and west. To the east of these ranges, there are very small flat areas, and there is a Coast Range which runs parallel to the coast line between Mualien and Taitung, and shows steep coast line. On the other hand, the western side of the ranges consists of relatively gentle foothills and broad coastal plains are distributed to the southwest.

Figure 1 shows the general physiographic division of Taiwan revised from the map prepared by Ho and Lee.

The Central Ranges consists of Central Range, Hsuehshan, Yuishan, Alishan, Ranges which extend parallel to each other in north-south direction. High peaks in the order of 3000 m above sea-level with the highest Yuishan (3, 997 m above sea-level) form these ranges and topography is very steep. These ranges are formed mainly of pre-Tertiary metamorphic rocks, Paleozoic and Mesozoic strata, and intensely folded Paleogene formations. These form the core of the geologic structure of Taiwan.

The foothill region to the west of the Central Ranges is the important area for oil and natural gas production in Taiwan. This region consists of mountains and hills with altitude of 200 - 1, 000 m, and most of them extend parallel to the Central Ranges. The four traverse lines of the present seismic survey are either all in this region or at least a part extends through the region.

Fig. 1 Physiographic Divisions of TAIWAN



1 : Central Ranges 2 : Foothills 3 : Eastern Costal Range
4 : Tablelands 5 : Coastal Plain 6 : Traverse Lines 7 : Ranges

The tablelands in the vicinity of Taoyuan in northwest Taiwan have relatively flat topography with altitude of 200 - 300 m and gradually becomes lower to the northeast. The geology consists of late Pleistocene laterite and gravel. The area is divided into three divisions of Linkou, Taoyuan, and Chunghi by the height of the terrace surface. Also there are many marshes in the region.

The coastal plain of southwest Taiwan is distributed between the foothills and Taiwan Straits, and the altitude is low in the range of 10 - 15 m.

The plains are covered by alluvium, and at present the area is growing toward the straits by the vast amount of material deposited by the rivers together with the rise of the land blocks. Traverse Line 3 extends through the plain from south of Changhu to Hsilo-Chi, and the western half of Traverse Line 4 runs through the coastal plain in the vicinity of Tainan.

The rivers in western Taiwan are generally steep and short with small estuaries. The largest river in this region is Hsilo-chi which flows westward. It flows from Yuishan with a total length of 186.4 km. The lower parts of the rivers are wide but shallow with thick deposits of coarse gravel because of the heavy tropical rain. This hinders the utilization of the rivers.

2 - 1 - 2 Geology (Attached map 1, Figure 2)

As outlined above, Taiwan is located at the intersection of Ryukyu Island Arc and Philippine Island Arc and Philippine Island Arc, and the geology shows complex folded structure. The past sedimentary process is also very complicated. The present distribution of geologic formations and the configuration of geologic structures clearly reflect the process which occurred repeatedly in geologic time; namely, the formation of geosyncline, development of geosyncline, orogenic uplift, and folding.

The geologic formations distributed in Taiwan are: metamorphic rocks which are said to be of Paleozoic to Mesozoic age such as crystalline schists, crystalline limestones, gneisses, hybrids, basic rocks and others; Paleogene geosyncline sediments such as mudstone, shale, sandstone, slate; Neogene Tertiary flysch sediments consisting of thick alternations of mudstone, shale, sandstone, and conclomerate; early Pleistocene molasse sediments; late Pleistocene terrace deposits; and effusive and intrusive igneous rocks emplaced by igneous activity throughout the Neogene Tertiary era. Generally, these rocks and strata are exposed in eastwest zonal distribution. The Tertiary system constitutes the most well developed strata, and the maximum thickness is more than 15,000 m. This is an evidence of the existence of a large geosyncline extending in northsouth direction throughout the Tertiary era in Taiwan, and it indicates that this geosyncline gradually moved westward later accompanied by oregeny. This is derived from the fact that younger formations are found to the west.

Structurally, Taiwan is controlled by the somewhat curved major lineations in N. - S., N. N. E. - S. S. W. direction. These structural lines tend to differ in their strike in northern Taiwan to N. E. - S. W. direction.

Meng (1968) presented an interesting view on this problem.

Fig. 2 Tectonic Divisions of TAIWAN

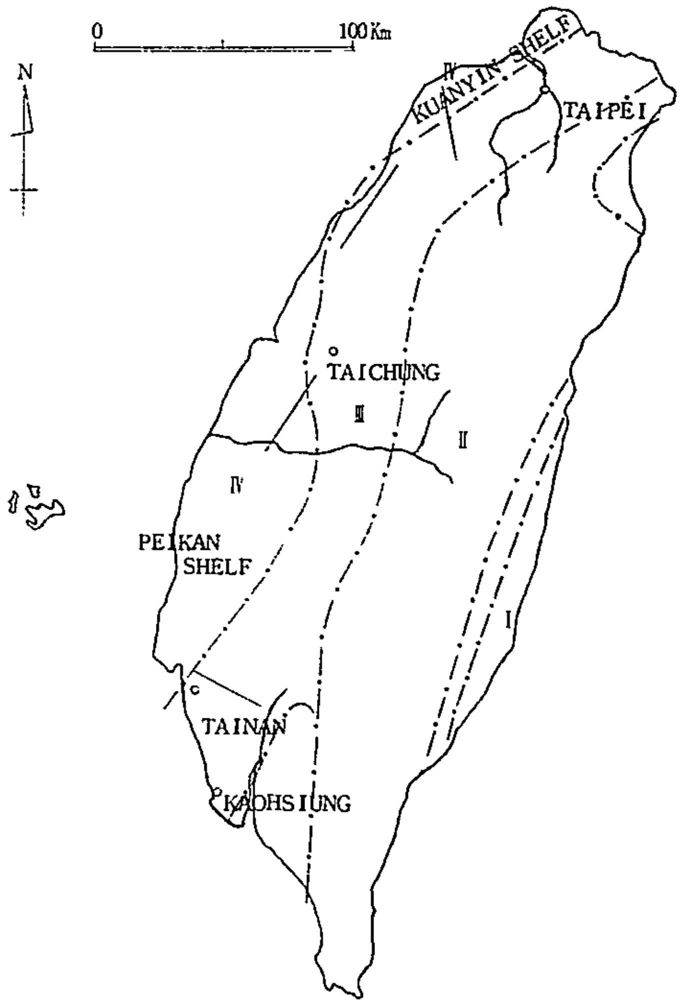


Figure 2 is a simplified version of tectonic division map prepared by Biq (1959) and Stach (1958). It can be seen from this figure that the geologic structure of Taiwan extends in northsouth direction, and it can be divided into zones arranged from east to west. Zone II constitutes the core of the geologic structure of Taiwan, and it consists of intensely folded and metamorphic zones of pre-Tertiary era. Zone I consists of folded Neogene Tertiary system, and forms the eastern wing of the Taiwan orogenic belt. Large rift valley extends in north-south direction between zones I and II. This rift valley lies between two large thrust faults and is believed to have been formed by compressional movements.

Zone III consists of intensely folded Neogene Tertiary system. The degree of folding decreases to the west. There is a large fault between zones II and III.

Zone IV consists of a shelf area gently sloping westward and folding is hardly observed. In this zone, there is an area extending from Peikang at west of Chayi to Penghu Islands, where Neogene basement is shallow. This area is called Peikang shelf or Peikang Massif. The post-Neogene sedimentary conditions differ greatly between the areas to the north and south of the shelf. As the shelf is the boundary, it is most interesting and important from structural and sedimentary viewpoints.

Zones III and IV comprise structures directly related to the present seismic survey, and the details will be reported in the next section.

2 - 1 - 2 - 1 Stratigraphy and geologic structure of western Taiwan.

The Neogene Tertiary areas of western Taiwan are the major producing areas of oil and gas and is directly related to the present seismic survey. These areas consist of foothills, tablelands, and coastal plains, of geologic formations younger than Neogene Tertiary; and includes structural zones III and IV.

(a) Stratigraphy and lithology

The geologic units distributed in western Taiwan are those of Neogene Tertiary and Quaternary system. Strata older than Paleogene Tertiary which form the basement are not exposed in this area.

The basement rocks are deeply buried in western Taiwan and the depth of these strata is hardly known. However, several structural drillings at Peikang west of Chayi confirmed a series of Mesozolic sedimentary rocks including Cretaceous ammonites and pyroclastic rocks at depths of more than 1,463 m. *

Neogene Tertiary systam

The Neogene Tertiary system consists of a series of thick geosynclinal sediments and the total thickness attains 7,000 m. Generally it is composed of alternation of mudstone and sandstone. As a whole, the sedimentary facies are those of shallow flysch type. In general, the strata are thin to the west and thick to the east.

* PK-2 well data.

Also the Peikang Shelf forms a boundary by which the lithology and the thickness of the strata differ greatly to the northern and southern sides. Generally, in the southern area, the grain size decreases and mudstone and shale occupies a larger part of the strata, also the strata becomes thick and the sedimentary facies show more marine environment than in the northern area.

There are some discrepancies and confusion concerning the nomenclature and stratigraphic division of Neogene Tertiary system and lower Pleistocene series among various areas and geologists. This is caused mainly by the lack of conspicuous unconformity within Neogene Tertiary strata, the lack of vertical lithological variation, and the existence of horizontal variation of lithology.

Age		Northern TAIWAN	North-Central TAIWAN	South-Central TAIWAN	Southern TAIWAN
Plio-Pleistocene		TOUKOSHAN F.: HUOYENSHAN Facies	TOUKOSHAN F.: HUOYENSHAN Facies		
		TOUKOSHAN F.: HSIANG-SHAN Facies	TOUKOSHAN F.: HSIANG-SHAN Facies	LIUSHUANG Formation	B Formation
				ERHCHUNGCHI Formation	A Formation
Pliocene		CHOLAN Formation	CHOLAN Formation	KANHSIALIAO Formation	Upper GUTINGKENG F.
				LIUCHUNGCHI Formation	Lower GUTINGKENG Formation
				YUNSHUICHI Formation	
				NIAOTSUI Formation	
		CHISHUI Shale	CHINSHUI Shale	CHONLUN Formation	
Miocene	Upper	KUEICHULIN Formation	KUEICHULIN F.: TAWO Siltstone	CHUTOUCHI Formation	KENGNEI Form (MUCHA F.)
				MAUPU Shale	
				AILIAOCHIAO F.	
			KUEICHULIN F.: SHIHLIUFEN Sh.	YENSHUIKENG Sh.	
			KUEICHULIN F.: KUANTAO-SHAN S.S.	TANGENSHAN S.S.	
		NANCHUANG Formation	SANGFUCHI S.S.	CHANG-CHIHKENG F.	
			HOPAI F.: TUNGKENG F.	HUNGHUATZU F.	
	Middle	NAN-KANG Formation: NAN-KANG S.S.	HOPAI F.: KUANYIN-SHAN S.S.	SHUILIKENG F. (HOSHE F.)	SHANMIN Formation
			TALU Shale		
		NAN-KANG Formation: TSOOHP F.	PEILIAO F.; PEILIAO S.S.		
		SHIHTI Formation	SHIHTI F.; CHU-HUANG-KENG F.	TAKENG Formation	
	Lower	TALIAO Formation	TALIAO F.; PILING Sh.	TSUKENG Formation	
		MUSHAN Formation	MUSHAN Formation		
		WUCHIHSHAN F.	WUCHIHSHAN F.		
Paleogene		WULAI Group	WULAI Group		

Table 1. Tentative Correlation chart of Western Taiwan Neogene Strata.

Table 1 shows the areal correlation and the major stratigraphic nomenclature in western Taiwan, the details of the correlation, however, is not necessarily definite at present.

The Neogene Tertiary system is subdivided into Miocene and Pliocene series.

Miocene series

The boundary between Miocene series and older strata are all fault contact throughout Taiwan at the surface and unconformity between the two cannot be observed. However, it is recognized by several drillings* at Peikang and Penghu Island that the relationship between the two are unconformity. It is inferred by these drilling that lower Miocene series do not exist at Peikang Shelf.

The Miocene series consist of three major sedimentary cycles, and are divided into lower, middle, and upper parts by these cycles. ** It is seen throughout the series that the thickness increases and grain size decreases from north to south and from west to east.

Lower Miocene series are developed in the northern part of western Taiwan and consist of Wuchinshan, Mushan, and Taliao formations. The lowermost Wuchihshan Formation is exposed only in the northern axial parts of anticlines and in areas along faults. In central west Taiwan, Wuchihshan Formation is not exposed, but it is confirmed by several oil and gas wells. At present, however, deep wells and drillings have not reached the bottom of the formation.

The lithology of the lower Miocene series which include the Wuchihshan Formation is alternation of siliceous sandstone intercalating coal, feldspathic sandstone and shale in the lower parts and gradually varies upward to alternation consisting mainly of pure marine mudstone and shale with some sandstone. In northern west Taiwan, basaltic conglomerate and tuffaceous sandstone are intercalated in the upper part of lower Miocene series. The grain size of the lower Miocene rocks decreases to the south. The existence of the series is not confirmed in southern Taiwan.

The middle Miocene series consist of Shihti and middle and lower Nankang formations in western Taiwan. Shinti Formation is coal bearing and it

* PK-2, PK-3, PC-1, SL-1

** The boundaries of these divisions vary somewhat by geologists. The writer followed that of Schreiber (1964).

gradually grades in the upper parts into marine Nankang Formation. In northern-central areas Shihti, Peiliao, and Talu formations are correlated to these formations. In central-southern west Taiwan, Taekeng, Shuilikeng, Shanmin formations all consisting of marine sandstone and shale alternation are more or less correlated to the middle Miocene series.

The upper Miocene series have thickness exceeding 1,000 m and cover areas larger than middle and lower Miocene formations. They are better developed in central and southern areas than in the north. In northern west Taiwan, the formations are from bottom upwards, shallow marine to littoral upper Nankang Formation, coal-bearing Nanchuang Formation, and Kueichulin Formation composed of alternation of marine sandstone and shale. In the northern to central areas, the Kueichulin Formation is subdivided into three units.

In southern areas, a series of formations between Shuilikeng Formation and Chutouchi Formation more or less corresponds to the upper middle Miocene series. These formations have relatively simple lithology namely, alternations of marine fine-medium sandstone, dark mudstone, and shale. These do not show distinct lithological characteristics as those in northern coal fields.

In southern area there is a thick alternation of dark gray mudstone and dark medium-fine sandstone called Kengnei Formation.

Pliocene series

The formations of the Pliocene series are generally distributed to the West of Miocene formations. They overlie the Miocene formations conformably, and are composed of alternations of marine mudstone and sandstone with thickness ranging from 2,000 - 3,000 m. The thickness of these formations increase and the grain size decreases southward as in the case of other Neogene Tertiary formations.

In central to northern areas, the series is divided into Chinoshui Shale Formation and thick Cholan Formation. In central to southern parts, the series is divided into five formations from Chunlun to Kanhsialiao formations by the conditions of the alternation, but since the vertical lithological variation is gradual and the lithology monotonous throughout the series, these divisions are somewhat artificial.

In southern areas the lower and upper Gutingkeng Formation with thickness exceeding 3,000 m is correlated to the Pliocene series in other areas.

This formation consists of shallow marine sediments composed mainly of massive and sandy mudstones with intercalated sandstone. The areas with rugged topography in the south are mainly the exposed areas of lower Gutingkeng Formation.

Plio-Pleistocene series

While the Neogene Tertiary system is composed of flysch sediments deposited during the subsidence of geosyncline, the formations deposited in late Pliocene to early Pleistocene are composed of malasse type lithology which were deposited during the period of transition of the geosyncline from subsidence to orogeny.

In northern Taiwan, this is called Toukoshan Formation, a delta deposit composed mainly of conglomerate more than 1,000 m thick with intercalations of mudstone and sandstone in the lower parts. Toukoshan Formation generally overlines Cholan Formation conformably, but small unconformities are observed locally. The conglomerates of this formation are best developed near Taichung, and mudstone and sandstone facies increase to the north and south.

In the central to southern parts of west Taiwan, Erhchungchi and Liushuang formations are correlated to Toukoshan Formation. These are shallow marine formations composed of alternation of sandstone and mudstone intercalating conglomerates.

The Plio-Pleiostocene series in southern Taiwan is A and B formations, and generally composed of loose sandstone and soft mudstone.

Upper Pleistocene series

The formations older than Plio-Pleistocene series are all folded and disturbed by reverse faults, while the upper Pleistocene formations are hardly folded and lie almost horizontally on the crests of foothills. These are terrace deposits composed mainly of laterite and gravel, are distributed widely from Taoyuan to Hsincho forming large flat areas.

Alluvium

Alluvium deposits form large coastal plains extending from Changhua in central west Taiwan to Kaohsiung and Pingtung in the south. Those distributed along the estuaries of rivers in Taichung basin, Hsinchu, and other areas consist of sand, gravel, and mud transported from the Central Ranges.

(b) Geologic structure

The Neogene Tertiary system of western Taiwan shows very complex structure controlled by faults and folds of N-S or N. N. E. -S. S. W. direction in the central and southern areas, and those of N. E. -S. W. direction in the north.

The folding structures are arranged in approximately east-west direction and the degree of folding decreases from east to west. The axial planes of the folds mostly strike north-south and dip eastward.

Many faults associated with fold structure or those intersecting structures are reverse faults or thrusts, and blocks are pushed up westward from the east. Those structural characteristics clearly indicate that the structural zone of the Central Ranges (Zone II) forms the core, and compressional forces were applied westward from the east after Neogene Tertiary deposition. It is inferred that the most intensive structural movement occurred during the earlier half of Pleistocene epoch.

Ho, Lee, and Stach (1956) subdivided west Taiwan structurally into inner foothills, outer foothills, coastal plains, and offshore zones.

The inner foothills is adjacent to the central zone (Zone II) and show complex geological structure the strata are intensely folded with well developed thrust faults. In this area, there are oil and gas-bearing anticlinal structures such as Chuyuangkeng, Chutonchi, and Tungtzechiao. However, the wings of these anticlines are steep and the structures are small, and together with the disturbance by faults, these are not necessarily suitable structures for oil and gas accumulation.

The outer foothills are located to the west of the inner foothills and the anticlinal structures of the area are wide and gentle. The displacement of faults become smaller. This is the most promising region for oil and gas production. Chinshui, Chutung, Niushan, and Tiechenshan oil and gas fields are located in this zone.

The coastal plains are covered by alluvium, but the buried Neogene Tertiary system has gently folded structures. Several oil and gas producing structures such as Tainan and Chungcho anticlines have been discovered under the plains.

Offshore areas include areas extending from Taiwan Straits to the western coast of Taiwan and a part of the Peikang Shelf. The Neogene Tertiary series are hardly folded and dips gently eastward. The basement rises to the west and is believed to continue to the continental China. There is also similar simple structure near Kuanyin in the northern coast, and the basement is expected to be shallow.

2 - 2 Geology in the vicinity of traverse lines

2 - 2 - 1 Geology in the vicinity of Traverse Line 2

(Sheet 2 Table 2)

Traverse Line 2 extends from a point 2 km east-northeast of Kuanyin through west of Yangmei to 5 km south of Kuanksi in N. N. W. -S. S. E. direction. To the north of Yangmei which is located in the middle of the traverse, is a large tableland covered by Pleiostocene laterite, foothills are distributed to south of Yangmei.

The area including the traverse line extends from Kuanyin Shelf in the north to geosynclinal basin in the south, and thus the lithology, thickness, degree of folding of the formation vary between the northern and southern parts.

The major tectonic lines controlling the area extends in E. -W. to N. E. - S. W. direction and the traverse line intersects them at high angles.

2 - 2 - 1 - 1 Topography

The topography of the area can be divided into the northern and southern parts with the boundry at Yangmei or near Shot Point II.

The area north of Yangmei consists of flat tableland covered by Pleistocene laterite. The altitude of the flat surface of the tableland is 200 m in the south and gradually decreases northward. There are numerous small swamps in the tablelands.

Hills of 200 - 400 m in height occupy the area south of Yangmei. These hills are very often dissected by rivers, and the height decreases to the north. Flat surfaces are often preserved on the top of these hills. These flat surfaces are covered by laterite, and are slightly curved conforming to the anticlinal structure of the Pliocene series. This fact is interesting in studying the structural movement after Pleistocene.

2 - 2 - 1 - 2 Geology

In the hills south of Yangmei, Plio-Pleistocene Toukoshan Formation and Pliocene Cholan and Chinshui formations are exposed. They are folded into anticlines and synclines with E-W to N. E. -S. W. striking axes. There are several reverse faults parallel to the fold axes and the formations have been pushed up westward. There is a large reverse fault immediately south of Shot Point III, and intensely folded Miocene formations are exposed in areas south of this fault. The tablelands north of Yangmei are covered by laterires and Toukeshan Formation is exposed in small scattered areas.

Age		Formation	Thikness m	Lithology	Distribution, outcrops
Recent		Alluvium		Gravel · sand · clay, sand dunes in beaches (unconformity)	Distributed in beaches and river estuaries
Pleistocene		Terrace deposits	2 ~ 5	Gravel · sand-clay (unconformity)	Distributed along river banks
		Lateritic deposits	10 ~ 30	Lateritic mud · gravel. (unconformity)	Widely distributed over tableland
Plio-Pleistocene		Toukoshan	+1200	Huayenshan facies: thick coarse - medium corglomerate with coarse sandstone intercalation. Hsiangshan facies: alternation of loose light gray medium- coarse sandstone and light bluish-green mudstone · sandy mudstone.	Distributed between Hukou & Tungkeng Anticlines Distributed widely in the foothills, exposed in lowlands in the north
Pliocene		Cholan	552** - 887***	Thick alternation of light gray muddy fine - medium sandstone & dark gray mudstone.	Exposed near the southern end of
		Chinshui shale	128** - 310***	Dark gray - dark blue sandy shale including foraminifera, vivalue fossils.	" "
Miocene	Upper	Kueichiulin Formation	313** ~ 615***	Upper: light gray - grayish white fine- medium massive sandstone intercalating shale, many coal.	Exposed south of shot point III, and buried underground in the area.
		Nanchuang	409** - 1140***	Lower: dark gray - gray fine- coarse sandstone intercalating dark gray shale. Upper: massive white sandstone intercating dark gray shale & coal seams.	" "
		Nankang	399** ~ 610*	Lower: light gray fine- medium sandstone & dark gray shale Kuanyinshan Sandstone: light gray- gray fine - medium sandstone Talu Shale: dark gray shale with white coarse sandstone in lower parts Peiliao Formation: massive luish gray - dark blue muddy fine- medium sandstone with dark gray shale intercalation	" "
	Middle	Shiht: Formation	244** ~ 500*	Grayish white fine - medium sandstone with dark gray shale, includes coal seams	" "
	Lower	Taliao Formation	308** - 587****	Alternation of dark gray sandy shale & gray - bluish gray fine - medium sandstone, intercalation of basaltic tuff & tuff breccia lenses.	" "
		Mushan	+75** ~ ±200	Alternation of white medium - coarse sanstone & dark gray shale, includes coal seams.	" "
		Wuchihshan Formation	751****	Alternation of white coarse sandstone & black - dark gray shale.	" "

* Tang, C.H. (1964): Subsurface geology and oil possibilities of the Taoyuan District, Chinese Petroleum Corporation. No. 3.

** KY-1 well.

*** YM-1 well.

**** Hsiao, P.T. (1950): Subsurface Plato from SY-1 on the Shantzechias structure, Taoyuan District, Symposium on petroleum geology of Taiwan, 10th Anniversary.

TABLE 2 Stratigraphy and lithofacies of strata in the area of Traverse Line 2.

Pleistocene terrace deposits are distributed on the banks of rivers, and alluvium is distributed in narrow areas of river estuaries and coastal plains.

This area is located between Kuanyin Shelf in the north and geosynclinal basin in the south, and there are considerable variation in lithology and thickness of formations as mentions above. Miocene formations are not exposed near the traverse line, but they have been confirmed underground at KY-1, YM-1, KT-1 wells. The thickness of the series increase to the south.

a) Stratigraphy and lithology

The stratigraphy and lithology of the formations exposed at the surface and those buried underground are listed in Table 2.

Wuchihshan Formation

This is the lowermost formation of the Miocene series, the observed boundaries between the Paleogene Tertiary strata are all fault contact. The existence of this formation is not confirmed in this area, but the formation of more than 751 m in thickness is observed at ST-1 well in Shantzechiao Anticline east of this area.

Mushan Formation

This is the lower coal-bearing formation at Taipei basin. The white sandstone is similar to that of Wuchishan Formation but the former is finer and less consolidated than the latter. It is confirmed underground by KY-1 well in the north but not by YM-1 well in the central area.

Taliao Formation

Basaltic tuff and tuff breccia are often intercalated in the lower parts. This is called the Kungkuan Tuff Formation. The thickness of this formation is 76 m at KY-1 well. But as it occurs in lense form, it may not necessary be distributed in the entire region.

Shihti Formation

This is the middle coal-bearing formation of Taipei Basin. The grayish white sandstone of this formation is the gas-producing layer at Chinshui and Chuhuangkang Gas fields.

Nankang Formation

This includes the Nankang and Tsouho formations at Taipei Basin. It is divided into Peiliao, Talu Shale, and Kuanyin Sandstone formations in ascending order. There is a white sandstone layer in the lower part of Talu Shale Formation which is the most important gas-producing layer at Chinshui and Tiechenshan Gas Fields. But in this area this white sandstone is almost non-existant. Generally the sandstones of Nankang Formation are graywacke and thus is not promising for gas-production.

Nanchuang Formation

The massive white sandstone of the formation often includes coal seams and is called upper coal-bearing formation at Taipei Basin. There was a gas seepage from this formation at R-1 well in this area.

Chinshui Shale Formation and Cholan Formation

These formations consist of thick Pliocene sediments and overlies the Miocene formations conformably. It is exposed with steep dip near Shot Point III.

Toukoshan Formation

This is of Plio-Pliocene epoch and overlies Cholan Formation conformably. Tang (1963) divided this formation into Yangmei Formation in the lower part and Tamaopu enoliths in the upper part. The former corresponds to Hsiangshan facies and the latter to Huayenshan facies. The lithology of the two generally grades into each other near the boundary, but small unconformities are observed locally.

Lateritic deposits

Laterite covers Toukoshan unconformably. It can be divided into two groups by the altitude of the flat surface. The first group forms large tablelands in the north and the altitude is between 20 and 200 m with gentle slope towards the coast. The other laterite covers the southern hills and is called Tientzuku Formation by Makiyama (1934). It forms flat surfaces with altitude between 200-400 m. It is gently folded along the anticlinal axis at Hukou Anticline.

Terrace and alluvium deposits

These are Pleistocene to Recent sediments, relationship of the two is unconformity, and they overlie laterite and lower formations unconformably. They are distributed in narrow areas along the river estuaries and the lowlands along the coast. Sand dunes are developed along the beaches near Kuanyin.

b) Geologic structure

The formations below Plio-Pleistocene series of this area are structurally controlled by folds and faults of B.-W. or N.E.-S.W. direction. The degree of folding decreases from south to north, and in areas north of Pingchen Anticline, the geologic structure is monoclinic gently dipping south with less than 10°.

(b - 1) Folds

Pingchen, Hulou, Tungkeng anticlines are continuous from north to south with synclines in between.

Pingchen Anticline

This is located between Kuanyin Shelf in the north and Hukou Anticline in the south. The dip of both wings is less than 15°. The anticlinal axis extend in E. -W. to E. N. E. -W. S. W. direction and pass 3-4 km north of Shot Point II. There is a gentle syncline with E. -W. strike at about 5 km north of the anticline, and in the area north of this syncline the formations have monoclinic structure with the strata becoming shallow toward the coast at loss than 10°.

Hukou Anticline

This is an asymmetrical fold of 15 km in length and 7 km in width with E. W. to E. N. E. -W. S. W. direction. The axis pass near Shot Point II. The southern limb dips 10°-35°, while the northern wing is steep at 50°-60° and is cut by Hukou Reverse Fault. The anticline is located where the thickness of the Niocene series changed from northern part to the southern parts, and the scale of the structure is favourable for oil and gas accumulation. Drilling is being carried out (HK-3 well) in this area.

Yangmei Anticline is located to the north, and this anticline connects the Yangmei and Pinzchen anticlines. There are two small faults of E. -W. and N. -S. strike immediately to the north.

Tungkeng Anticline

This anticline is located in the southern part of this area and the axis extends in east-west direction intersecting the traverse line at 5 km north of Shot Point III. The dip of the southern wing is less than 15°, while that of the northern limb is near 50°. Extensive Hsinpu Anticline lies between Tungkeng and Hukou anticlines. Hsinchu Fault extends east-west at 600-700 m north of the anticlinal axis.

From this anticline southward to Shot Point III, the structure is synclinal. The dip of the northern wing of the syncline is less than 15°, but that of the southern wing is more than 60° and is disturbed by reverse fault. The axis of the syncline runs in N. E. -S. W. direction intersecting the traverse line at approximately 3 km north of Shot Point III.

(b - 2) Faults

Almost all of the faults in this area are reverse faults, and most of them strike E.-W. to N.E.-S.W. The major ones are Hukou, Hsinchu faults and N.E.-S.W. fault at the southern end of the traverse line.

Hukou Fault

This fault extends through the northern limb of the Hukou Anticline in E.N.E.-W.S.W. direction. This is difficult to trace on the surface-because of the lateritic cover, but it can be traced easily by aerial photograph. Also it is confirmed by seismic reflection surveys. This fault is reverse fault dipping 60° southward and the vertical displacement is inferred to be about 200 m. The east-west trending Laowo Fault and north-south trending Yanghsiwo Fault extend between the Hakou Fault and Hukou Anticline axis. The former is a high angle fault dipping south with maximum displacement of 200 m, and the eastern block of the latter fault was displaced downward.

Hsinchu Fault

This is a reverse fault extending in E.-W. direction 600-700 m north of the Tungkang Anticline axis, and the vertical displacement is estimated to be 400-500 m. The dip is 50°-60° south.

N.E.-S.W. Fault at southern end of traverse

This is a large reverse fault passing near Shot Point III, and strongly disturbs the formation on both sides. The Miocene formations are exposed with repeated strong folds to the south of this fault. This is inferred to be the south-west extension of the Hsinchuang Fault at Shantzechiao Anticline area. The Hsinchuang Fault dips 40°-50° south-east and the displacement is very large.

2 - 2 - 1 - 3 Geological objective of Traverse Line 2

There are two major objectives for observation along Traverse line 2. One is to obtain data on the depth variation and the lithology of the Miocene basement formations. The other is to determine the underground geological structure of Hukou, Tungkang, and Pinchen anticlines.

(1) The northern area in the vicinity of Kuanyin is called the Kuanyin Shelf where the basement is shallow. This has been confirmed by various geophsical surveys and KY-1 well. It seems that KY-1 was drilled where the Miocene series is most shallow. The Miocene formations observed in KY-1 are thinner than those observed in any area except at Peikang Shelf and they become thicker to the east, west, south, and northeast. Tan (1963) estimates the depth of the basement at KY-1 to be abound 4,000 m. It becomes deeper in the above directions. The results of reflection seismic survey show that

the dip of the middle Miocene series from Kuanyin Shelf to the southern geosynclinal basin is less than 10°. It is believed, however, that where the middle Miocene series becomes thicker toward south, the dip of the lower Miocene and the basement surface naturally will be steeper than the above.

The distribution of the Bouguer anomally contours which are at equal distances between Kuanyin and Yangmei, abruptly changes between Yangmei and Kuanhsi. This is believed to be the reflection of the nearly constant dip of the basement in the area between Kuanyin and Yangmei abruptly becomes deeper to the south of Yangmei. This change of the basement depth cannot be unrelated to the variation of the formation thickness and lithology of the Miocene series, and the movement and accumulation of oil and gas occurs more often in these areas with these changes. Therefore, if these changes can be confirmed by seismic survey on Traverse Line 2, it will be a great contribution to oil and gas prospecting.

Also if the basement at Kuanyin Shelf consists of Mesozoic formations like that at Peikang Shelf, the Paleogene Tertiary strata must thin out northward in an area included in this traverse. In such an area, there are possibilities of the existence of stratigraphic traps of oil and gas in the Paleogene Tertiary formations.

(2) Hukou Anticline is most promising among Pingchen, Hukou and Tungkeng anticlines for oil and gas production. This anticline is situated in an area where the thickness and lithology of the Miocene series, and the depth of the basement change. This is favourable condition for stratigraphic trap as mentioned before, and the anticline itself has suitable shape and size for oil and gas accumulation. In the northern limb, however, there are Hukou and Laowo reverse faults inclining southward and there is a possibility of their disturbing the structure in the deeper parts. Therefore, it is of vital importance to know the structure in deeper parts, and the dip of the faults. The same applies to Tungkeng Anticline and Hsinchu Fault.

Faults large enough to disrupt the structure of Pingchen Anticline have not been found. There is a possibility that the position of the anticlinal axis may differ somewhat between the surface and the deeper parts. This is caused by the variation of the thickness of the Miocene series. It is necessary to know the position of the crest of the anticline in the deeper parts for the determination of future drilling points.

2 - 2 - 2 Geology in the vicinity of Traverse Line 1

(Sheet 3, Table 3)

Traverse Line 1 extends parallel to the coast from a point about 5. 5 km south-west of Hsinchu City to about 2. 5 km east of Yuanli. The area including this traverse has gently folded structures and gas-producing Tiechenshan-Tunghsiao anticlines are located in the area. The traverse is parallel to the axis of Tunghsiao Anticline extending in E. E. -S. W. direction.

2 - 2 - 2 - 1 Topography

Most of this area is occupied by hills, and flat plains are distributed in small areas near the mouth of Chungkang-Chi, estuary of Houlung-Chi in Miaoli Basin and other parts. The area is divided into three regions of south of Houlung-Chi, between Houlang-Chi and Chungkang-Chi and north of Chungkan-Chi. Area south of Houlung-Chi consists of hills and Miaoli Basin. At the southern end of this area, Muorenshan stands 602 m high, and from this mountain lower hills continue north-westward to the coast. The hills extend in north-south direction and the topography is gentle. The height of the hills ranges from 150-200 m and becomes lower towards the coast.

Miaoli Basin is situated to the east of Muorenshan hills, and is covered by alluvium transported by the meandering Houlung-Chi.

The area between Houlung-Chi and Chungkung-Chi consists of low hills of less than 112 m in height and alluvial plains along the coast. Sand dunes are developed from the coast to the west of the hills.

The area north of Chungkung-Chi is composed of fairly well developed plain, Hsinchu lowlands and low hills. The height of the hills is less than 100 m.

2 - 2 - 2 - 2 Geology

The Plio-Pleistocene formations which form the hills are gently folded with the fold axes trending N. -S. to N. E. -S. W. The laterite and terrace deposits of the uppermost Pleistocene are distributed in flat surfaces along the river banks, on the tops and sides of the hills. The flat plains are covered by alluvium deposits.

Only the formations younger than the upper Pliocene series are exposed in this area, but a series of thick strata from lower Miocene to Pliocene exist underground.

The traverse line extends almost parallel to the anticlinal axis at the surface.

Age		Formation	Thickness m	Lithology	Distribution . outcrops
Recent		Alluvium	15	Sand · gravel (unconformity)	Northern estuary of Chung kangchi, estuary of Houlung-chi, coastal plains.
Pleistocene		Terrace deposits		Upper: reddish brown - dark yellowish brown mud. Lower: gravel (unconformity)	Foothill slopes, estuaries of rivers.
		Lateritic deposits		Red lateric clay (unconformity)	Near Paishatun, foothills south of Miaoli
Plio-Pleistocene		Toukoshan Formation	+848	Upper: thick conflomerate including boulders Lower: alternation of loose fine sandstone, bluish gray mudstone, sandy mudstone, many shell fossils.	Upper part in southern part of the area. Lower part in foothills of the area
Pliocene		Cholan Formation	1,054* ~ 1,214	Alternation of gray fine - medium sandstone and gray-dark gray mudstone, sandy mudstone	Exposed in exial parts of Tunghsiao, Tiechenshan Anticline, and in wide areas northeast of Miaoli
		Chinshui Shale	143* ~ 252	Bluish gray - dark gray shale · sandy shale· very fine sandstone, many foraminifera, shell fossils.	No exposure in this area
Miocene	Upper	Kueichiulin Formation	379* ~ 530	Siltstone: alternation of massive bluish gray muddy sandstone and sandy silt Shinliufen Shale: dark-gray shale, sandy shale Kuantaoshan Sandstone: gray-bluish gray muddy sandstone with dark gray shale. white sandstone intercalation.	No exposure in this area, but buried underground.
	Upper	Nanchuang	579* ~ 890	Shanhuchi Sanstone: white medium - coarse sandstone with shale · coal intercalation. Tungkeng Formation: bluish gray fine-medium sandstone with shale intercalation.	" "
	Upper / Middle	Nankang Formation	911* ~ 1,031	Kuanyinshan Sandstone: bluish gray muddy fine sandstone with developed bedding and dark gray intercalation Talu Shale: dark gray shale with muddy fine sandstone with fair amount of shale intercalation.	" "
	Middle	Shihti Formation	326** ~ 420	Alternation of grayish white sandstone and dark gray shale with thin coal seam intercalation.	" "
	Lower	Taliao Formation	360**	Bluish gray graywacke intercalation in dark gray-black shale	" "
	Lower	Mushan Formation	687***	Alternation of white medium - coarse sandstone and sandy shale with thin coal seam intercalation.	" "
	Lower	Wuchihshan Formation	+200***	Dark gray shale and grayish white sandstone	Confirmed only at TCS-8 well.

* CTH-5, CTH-4, PST-1, and other gas well data near Tiechenshan structure

** TCS-2, CT-1, SS-53 (: Stratigraphic correlation of subsurface formation in northwestern Taiwan, Chinese Petroleum Corporation No. 5)

*** TCS-8

TABLE 3 Stratigraphy and lithofacies of strata in the area of Traverse Line 1.

(a) Stratigraphy and lithology

The underground data from gas wells at Tiechenshan and Tunghsiao anticlines and south of Hsinchu together with those at Chuhuankeng anticline adjacent to this area, are compiled. The result is the stratigraphy and lithology of Table 3.

Wuchishan Formation

This is the lowermost Miocene formation. Only TCS-8 well reached this formation but the bottom of this formation is not confirmed.

Mushan Formation

Since the lithology of this formations is similar to that of Wuchihshan Formation, the boundary between the two formations is somewhat artificial. The sandstone of this formation is more or less finer grained than that of Wuchihshan.

Taliao Formation

This is also called Piling Shale Formation in this area.

Shihti Formation

This is a middle coal-bearing formation at Taipei Basin, but the coal seams are poorly developed in this area. At the Chuhuankeng Gas Field in the south-eastern part of this area, the white sandstone of this formation is the major gas bearing formation.

Nankang Formation

This is divided from lower up into Peiliao, Talu Shale, Kuanyinshan Sandstone formations. The white medium to finegrained sandstone of the lower Talu Formation is the only gas-producing layer in Tienchan Gas Field and is called TT-1 Zone. This sandstone is the thickest in this area at 120 m, while it thins to 50 m at Chinshui Gas Field, and is only 2 m in Chuhuankeng anticline in the south-east.

Nanchuang Formation

This is divided into Tungkeng and Shanhuchi Sandstone formations. The latter is a loosely consolidated orthoquartzite, and becomes gas-producing bed in many cases. Nanchuang Formation becomes thicker to the north.

Kueichiulin Formation

This is divided into Kuantaoshan Sandstone, Shinliufen Shale, silt formation in stratigraphically ascending order. The Kueichiulin Formation becomes thicker to the north and is 960 m at Chutung.

Chinshui Shale Form

This is of lower Pliocene series and conformably overlies Kueichiulin Formation. Lithology and thickness is quite similar to those of the eastern neiboring area.

Cholan Formation

The thickness increases to the north and east. It is 1520 m at Chinshui Gas Field, 1680 m at Chutung Gas Field. Only the uppermost part of this formation is exposed on the surface in this area.

Toukoshan Formation

This formation is widely exposed in this area. As the lithology between Cholan Formation varies gradually, the boundary between the two is somewhat artificial.

(b) Geologic structure

The major structural features of this area are gentle fold with N. E. -S. W. trend and E. -W. trending faults. One of the largest gas fields of Taiwan, Tienchenshan - Tunghsiao Anticline is located in the southern part of this area.

(b - 1) Folds

Tienchenshan - Tunghsiao Anticline

This anticline is located in the south of this area and the axis trends in N. E. -S. W. direction in S-form along the coast. This is divided into northern and southern parts by a small structural saddle at east of Yuanli. The northern part (Tunghsiao Anticline) is structurally 300 m higher at the surface than the southern part (Tienchenshan Anticline). However, the depth of TT-1 Zone which is the gas-producing layer of Talu Formation, the northern part is 140 m higher than the southern part.

The eastern wing of this anticline is composed of the lower strata of the Toukoshan Formation (Hsiangshan facies) whose dip is less than 10° east. At the axial parts, Cholan Formation is exposed to the east of Tunghsiao. The western wing of the anticline has gentle slope near the axis at less than 10°, but it increases away from the axis and dips more than 35° westward. The north-eastern end of this anticline is cut by Tungshiho Fault which trends east-west.

Semi-basin structure

The area between Tungshikwo Fault and Chungkang-Chi is structurally a semi-basin with N. N. E. -S. S. W. fold axis, the traverse line intersects the

Age		Formation	Thickness m	Lithology	Distribution . outcrops
Recent		Alluvium		Gravel . coarse sand (unconformity)	Coastal plains. . Taichung basin
Recent		Alluvial fan	10 ~ 30	Gravel . sand (unconformity)	Western foothills of Pakuanshan Hills.
Pleisto-cene		Terrace deposits	±10	Gravel in lower part, reddish brown - dark yellow brown clay in upper part (unconformity)	Eastern foothills of Pakuanshan Hills and crests of hills.
Pleisto-cene		Laterite	3 ~ 6	Red laterite, clay (unconformity)	Crests of Pakuanshan Hills
Plio - Pleis-tocene		Toukoshan Formation	+370	Upper: thick conglomerate with coarse sandstone and mudstone intercalation, oblique bedding. Lower: bluish gray - gray sandstone, include gravel.	Upper part exposed in Pakuanshan Hills with anticlinal structure. Lower part buried underground.
Pliocene		Cholan Formation	+1179**	Alternation of gray fine sandstone · dark gray shale · sandy shale · oblique bedding with ripple marks	Buried underground
Pliocene		Chinshui Shale	151* ~ 168	Dark gray - dark blue mudstone · sandy mudstone including many merine shell and foraminifera fossils.	" "
Miocene	Upper	Kueichulin	346* ~ 417	Upper: bluish gray muddy very fine sandstone . sandy mudstone. Middle: dark gray shale . sandy shale alternation Lower: gray · yellowish brown massive muddy fine sandstone	" "
Miocene	Upper	Nanchuang Formation	445* ~ 646	White sandstone · gray sandstone · dark gray shale alternation with two layers of coal seems	" "
Miocene	Upper / Middle	Nankang Formation (Shuilikeng Formation)	1, 137**	Upper: gray massive mica sandstone with shale intercalation (Kuanyinshan sandstone) Middle: massive shale (Talu Shale) Lower: sandstone · shale intercalation (Peiliao formation)	" "
Miocene	Middle	Shiti Formation (Takeng Formation)	349**	Light gray - gray fine sandstone · dark gray shale alternation. Glauconite muddy sandstone locally intercalated.	" "
Miocene	Lower	Taliao	360**	White fine sandstone · dark gray shale alternation. Intercalation of purplish red tuffaceous shale in middle part.	" "
Miocene	Lower	Mushan	687***	White medium - coarse sandstone · sandy shale alternation	" "
Miocene	Lower	Wuchihshan Formation	+78****	Dark gray shale and grayish white sandstone, lower limit unknown.	" "

* Tiechenshan Gas Field. TCS-1, TCS-2, TCS-3, TCS-6, TH-1, R-2.

** TCS-2 } Chiu, H. T. (1967): Stratigraphic correlation of subsurface formations in northwestern Taiwan, Chinese Petroleum Corporation. No. 5

*** TCS-8

**** Chinshui Gas Field CS-53

TABLE 4 Stratigraphy and lithofacies of strate in the northern half of Traverse Line 3.

synclinal axis at low angles. Near the axial parts where the traverse line runs, the lower part of the Toukoshan Formation is widely distributed with a very low dip of less than 8°. The strike of the strata near the axis is locally disturbed. The dip increases away from the axis and the eastern wing continues to the Chinshui Anticline in the east at 30-60° dip. Cholan Formation is widely distributed in the eastern wing.

The anticlinal structure north of Chungkang-Chi

There is an anticline with N. E. -S. W. trend to the north of Shot Point I in the northern part of Chungkang-Chi. The dip of the strata is gentle at less than 10°, and Cholan Formation is exposed in small areas in the axial part. This structure is inferred to be the northern extention of the Tienchenshan - Tunghsiao Anticline.

(b - 2) Faults

Tungshikwo Fault

This is a high angle reverse fault extending from Miaoli to Paishatun in E. -W. direction, and passes a point 5. 2 km south-east of Shot Point II. It intersects the northern part of Tiechenshan-Tunghsiao Anticline, the northern block displaced downward 120-150 m. By the drag of this fault, the strata on the northern side dips about 30° for a distance of several hundred meters from this fault.

Chungkang Fault

This is a high angle reverse fault extending from Chungkang and passing north of Toufen, and the displacement is estimated to be about 100 m.

Also a right lateral fault striking E. -W. is inferred along the southern bank of Chungkang-Chi from topography and aerial photographs.

2 - 2 - 2 - 3 Geological objective of Traverse Line 1

Traverse Line 1 extends north along the axis of Tien Tienchenshan - Tunghsiao Anticline which is one of the major gas structures, cuts through some faults and reaches southern Hsinchu sedimentary basin. There are many deep wells as well as many underground geological data of gravity, reflection seismic surveys in this area. Thus the geological conditions to 5, 000 m in depth are relatively known along this traverse compared to other areas of the present survey. Also since the traverse extends approximately parallel to the anticlinal and synclinal axes and the number of faults is small, the interpretation of the results will most probably be simpler and clearer than those of other areas. Thus it is expected that the correlation of seismic wave velocities and the rocks can be done with high accuracy from the results of the survey in this area. The results of the interpratation, therefore, will produce basic data necessary for the interpretation of the refraction seismic survey in other areas.

Schreiber reports that the area in the vicinity of Miaoli and Tienchen-shan - Tunghsiao Anticline was a small uplift of the basement during the deposition of Miocene series and that it was located between Hsinchu sedimentary basin and Taichu sedimentary basin in the south. Since the traverse extends through this small uplift and the Hsinchu sedimentary basin, it is suitable for obtaining data on the thickness variation of formations, basement depth, basement topography and others between both sedimentary areas. These data will be vital in understanding the mechanism of the movement and accumulation of gas and oil from the time of deposition. Also they will present important clues for the future exploration of oil and gas in the Taiwan Straits.

2 - 2 - 3 Geology in the vicinity of Traverse Line 3
(Sheet 4, Figure 3, 4, Table 4)

2 - 2 - 3 - 1 Topography

Traverse Line 3 extends from central Taichu Basin through Pakuanshan Hills, plain areas, Choushui-Chi and reaches south of Hsilo. The altitude of the area is less than 30 m with the exception of the northern Pakuanshan Hills.

Pakuanshan Hills are narrow range of hills elongated in north-south direction and the altitude is less than 287 m. Many small streams flowing east-west are developed on the eastern and western flanks of the hills.

Choushuichi flows westward in the plains in the southern part of the area. It has a shallow and wide river bed covered by coarse gravel. The width of the bed is about 2 km at the intersection of the traverse line.

2 - 2 - 3 - 2 Geology

The area of the traverse is located between the center of Neogene Tertiary sedimentary basin (Taichu Basin) and Peikang Shelf in the south. It is inferred that the Neogene Tertiary formations rapidly become thinner from north to south and finally thin out in this area. The traverse line intersects the north-south trending structure of the Neogene Tertiary formations obliquely.

Most of the surface in this area is covered by alluvial plains and Pleistocene and upper Plio-Pleistocene strata are exposed only at Pakuanshan Hills. Wells have not been drilled in this area. Therefore the stratigraphy and lithology below the Neogene Tertiary formations of this area can only be inferred from the well data in the northern and southern neiboring areas and the exposures in the hills in the eastern neiboring area.

(a) Stratigraphy and lithology

Since this area extends from the center to the margin of the sedimentary basin, distinct variation of stratigraphy and lithology between the northern and southern parts are expected. Thus the description of the stratigraphy and lithology will be done separately using material of the Tiechenshan Anticline for the northern part, and of Peikang well (PK-2) for the southern part.

(a - 1) Northern part of the traverse

The stratigraphy and lithology of the formations younger than Neogene Tertiary in the northern part is summarized in Table 4 from test well data of the Tienchenshan Anticline and the Tertiary and Quaternary series distributed in the neiboring areas.

The Neogene Tertiary formations confirmed in the eastern part of the area near Nantou are those younger than Toukeng Formation (Taliao Formation), and those older than Mushan Formation areas are not yet discovered.

Nankang Formation

This formation is divided into Peiliao, Talu Shale, and Kuanyinshan Sandstone formations at the Tienchenshan Anticline area. White coarse sandstone included in the Talu Shale Formation is the important gas-producing layer of the Tienchenshan Anticline.

Nanchung Formation

This is divided into Tungkeng and Shangfuchi Sandstone formations at Tienchenshan Anticline area.

Kueichulin Formation

This formation is 379 m thick at TCS-2 well of the Tienchenshan Anticline, but the exposure near Nantou is +600 m thick (Ho et al., 1956), and it becomes thicker southeastward.

Chinshui Shale and Cholan Formation

The thickness of the formations increases eastward and the variation of lithology is small.

Toukoshan Formation

The lower parts of this formation cannot be seen on the surface, but the upper parts are widely exposed at Pakuanshan Hills. Here, the thick conglomerate bed of the upper part forms a gentle anticline.

Strata higher than Pleistocene are laterite, tableland sediments, alluvial fan deposits, and alluvial deposits in ascending order, and their relationship is unconformity. They crop out in this area and the thicknesses are all less than 30 m.

(a - 2) Peikang Shelf area

The Peikang Shelf in the southern part of this traverse line is where the Miocene series becomes extremely thin and the basement rises to the shallower parts as mentioned previously.

The underground stratigraphy of the Peikang Shelf is shown in Figure 3. It consists of lower Cretaceous basement, middle Miocene Peikang Formation, Pliocene Cholan Formation, Pliocene-lower Pleistocene Toukoshan Formation, and Recent sediments in ascending order.

Basement

The rocks observed at PK-2 well are mainly hard dark gray shale and gray sandstone with conglomerate in the basement and andesitic pyroclastic rocks in the upper parts. Three species of ammonites, Cheloniceras aff. Orientale, Dufrenoyia, aff. justinae, D. aff. discoidalis occur in three horizons at 1,645 m, 1695.20 - 1,701.00 m, and 2,034.70 - 2,065.66 m in depth. These fossils are of Aptian - Neocomian of early Cretaceous age (Matsumoto et al., 1965). Thickness of the strata is 709 m (PK-2 well).

Middle Miocene series (Peikang Formation).

Correlation of several test wells at Peikang Shelf shows that there is a denuded surface between the bottom of the Peikang Formation and the lower Cretaceous system. PK-3 well data which is a type columnar section of this formation, shows that it consists mainly of dark gray shale and sandy shale with intercalation of thin gray muddy sandstone and limestone. The section of PK-2 well shows the same lithology with intercalation of Orbiteid limestone in the upper parts and shell limestone in the lower parts. Study of foraminifera by Huang (1963) shows that the upper part of this formation is correlated to Talu Formation of the Nankang Formation and the shell limestone of the lower part is correlated to formation of higher horizons than Taliao Formation. Therefore, lower Miocene formations are lacking in this area.

Fig. 3 Geologic Columnar Section of PK-2 Well

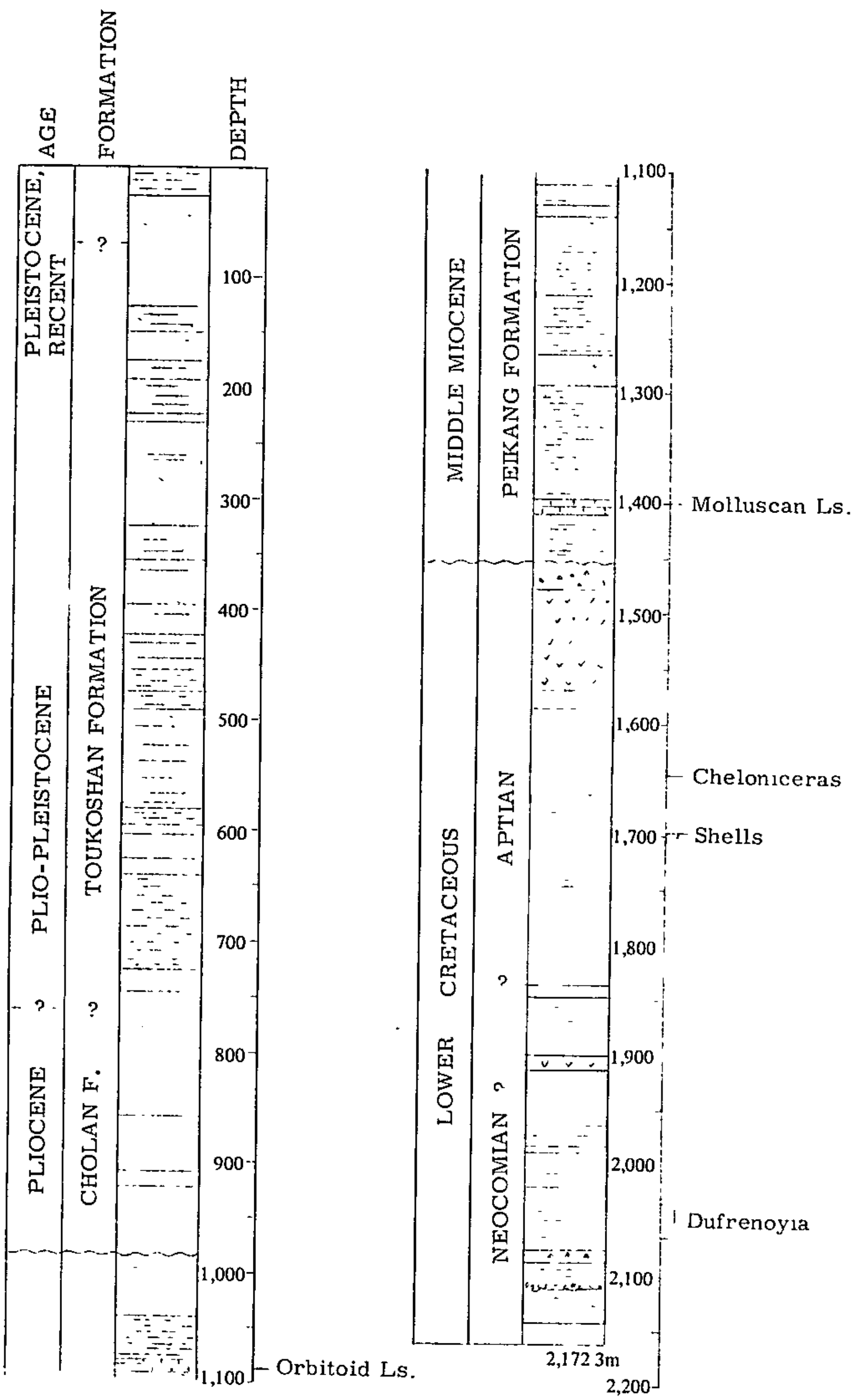
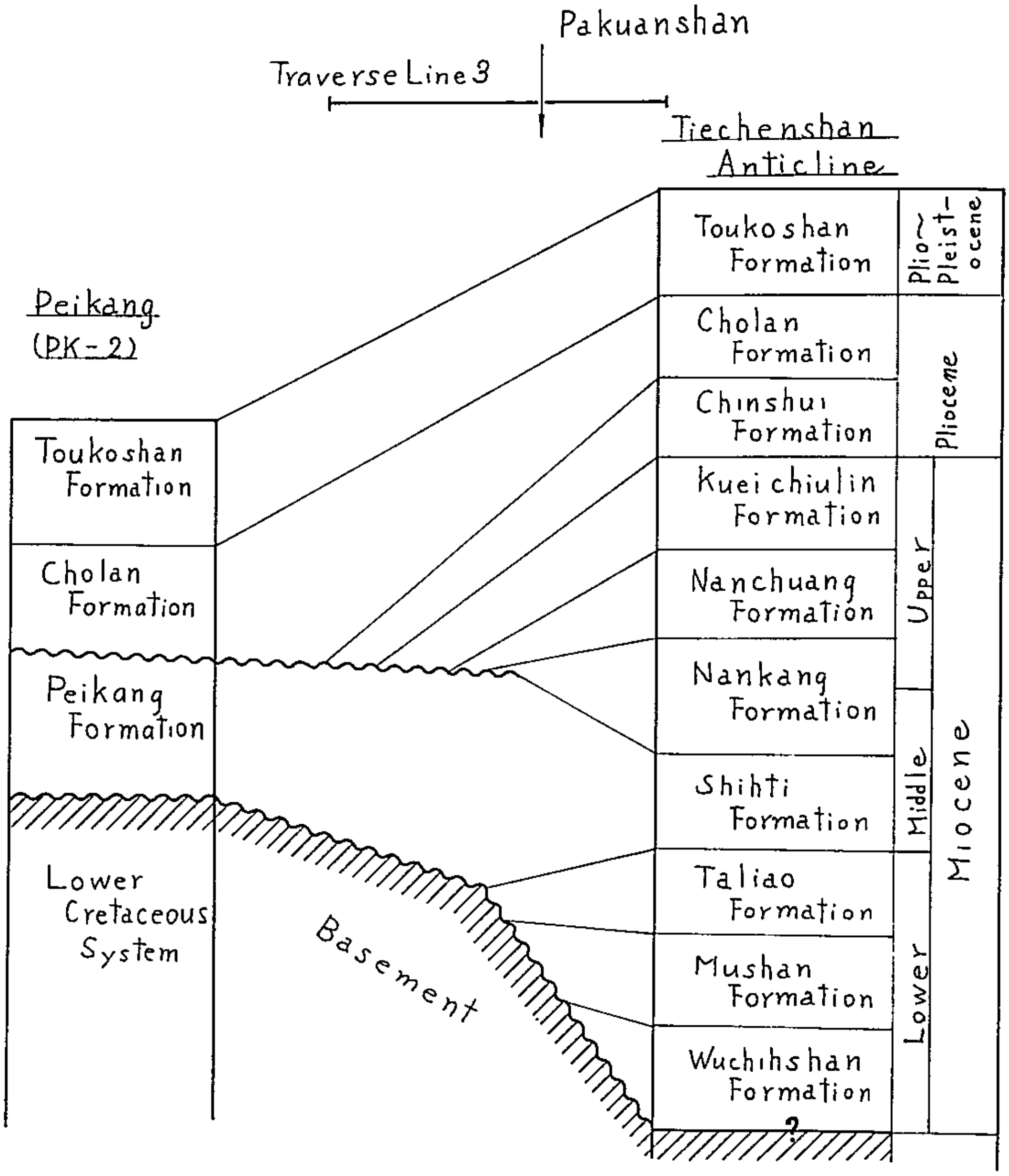


Fig. 4

Sun, S. C. (1965) : Geology and petroleum potentialities of the Chinshui-Yuanlin Area, Taiwan. Petr, Geol, Taiwan No. 4 P161-173 Plate II



Therefore, lower Miocene formations are lacking in this area. Thickness of Cholan Formation ranges from 444m* to 460m**.

This formation overlies Peikang Formation unconformably. Chinshui Shale Formation and upper Miocene series are lacking in this area. This formation consists mainly of gray muddy fine sandstone with shale intercalation. The lithological change between this and Toukoshan Formation is gradual and thus the boundary between the two is artificial, but here Chang's data (1963) is used. Thickness of the formation is about 280 m. ***

Toukoshan Formation

This formation consists of alternation of muddy sandstone, sandy mudstone, and mudstone. As can be seen in the columnar section of PK-2 well, Yenshan conglomerate facies is lacking in this area, and the lithology of PK-2 is believed to be the Hsiangshan facies of the lower Toukoshan Formation. The boundary between the Pleistocene and alluvium sediments are not clear. The thickness of the formation is 750 m. ****

(a - 3) Lithological and thickness variation in north-south sirection of Miocene and Pliocene series in the vicinity of the traverse

As mentioned in a - a and a - 2, the stratigraphy and lithology in the northern part of this area is similar to Tienchenshan Anticline area, and those of the southern part is similar to those of Peikang Shelf. It is inferred that the stratigraphy, lithology, thickness and basement depth change quite abruptly in north-south direction. Figure 4 is a schematic sketch of stratigraphic variation, based on the correlative cross section of the two areas by Sun (1965). It can be seen from this figure that the traverse runs through areas where the thickness variation is most distinctive. Sun's cross section (1965) shows that the basement steeply subsides to the north and the lower Miocene series is denuded or thins out southward near Pakuanshan. The upper Miocene series is also shown to thin out in this area. Formations stable in both northern and southern parts are those of the middle Miocene and Cholan or higher horizons. In other words, this is a geologically very interesting area where large sedimentary changes occurred.

* PK-3 well ** PK-2 well *** PK-2 well

**** From the mouth of the well to the upper limit of Cholan Formation

(b) Geologic structure

This area is covered by alluvial plains with the exception of Pakuanshan Hills, and thus it is not possible to observe the structure of the Neogene Tertiary system at the surface. However, the data from the regional survey including this area by gravimetric, reflection seismic and surface geological survey indicate that this area can be divided structurally into Taichu structural basin, Pakuanshan Anticline, and monoclinic structure between Peikang and Yuaulin.

Pakuanshan Anticline

Toukoshan Formation is exposed with a gentle anticlinal structure at the Pakuanshan Hills. The anticlinal axis passes through the crest of the mountain and extends in N. -S. direction parallel to the elongation of the hills. The dip of the eastern wing of the anticline is less than 10°, and that of the western wing less than 20°. This anticline extends in north - south direction in elongated S-shape, and the northern extension continues to the Tienchenshan Anticline through Tatushan Anticline. It is inferred that the southern extension centinues to the Neilin Anticline although it is cut by faults. Since Tienchenshan and Neilin anticlines have steeper western wing than the eastern flank, it is believed that the Pakuanshan Anticline has the same structure as the former two. Pan's (1967) underground structural map shows an anticlinal structure immediately east of Changhua and Yuanlin, this is the underground extension of the Pakuanshan Anticline. There is a saddle of the Pakuanshan Anticline axis where the traverse pass through the hills in the structural map.

Taichung basin structure

There is a structural basin in the Taichu Basin which is located to the east of the Pakuanshan Anticline according to the structural map, and the center of the structure is at Wufeng which is located east of Shot Point 1. The slope of the structure from the margin towards the center is fairly steep and is estimated to be about 25°.

Areas with monoclinic structure

The structure from the western flank of the Pakuanshan Anticline to the Peikang Shelf is monoclinic with the strata becoming shallower to the south. The underground contour (Cholan Form) runs in approximately north - south direction with gentle eastward dip. The northeast dip of the structure is less than 5° in average. Some normal faults with N. W. -S. E. trend and displacement of several tens of meters are inferred in this area.

Inferred fault between Pakuanshan Anticline and monoclinal area

The existence of a north-south trending fault with elongated S-shape is inferred to occur in this area from the results of the gravimetric and seismic surveys. Pan estimates that this fault passes between Yuanlin and the foot of Pakuanshan Hills, passes the edge of Changhua and changes the strike to N. E. -S. W. direction. Thus the fault passes somewhat north of the point between Shot Points I and II.

2 - 2 - 3 - 3 Geological Objectives of Traverse Line 3

This is an area where the stratigraphy and structure are expected to differ between north and south. As mentioned in a - 3, the Neogene Tertiary system of Taichung sedimentary basin and Pelkang Shelf is expected to come in contact at Pakuanshan and its western side. The basement rapidly rises south-westward in this area, and the upper and lower Miocene series is expected to thin out. In the Pakuanshan Hills and its western part there are Pakuanshan Anticline and the inferred fault which form the boundary between the Taichung structural basin and to the east and the monoclinic structural area to the west. The inferred fault exists at the part where abrupt change of the formations is expected, and thus it is believed that the fault was active not only with the present structure, but also at the time of the deposition of the Miocene series, affecting the sedimentation of the strata and is thus an important structural lineation.

In areas where such contraction, thinning out of formations occur and where the thickness of the sediments differ on the sides of faults, transportation and acculumation of oil and gas and often occur and stratigraphic traps and traps by faults are found in many cases.

The purpose of the survey along this traverse is to confirm the above and also a more basic result expected is the local variation of the basement. As this area is located immediately northeast of the Peikang Shelf which is the only locality in western Taiwan where the basement depth is known, it is favourable for detecting the variation and subsidence tendency of the basement.

On the other hand, the Pakuanshan Anticline is considered to be the southern extension of the Tienchenshan Anticline which is an important gas-producing structure and as the shape of both structures are inferred to be similar, this structure is hoped to be gas-producing.

The Pakuanshan Anticline, however, is a structure consisting of formations younger than Plio-Pleistocene series. It is not yet known whether the structure continues to the Neogene Tertiary system which is the gas-gearing strata.

The objectives of the present refraction seismic survey can be summarized as, to grasp the depth and subsidence tendency of the basement, and to obtain data on the shape of the deep structure of the Pakuanshan Anticline.

2 - 2 - 4 Geology of the vicinity of Traverse Line 4
(Sheet 5, Table 5)

2 - 2 - 4 - 1 Topography

Traverse Line 4 extends through the foothills and the coastal plains from the north of Tainan City to the north-west of Chishan. The eastern part of the traverse is an area with low hills of 50 - 250 m in height and the western part is well cultivated farmland.

The foothills are eroded and disected by small streams and the difference of altitude is very small. Lower Guting keng Formation is exposed in the hills 3-7 km from Shot Point III at the eastern end of the traverse, and vegetation is very poor in the area resulting in a very rugged topography. Terrace deposits of upper Pleistocene series are distributed near Shot Point III and the topography of the vicinity is flat.

2 - 2 - 4 - 2 Geology

The formations exposed in this area are upper Miocene Kengnei Formation, Pliocene Upper and lower Gutingkeng Formation, Plio-Pleistocene A and B Formation, upper Pleistocene terrace deposits, and alluvium deposits. The formations from Kengnei to terrace deposits are exposed in the hills east of Kuanmino, and the alluvium deposits are distributed in the plains west of Kuanmino.

(a) Stratigraphy and lithology

The outline of the stratigraphy and lithology is shown in Table 5.

Kengnei Formation

This is the lowermost formation in this area and is distributed on the western side of the Lungchuan Fault. The lower limit is not confirmed.

Lower Gutingkeng Formation

This formation overlies the Kengnei Formation conformably. It is not possible to know the thickness of this formation in this area since it cut by faults. It is observed by test wells CC-2 and PPS-1 that there is a thick massive mudstone formation under the plains to the south of Tainan City. The data from CC-2 well shows that the strata between 460 and 3,946 m in

TABLE 5 Stratigraphy and lithofacies of strata in the area of traverse Line 4.

Age	Formation	Thickness m	Lithology	Distribution, outcrops
Recent	Alluvium		Lagoon, marsh, delta sediment, gravel, sand, mud.	Coastal plain
Pleis-tocene	Terrace deposits	12 - 100**	Littoral sand, gravel, mud (unconformity)	Vicinity of Kuan miao (Tainan Formation) and of shot point III
Plio-Pleis-tocene	"B" Forma-tion	+540**	Alternation of loose yellowish gray fine sandstone and light gray mudstone, include small lime-stone nodules and mud patches. Many shell fossils.	Expose with low slope near Kuanmiao and shot point II. Distributed in shallow underground of coastal plains.
	"A" Forma-tion	1080**	Alternation of dark gray - bluish gray soft mud-stone and yellowish brown fine sandstone sorting of sandstone grains good.	Exposed between Chiting and Fansha. Distributed under plain near Tainan City.
Pliocene	Upper Gutingkeng Formation	550*	Alternation of sandy mudstone and sandstone. Thin limestone bed with shell fossils in the upper part.	Exposed in long narrow strip west of Fansha. Distributed under plains near Tainan City.
	Lower Gutingkeng Formation	+2600*	Dark gray mudstone and sandy mudstone with light gray fine-medium sandstone intercalation. Bedding poor. Marine shell and foraminifera fossils. Vegetation poor resulting in steep topography due to salt content of soil ****	Exposed in wide bands on both sides of Lungchuan Fault. Distributed under plains south of Tainan City.
Mio-cene	Kengnei Formation	+370*	Gray - bluish gray muddy fine - medium sandstone and gray shale alternation. Include carbonaceous, nodules, coral fossils.	South (eastern) side of shot point III and western side of the point. Along Lungchuan Fault.

* (1959) : Chinese Petroleum Corporation File

** (1957) : Stratigraphic Column on west Flank of the Lungchuan Fault, Kuanmiao Section, Part 1. Chinese Petroleum Corporation File

*** PPS – 1, TN – 1, CC – 2

**** Shih, T. T. (1967): A survey of the active mud volcanoes in Taiwan and a study of their types and the character of mud, Petroleum Geology of Taiwan No. 5.

depth consist of dark gray to dark greenish-gray sandy mudstone with intercalations of gray fine - very fine sandstone with shell fossils near the crest of the Chungchou Anticline. The dip within the mudstone varies considerably in each horizons from 4° to 50°, and thus folding within the formation by turbid sedimentation, faults and other factors is inferred. This thick mudstone bed is correlated to lower Gutingkeng Formation on the basis of various surveys carried out by the Chinese Petroleum Corporation.

The surface topography of the area where lower Gutingkeng Formation is distributed is generally very rugged. This is caused by the disturbance of the strata by Lungchuan Fault (to be mentioned later) and development of fissures, but also it is caused by the chemical nature of the mudstone itself, Shin (1967) reports that the rock is unfavourable for vegetation because of its high salt content, and this is one of the factors contributing to the rugged topography of the area.

Upper Gutingkeng Formation

The lithology and petrology of this formation is similar to the that of the lower Guttingkeng Formation, but this formation is somewhat coarser grained. Several thin limestone beds with shell fossils are developed in the upper part.

A Formation

The boundary between the underlying Upper Gutingkeng Formation is more or less artificial. Here, Hsu's division is adopted.

B Formation

The petrology and lithology is very close to those of A Formation. Mudstone is prominent in the A Formation while sandstone is abundant in the B Formation. The boundary between A and B formations are artificial. The sandstone is loosely consolidated and is easily weathered. The sorting of the grains of the sandstone is good.

Tableland sediments

The sediments are distributed in the area from near Shot Point 3, and Kuanmiao towards Tainan. Those distributed in the Tainan area are called Tainan Formation and are distributed in the plain areas under alluvium deposits.

Alluvium deposits

These are distributed widely southward from near Tainan City. The thickness of the sediments is only several meters.

(b) Geologic structure

The geologic structure of the area in the vicinity of Travers Line 4 consists of anticlinal, synclinal and faults all trending in N. N. E. -S. S. W. direction, and the strata are arranged in zonal arrangement elongated in approximately north-south direction. The traverse intersects the folds, faults, and the strata almost perpendicularly.

The major structural units are from east to west Chiaotzuto Fault, Chungpu Syncline, Kengnei Anticline, Lungchuan Fault, Kangshan Syncline, Chungchau Anticline, Tawan Syncline, Tainan Anticline. These units are arranged parallel to each other.

(b - 1) Folds

Chungpu Syncline

This syncline is located near the eastern edge of this area, the axis extends in N. -S. direction through 1. 5 km west of Shot Point III. Both eastern and western wings of the syncline are cut off by Chiaotzuto and Lungchuan faults. The strata at the axial parts and wings dip more than 50° east or west.

Kengnei Anticline

The axis of this anticline trends N. N. W. -S. S. E. along Lungchuan Fault. The northern part of the axis is cut by the above fault. The axial parts and the wings are formed by Kengnei Formation and the dip is steep at more than 70°.

Kangchan Syncline

The strata west of Lungchuan Fault to Kuanminao have monoclinic structure with westward dip. The axis of this syncline trends approximately N. -S. through 2 km west of Shot Point II. At the eastern wing of the syncline, B and A formations, upper and lower Gutingkeng formations are exposed from west to east, the eastern edge of the wing is cut by Lungchuan Fault, and is in contact with the western wing of Kengnei Anticline or Chungpu Syncline across the fault.

The inclination of the strata of the eastern wing of the syncline is less than 15° to near Chiting, 20°-50° from Chiting to Fansha, and sharply increases from Fansha to Lungchuan Fault, and the strata are vertical or overturned near Lungchuan Fault. The steep inclination at the eastern wing is believed to be caused by the movement of the Lungchuan Fault.

Small faults with east-west trend are developed in the eastern wing.

The western wing of the syncline cannot be observed on the surface, because of the dilluvium and alluvium cover. The results of the reflection seismic survey of CPC shows that the western wing has inclination of 15° - 20° and is continuous to the Chungchao Anticline in the west.

Chungchao Anticline

The results of the reflection seismic survey* indicate that this anticline exists under the plains between Tainan and Kaohsiung with axial trend of N. - S., and passes through 5 km west of Shot Point II. The eastern wing of the anticline has inclination of less than 20° while that of the western wing is under 45°. The interpretation of aerial photographs by Sun (1964) revealed that the position of the axis on the surface and in the deeper parts differ, and it is inferred that the axial plane dips eastward.

There are upper Gutingkeng Formation in the shallower parts and thick mudstone bed (correlated to lower Gutingkeng Formation) in the deeper parts according to the data of test well CC-2 at the axial part.

Tawan Syncline

This syncline is located on the westside of Chunchao Anticline, and the synclinal axis runs N. N. E. -S. S. W. direction passing a point 9 km west of Shot Point II. This is generally a gentle syncline, and the western wing is gentler than the eastern part. There is the Liuchiation Fault between this syncline and the Chungchiao Anticline, the fault plane is inferred to dip eastward.

Tainan Anticline

This is located to the west of Tawan Syncline, it passes through the eastern edge of Tainan City, intersects the traverse at 7 km east of Shot Point I. The strike of the axis is parallel to the Chungchiao Anticline and Tawan Syncline. This has an almost symmetrical section, and the western wing is slightly gentler in its slope at 25°. The western side of this syncline is made of monoclinic strata inclining toward the straits.

The data from well TN-1 at the crest of this anticline shows that alternation of sandstone and mudstone considered to be of upper Gutingkeng Formation exists between 12 m - 373 m in depth, and thick mudstone strata compose the deeper parts.

* Structural map of the top of the upper Gutingkeng Formation on Tainan, Chungchou, and Paupingshan Anticlines, Chinese Petroleum Corporation Data, 1964.

(b - 2) Faults

Chiaotzuto Fault

This is a N. -S. trending reverse fault, it passes the immediate east of Shot Point III at the eastern edge of this area. The dip of the fault plane is 75° - 80° east. Kengnei Formation is exposed on the east side and lower Gutingkeng Formation which forms the Chungpu Syncline on the west side, and the apparent displacement of the fault is more than 2, 000 m.

Lungchuan Fault

This is the largest fault in this area, it forms the boundary between the Chungpu Syncline or the Kengnei Anticline and the Kangchan Anticline. The total length is about 20 km and passes 3. 8 km west of Shot Point III in N. N. E. - S. S. W. direction. The fault is a reverse fault with downward displacement of several thousand meters of the western block. The inclination of the fault plane is not constant, but is generally more than 70° with eastward or westward dip.

The sheared zone of the fault is more than 20 m wide, and is accompanied by numerous small faults, and fault clay and fault breccia. On both sides of the fault the formations have been strongly disturbed for more than several hundred meters, and intra-formational folding, overturned strata are observed. There are small mud volcanoes along the fault.

This fault is considered to be the anticlinal axial fault formed along the axis of the Kengnei Anticline. Also a small anticlinal structure (Lungchuan Anticline) is accompanies this fault on the eastern side of the northern part of the fault.

2 - 2 - 4 - 3 Geological objectives of Traveres Line 4

Chungchou, Tainan Anticlines and other anticlinal structures have been discovered under the plains from near Tainan City towards Kaohsiung. Chungchou and Tainan anticlines are favourable for the acc mulation of gas and oil in their shapes and dimensions, and if suitable sandstone layers could be found under the thick mudstone strata, these will be considered as promising reservoir structures.

The deep drillings (CC-2, R-1, TN-1) carried out at the axial parts of these anticlines show, however, that the mudstone formation continue down to almost 4, 000 m deep and it has not yet been penetrated. The electric logging and core observation indicate that the dip of the mudstone layers within the formation varies by horizons, and in some horizons it is more than

70°. The reflection seismic survey carried out in the plain regions of this area showed that there are good reflecting surfaces in the shallow parts while the reflections obtained from the deeper mudstone layers are almost nil. These parts with very little reflection correspond to the mudstone layers confirmed by drilling. It is difficult to determine whether this abnormally thick mudstone formation was formed as the result of 1) particular geologic structures (diapir structure, intra-formational folding or of 2) abnormal sedimentary process. Since sandstone which will be the major gas and oil reservoir rock is lacking within this formation, the possibility of oil and gas production is laid on the Kengnei Formation which is the member of the lower Gutingkeng Formation. However, the thickness of this form, is unknown neither on the surface nor by drilling. Thus if the process of the formation of this abnormally thick mudstone can be understood to a certain extent from the present seismic survey, it will be a great contribution to the future surveys and development projects.

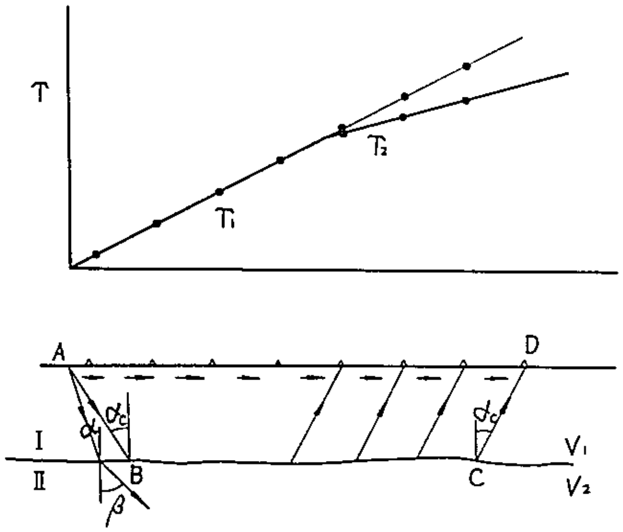
In areas south of Peikang, the Neogene Tertiary system becomes thicker and the muddy part becomes prominent compared to the northern parts. The basement of the Neogene Tertiary system is yet unknown in the south of Peikang, and knowledge concerning the existence of the middle and lower Miocene series as in the case of the northern part, and if they do exist the thickness variation and the depth of these formations are some of the most important problems. These knowledge will be important basis for future oil and gas exploration under the Taiwan Straits.

On the other hand, it seems difficult to expect oil and gas production in the eastern part of the traverse, especially near Lungchuan Fault because of the intense disturbance of the strata by the fault movement. But there is an anticlinal structure adjacent to the Lungchuan Fault to the west, and the shape of this anticline in the deeper parts,. the existence of fault trap in the deeper parts, and the possibility of distingulshing the boundary of between Lower Gutingkeng Formation and Kengnei Formation are some of the important and interesting problems related to the geologic structure of the area.

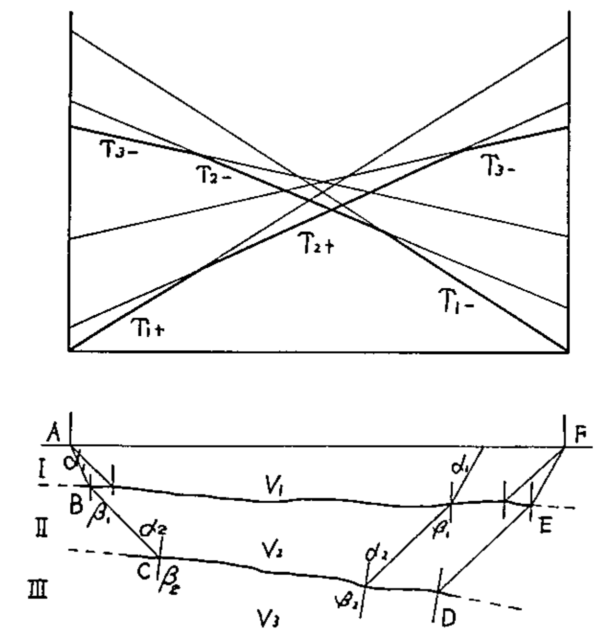
III Seismic Prospecting

III Seismic Prospecting

Fig. 5 Sketch Illustrating Refracted Wave Paths through 2 or more Layers and Refraction Travel-Time Curves



The case of two layered structure



The case of three layered structure

3 - 1 Method of survey

3 - 1 - 1 Outline

Refraction seismic method was employed for this survey.

Artificial seismic waves (elastic waves) are propagated through geological formations by reflection or refraction. By using the refracted waves it is possible to calculate the depth, inclination, lithology, and other properties of the formations, this is the principle of refraction seismic method.

Explosives are mainly used as energy source for generation of seismic waves. When the seismic waves generated by explosion reaches the boundary of formations with differing elasticities and densities, a part of the waves is reflected from the boundary surface, but the other part enters the lower formation after refraction. The law of refraction is $\frac{\sin\alpha}{\sin\beta} = \frac{V1}{V2}$ when the velocities of the waves in formations I and II are V1 and V2, incident angle α , and refraction angle β as shown in Figure 5.

Snell's law holds for seismic waves just as in the case of light, that is the waves can return the paths through which they have come. Thus the waves which entered formation I from formation II along the refraction angle β , will travel to the surface along the incident path with angle α .

Now, if the incident angle (critical angle) when the refraction angle α = 90°, be designated as α , $\sin \alpha_c = \frac{V1}{V2}$.

This shows that the seismic waves which reached formation II at critical angle α_c will be refracted at approximately 90° and travel along the boundary, and a part of it will be refracted into formation I again at the angle α_c and reach the surface.

Refraction seismic method is a method by which the time necessary for the seismic waves to travel from the shot points to the receiving points in paths ABCD of the figure and to calculate the structure of the refracted surface, depth and other factors.

In actual operation, several shot points and many receiving points are set on a single traverse and the travel-time is measured for the shot points and receiving points.

Figure 5 is a schematic sketch showing the refracted wave paths and refraction travel-time curves of two layer structures. In actual geological structures, it is generally far more complex with three, four layered structures.

In these complex structures the basic principle in the case of the two layered structures (law of refraction and Snell's theory) is repeated in the propagation of the refracted waves. The travel-time of refracted waves are recorded as initial motion, motion through second, third layers . . . etc. for each layer.

These travel-time curves are treated in accordance to the above basic principles and geometrical laws such as :

The terminal travel-time of the two way travel-time curve is equal.

All the travel-time curves starting from the same shot point through the same layer will show the same zero point travel-time.

All travel-time curves in the same direction of a single layer are parallel.

Of two initial motion travel-time curves in the same direction, the travel-time interval will decrease with the increase of distance.

The cross points between the same two formations are both within on outside of the zero point in two way travel-time curves.

In the present survey, measurements on long distances of over 40 km were necessary and special care was necessary in handling the observed data.

In the present survey ideal traverse plans and survey methods could not be adopted because of the following requirements, the objective of the survey was a reconnaissance of the basement structure of the entire western coast, measurements on long distances were planned in spite of the relatively short time available, the basement was located very deeply, large variation of the underground velocity increase could not be expected, long traverse lines in the vicinity of 40 km were required, operational conditions such as weather, topography, transportation etc., were not very favorable, and other factors. The deviations from ideal operating conditions are as follows, the arrangement of observation points were not precisely linear and equi-distant, the spread was off the traverse line center and not continuous in some areas, the number of shot points was not as sufficiently large, in some areas the center of the traverse line was somewhat courved, JJY was the only time element which we could rely on, magnetic records could not be taken for the total time after the explosion, these resulted in a considerable loss on the accuracy of the survey.

In the explosions of this survey, however, the initial kick was extremely good, and the following phases were also very continuous and clear. Thus the loss of accuracy on the analysed profile because of the above conditions was compensated many times by the initial kick and the continuity of the later phases.

Also relatively conspicuous reflection waves and later phase waves were observed by the refraction measurements for long distances by near the shot points. Velocity sections of the refraction method could be checked and corrected by these data.

Various surveys such as geological survey, gravimetric survey, reflection method, drilling, logging, etc., have been carried out in the surveyed area. Planning, analysis, and interpretation of the refraction seismic survey are closely related to these surveys, and operations were carried out with close correlation of these results.

3 - 1 - 2 Survey Equipment used

The following equipment were used during the survey

Seismic prospecting equipments

PT100 + MR20	(Frequency modulation magnetic recording) 24 components			1 unit
G11 + PMR7	(Amplitude modulation magnetic recording)		24 components	1 unit
G33	(Chinese Petroleum Corporation)		24 components	1 unit
Receivers	Mark Product	4 High sensitivity receivers		72 units
Radios	Yaesu Musen	FT-50 20W SSB Tranceiver Frequency range 36, 7, 12, 27 MC bands		6 units
	National	1 W 150 MC band		5 units
	National	0.5 W 27 MC band		4 units
	National	0.1 W 27 MC band		3 units
	Toshiba	0.1 W 27 MC band		3 units
JJY Receivers	Kikusui Denki	Receiving frequency range 25, 5, 10, 15 MC		6 units
JJY Signal rectifiers	Ube Kosan			6 units
Visigraphs	Sanei Sokuki	6 component Recorder speed range 1, 5, 10, 20 cm/o.		2 units
Generators	HONDA	Portable AC generators 100 V 300 W		3 units
Observation cables	400 M per drum	24 core terminal interval 120 M		24 drums
Observation relay cables	400 M per drum	24 core		8 drums
Pumps	Chuo Kiki	GPD-750 Hydropump 5 HP		3 units
Drilling machines	Car mount rotary drill	(Chinese Petroleum Corporation)		2 units
Observation cars	Toyota Land Cruiser			2 units
	GM (Chinese Petroleum Corporation)			1 unit

3 - 1 - 3 Survey method

(a) Arrangement of traverse lines and topographic survey

Traverse lines were arranged with due consideration of the objectives of the survey, and four traverse lines were arranged from north to south on land along the western part of Taiwan as shown in Sheet 1. All traverses were about 40 km in length, observation points arranged at 100 m intervals with three shot points, and these were designed for reconnaissance survey. The spread was first planned on a 50, 000 : 1 topographic map after field survey.

The following points were considered in establishing the spread.

Spread was set on roads not very far from the center line of the traverse and efforts were made for the efficiency of the operations and the decrease of compensatory expenses. Avoid vicinity of noise sources such as main roads, rivers, and also within villages.

Intervals of observation points were set at 100 m, but in the spread in mountains and those crossing the traverses obliquely were set at 75 m. All the intervals are the projected distance on the center line. The intervals near the shot points were set at 30, 50, and 100 m from the shot point. Avoid cliff type topography for the shot points in order to increase the explosions effect. The shot points were at least 200 m apart from all surface installation for safety.

The receiving points and shot points of each travers are shown in Sheet 6 - 9. The traverse line program is shown in Table 6.

Table 6 Traverse Line Program

Traverse No.	Traverse location	Traverse length	Spread	Re-ceiving point	Maximum elevation difference	Number of shot point
2	Kuanyin-Yangmei-橫 山	33, 714m	9	216	294m	3
1	香 山 -Houlung-Yuanli	42, 775	12	288	121	3
3	Wufeng - 北斗鎮 -Hsilo	45, 168	12	288	208	3
4	Tainan-Kuanmiao-Chishan	32, 231	12	288	238	3
Total		153, 888	45	1, 080		12

The major work of the topographic survey was the establishment of receiving points and the measurement of the altitude of the receiving points. These operations were done according to the spread program set after field survey, and were carried out by the topographic survey team of the CPC in the order of Traverse Lines 4, 3, 1, and 2.

Flags of 1-2 m high were set at each receiving points as a mark during observation and spread.

It was also necessary to prepare traverse plan maps of 25,000 : 1 scale including the arrangement of receiving points, nearby roads, major topographic features, locality names, etc., tables including the altitude of each receiving point, the total distance from shot point I , and diagram showing the arrangement of the shot holes of each shot point.

These were prepared for observation operations, analytical operation, and for records, all with accuracy corresponding to that of the survey ($\pm$ 1 m for altitude and distance). Thus the local topographic survey for this operation was done with the parameters of the 25,000 : 1 scale topographic map as the basis.

(b) Drilling of the shot holes

The drilling of the shot holes was all done by the drilling team of CPC. Most of the operation was done in alluvium sediments of the Quaternary system and the drilling equipment was rotary driller transported on motor cars.

The shot point program is shown in Table 7.

Traverse No.	Shot point	Number of shot holes	Hole depth	Hole diameter	Remarks
2	I	7	40^m x 7 = 280^m	100 m/m	all Casing
	II	4	40 x 4 = 160	"	"
	III	7	40 x 7 = 280	"	"
1	I	7	40 x 7 = 280	"	"
	II	4	40 x 4 = 160	"	"
	III	7	40 x 7 = 280	"	"
3	I	7	40 x 7 = 280	"	"
	II	4	40 x 4 = 160	"	"
	III	7	40 x 7 = 280	"	"
4	I	7	40 x 7 = 280	"	"
	II	4	40 x 4 = 160	"	"
	III	7	40 x 7 = 280	"	"
Total	12 Point	72	40 x 72 =2,880		

Table 7 Shot Point Program

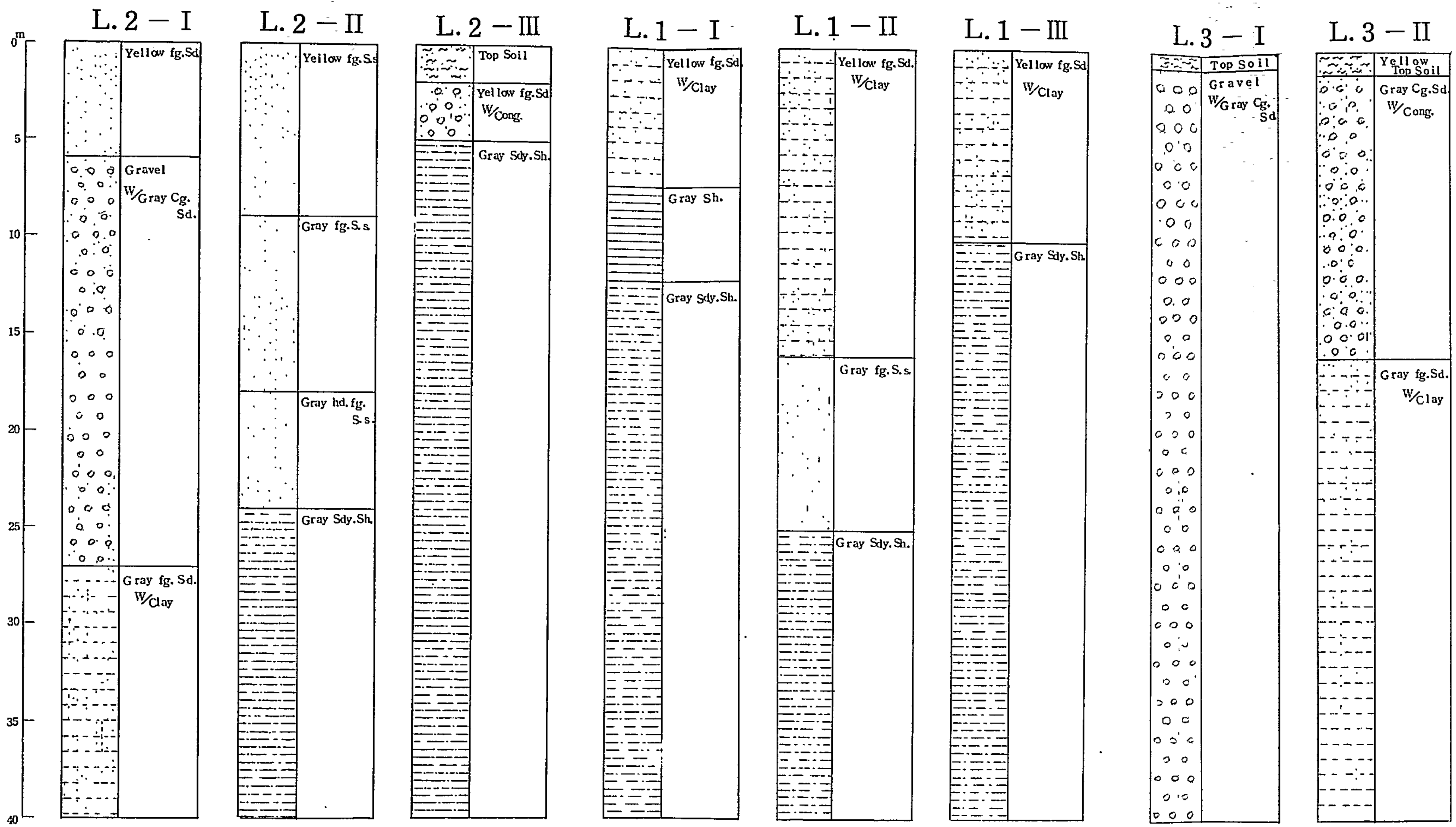


Fig. 6 GEOLOGIC COLUMNAR SECTIONS OF SHOT HOLE

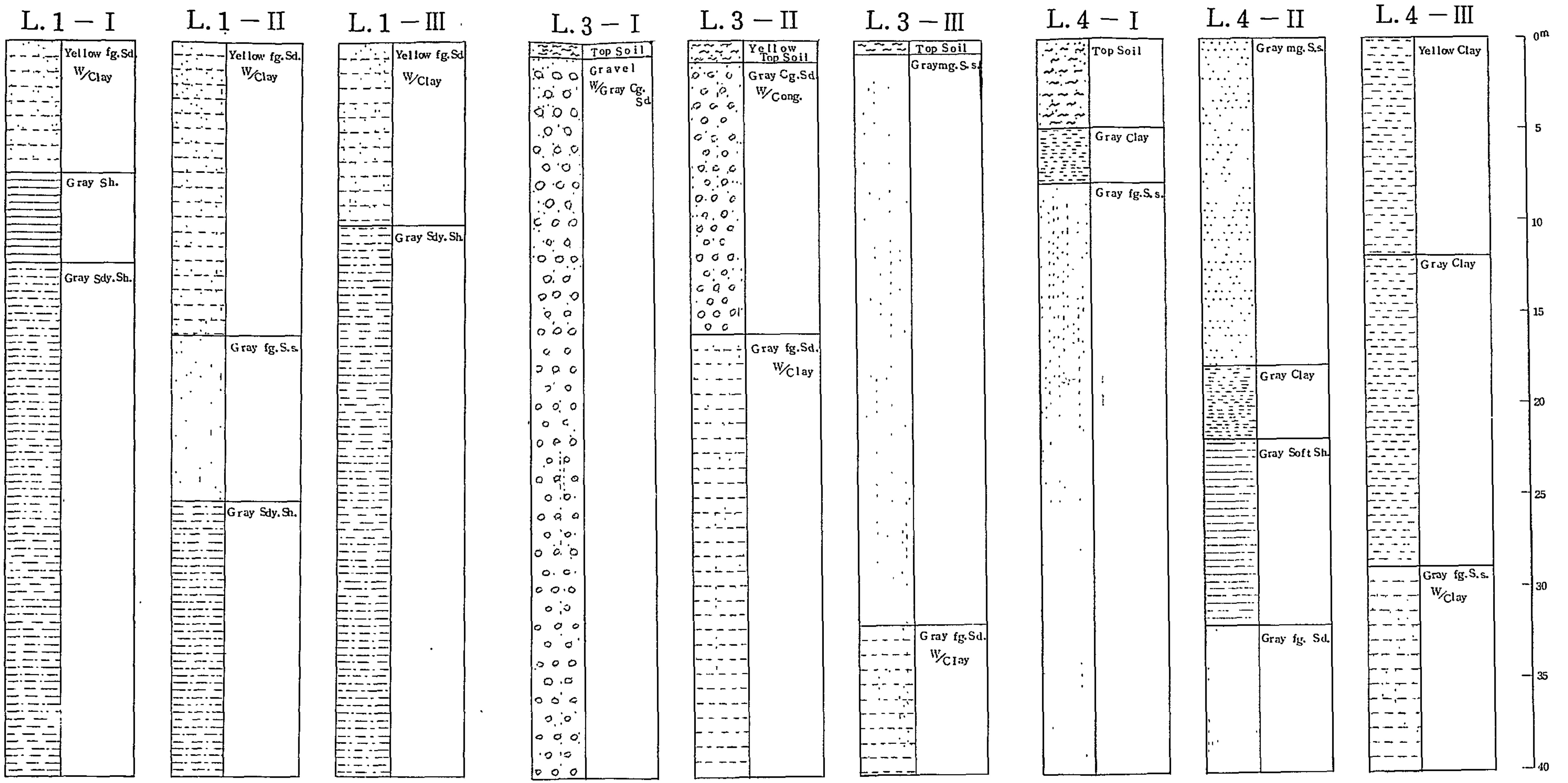


Fig. 6 GEOLOGIC COLUMNAR SECTIONS OF SHOT HOLES ES

The shot holes were arranged for pattern shooting and they were generally in circular form with 20 m intervals, but in some areas they were arranged in rectangular shape perpendicular or parallel to the traverse. These arrangements were recorded in detail. The shot holes were 4" in diameter and casing was fit to the bottom. The geologic column of each shot hole in laid out in Figure 6. It can be seen that the geology the shot holes are almost all quaternary mudstone, with the exception of Traverse Line 2, I and Traverse Line 3, II, where coarse sandstone with gravel occur almost from the surface. These sand and gravel beds were deposited after the erosion of the surface sediments and they seem to be river bed formations. These sand gravel beds were of great nuisance for our drilling operation.

(c) Survey operations

Detonation

As maximum of 500 kg of explosive charge was planned for each shooting, safety instructions were given to the workers. Four hole pattern shooting was adopted, and the explosives used were dynamite for large scale seismic survey (diameter 75 mm, length 650 mm, weight 4. 5 kg, packed in vinyl). Large sized explosives were required because they were split into one or two sticks and had to be pushed into the shot holes to the bottom safely.

The specifications of the dynamite used are

Grade C

Ammonia Gelatins

Giant 90%

Strength 90 Velocity of Detonation 5, 000 m/s (confined)

Detonation Transmission 16" Density 1. 4 Water Resistance excellent Consistency gelatinous Fume Rating class 2.

(U. S. B. M.)

The amount of explosives for each traverse is listed in Table 8, and that for each shot point in Table 9.

Table 8 Statistics of Explosive Charge for each Traverse Line

Traverse No.	Consumed explosive	Number of shots	Average charge per shot	Maximum charge per shot	Consumed detonation Cop.
2	2,933.0 Kg	13 times	225.6 Kg	432.0 Kg	35 pcs.
1	4,134.9	16 "	258.4	544.5	38 "
3	2,933.0	12 "	244.4	450.0	36 "
4	2,211.75	12 "	184.3	405.0	34 "
Total	11,212.65	53 times	230.4		143 pcs.

The detonation party was responsible for the operations related to detonation, at the same time notified the communication party of the time of the detonation, and also recorded the time on (JJY) chart. The survey area was hot, weather unstable, and radio communication was often disturbed. The detonation party notified the detonation time in the above two methods for precaution against radio disturbance.

o Commucation

The work was done with nine parties consisting of three detonation parties, three observation parties and three spread parties, scattered along the 40 km traverse line. Portable medium-short wave radio telephone with 20 W output was used for communication among the parties and transmission and reception of the detonation signal. Four radio frequencies in the range of 3.6 MC - 27 MC were used, but 3.6 MC band was most effective.

It was possible to reach the whole length of traverse with this frequency in flat areas, but it was necessary to relay the communication in mountainous areas.

Also the detonation parties carried 27 MC, 0.1-0.5 W, tranceivers for safety precaution and lookout at detonation, and the observation parties carried 150 MC band, 1 W microwave radio telephone for communication with the receiver spread parties at a distance of 2,300 m.

o Observation

The observation parties consisted of two groups for magnetic tape recording seismic equipment operation, and a group for direct recording seismic equipment operation. Three spread parties were coordinated with these groups the spread parties set the receivers and spread the cables.

Table 9 Statistics of Explosive Charge for each Shot Point

Traverse No	Data	Shot point	Explosive charge	Number of slot holes	Number of detonation caps	Spread	Receiving distance Minimum	Receiving distance Maximum	Remarks
2	7.25	I	140.0 Kg	1	1	1, 2, 3	0 m	10, 860 m	
"	7.26	I	135.0	1	1	" " "	0	10, 860	
"	" "	II	237.0	3	6	" " "	7, 460	18, 320	
"	" "	III	432.0	3	7	" " "	22, 854	33, 714	
"	7.27	I	243.0	2	2	4, 5, 6	12, 600	22, 220	
"	" "	II	72.0	1	1	" " "	0	5, 270	
"	" "	III	234.0	1	4	" " "	11, 494	21, 114	
"	7.28	I	360.0	3	3	7, 8, 9	23, 620	33, 714	
"	" "	II	171.0	2	2	" " "	5, 300	15, 394	
"	" "	III	126.0	1	1	" " "	0	10, 094	
"	7.29	I	216.0	2	3	1, 4, 5	0	18, 320	
"	" "	II	207.0	2	2	" " "	0	18, 320	
"	" "	III	360.0	1	2	" " "	15, 394	33, 714	
	Total		2, 933.0		35				
	Max.		432.0	3	7			33, 714	
1	7.16	I	180.0	1	2	10, 11, 12	33, 325	42, 775	
"	" "	II	216.0	2	2	" " "	11, 545	20, 995	
"	" "	III	99.0	1	1	" " "	0	9, 450	
"	7.17	I	425.4	2	2	7, 8, 9	21, 780	32, 875	
"	" "	II	117.0	2	2	" " "	0	11, 095	
"	" "	III	211.5	2	3	" " "	9, 900	20, 995	
"	7.18	I	201.5	3	3	4, 5, 6	9, 630	19, 430	
"	" "	II	126.0	2	2	" " "	2, 350	12, 150	
"	" "	III	337.5	2	3	" " "	23, 345	33, 145	
"	7.19	I	105.0	1	1	1, 2, 3	0	9, 030	
"	" "	II	211.5	2	2	" " "	12, 750	21, 780	
"	" "	III	540.0	4	4	" " "	33, 745	42, 775	
"	7.20	I	487.0	4	4	10, 11, 12	32, 875	42, 775	
"	" "	III	121.5	1	2	" " "	0	9, 900	
"	7.21	II	211.5	2	3	1, 2, 3	12, 750	21, 780	
"	" "	III	544.5	2	2	" " "	33, 745	42, 775	
	Total		4, 134.9		38				
	Max.		544.5	3	4				

Traverse No	Data	Shot point	Explosive charge	Number of slot holes	Number of detonation caps	Spread	Receiving distance		Remarks
							Minimum	Maximum	
3	7. 8	I	432.0Kg	3	4	10, 11, 12	29,185 m	43,588 m	
"	" "	II	188.0	2	2	" " "	4,300	18,703	
"	" "	III	144.0	1	1	" " "	0	14,403	
"	7. 9	I	288.0	3	4	7, 8, 9	18,030	27,385	
"	" "	II	90.0	1	1	" " "	0	6,855	
"	" "	III	261.0	2	2	" " "	16,203	25,558	
"	7.10	I	198.0	2	5	4, 5, 6	9,220	18,030	
"	" "	II	162.0	2	2	" " "	6,844	15,665	
"	" "	III	351.0	3	4	" " "	25,558	34,368	
"	7.11	I	99.0	2	2	1, 2, 3	0	8,170	
"	" "	II	270.0	3	3	" " "	16,715	26,465	
"	" "	III	450.0	3	6	" " "	35,418	45,168	
	Total		2,933.0		36				
	Max.		450.0	3	5			45,168	
4	6.29	II	204.75	3	3	1, 2, 3	11,698	20,143	
"	6.30	I	81.0	1	1	" " "	0	8,445	
"	" "	III	333.0	4	6	" " "	23,786	32,231	
"	7. 1	I	144.0	2	2	" " "	0	8,445	
"	" "	II	117.0	2	5	4, 5, 6	4,798	11,698	
"	7. 2	III	279.0	2	4	" " "	16,886	23,786	
"	7. 3	I	234.0	2	2	7, 8, 9	18,763	25,526	
"	" "	II	63.0	1	1	" " "	0	5,383	
"	" "	III	135.0	2	3	" " "	6,705	13,468	
"	7. 4	I	405.0	3	3	10, 11, 12	25,526	32,231	
"	" "	II	153.0	2	2	" " "	5,383	12,088	
"	" "	III	63.0	1	2	" " "	0	6,705	
	Total		2,211.75		34				
	Max.		405.0	4	6			32,231	
	Grand Total		12,212.65		143				

The observation parties were responsible for maintenance and adjustment of observation instruments, observation, and general supervision of all operations, spread parties carried out the spread and recovery of receivers and cables, coordination of noise sources near the spread, and maintenance of receivers and cables.

The observation operations were done by team work of observation, spread, and detonation parties. The main line of work of these parties from preparation to withdrawal were all done in accordance to the direction of the observation party which became the center for the operations of the day. The observation of the seismic waves need the most close cooperation of the members and the workers of the three parties carry out all operations from detonation preparation, lookout for spread, record preparation, to detonation, switching on recorders and magnetic tape recorders in the prescribed order and time with the direction from the observation party in charge.

The detonation parties must also record the JJY signals including long signal every minute and the shot marks. The shot marks were often disturbed in long distance communication. In such cases, the above JJY signals of the detonation and observation parties are correlated and thus the positions of the shot marks in the records can be inferred.

In the survey areas, JJY signals were transmitted in four sections of 0 - 5 min., 15 - 20 min., 30 - 35 min., 45 - 50 min. every hour. The operations were started within these time sections with the long every minute signal in the record.

Thus operations of one spread a day, three spreads with three parties were carried out every day.

The system for recording shot marks and JJY signals is shown in Figure 7.

The instruments were adjusted to the following conditions.

Output level ..... The after phase were suppressed to the level suitable for reading.

Input gain ...... Gain was increased to the allowably noise level against the suppression of the output level.

AGC .... Set at F.

Filter .... Low pass filter of out - 42 cycles, out- [illegible] cycles were used in order to eliminate the high frequency noise and improve the S-N ratio of low frequency seismic waves.

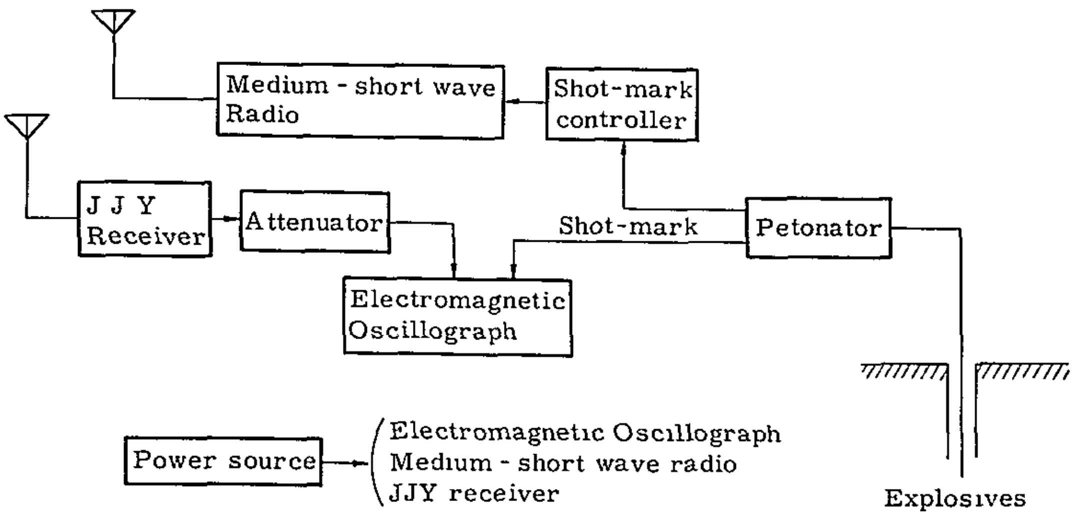
60 cycle rejection filter ...... This filter was used where the induction effect of power lines was large.

Chart speed .... The record chart speed was slowed down to 1/2 of the normal as the recording time of the seismic waves was 15 - 20 seconds. Two recorders were set at 15 cm/sec., and one set at 18 cm/sec.

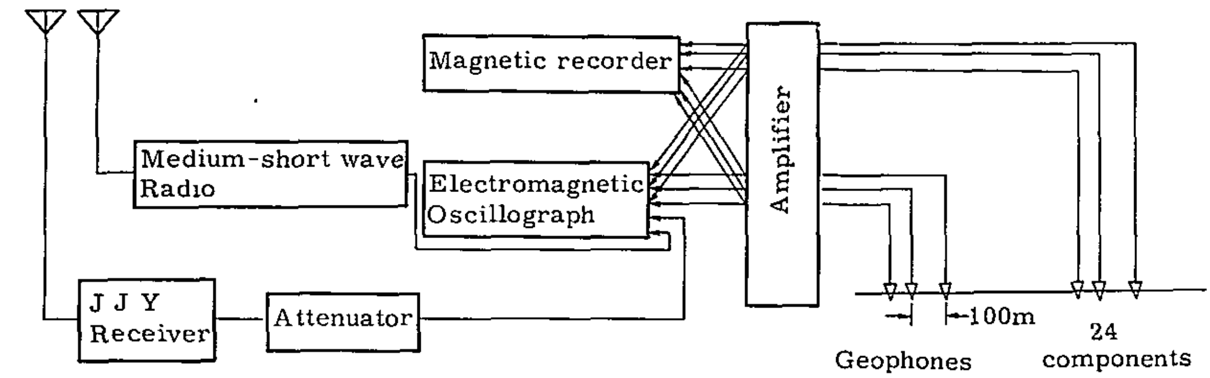
Magnetic tape recording system ...... The recording time can be set for 5 or 10 seconds. Thus it is difficult to record the entire seismic vibration. Thus only the later phases were recorded, and assumed travel-time curves were drawn from the probably geologic structure and the starting time was calculated. Low pass out - 24 cycles and out - 27 cycles filters seem to be best for playing back the records.

The monitor records are listed in Table 10 and play back records in Table 11.

Fig. 7 Shot - Mark and JJY - Signal Recording System



Shot - mark and JJY - signal recording system
for detonation party



Power source
- Amplifier
- Magnetic recorder
- Electromagnetic oscillograph
- Medium - short wave radio
- JJY receiver

Shot - mark and JJY - signal recording system
for observation party

Fig. 8 Flow Chart of Seismic Refraction Survey Operations

3 - 2. Analysis

Refraction seismic survey consists of various stages of operation from the planning stage to the preparation of the report. The major stages are shown in Figure 8.

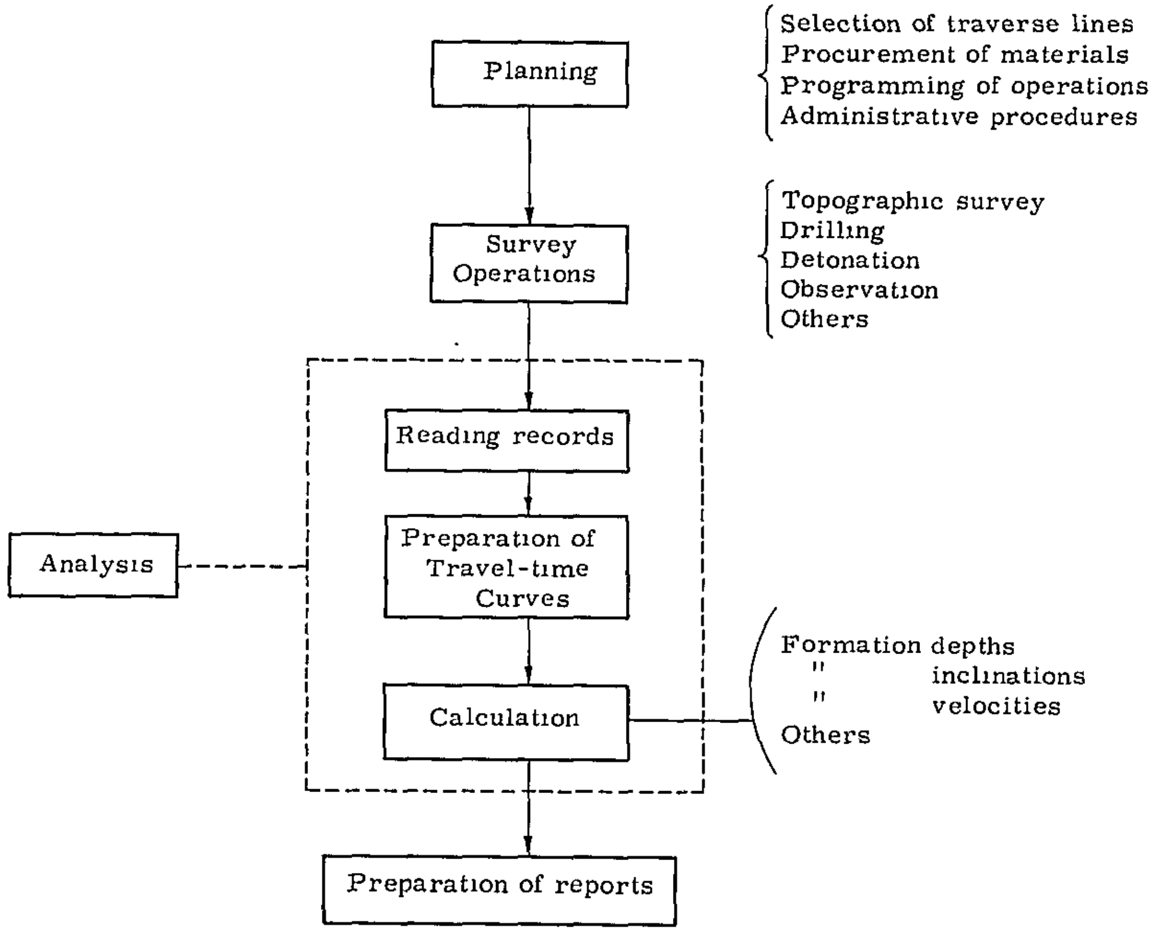


Table 10 Index of Monitor Records

Traverse Line 2

FM : PT100 + MR20
AM : G11 + PMR7

Record No.	Spread	Shot point	Detonation time Date	Hour	Minute	Second		Seismic equipment	Filter	Gain	Amp	Tape No.	Re-marks
2- 1	1	I	7/25	16	02	52	539	AM	OUT-42	30-45	30	19294	
2- 2	2	"	"	"	"	"	"	G-33	OUT-47	30-31	25		
2- 3	3	"	"	"	"	"	"	FM	"	-30db	19	52001	
2- 4	1	"	7/26	16	17	51	329	AM	OUT-42	48-50	30-32	19297	
2- 5	"	II	"	14	47	55	325	"	"	55-60	30	19295	
2- 6	"	III	"	15	47	52	383	"	"	52-59	32	19296	
2- 7	2	I	"	16	17	51	329	G-33	OUT-47	32-38	25		
2- 8	"	II	"	14	47	55	325	"	"	32-40	"		
2- 9	"	III	"	15	47	52	383	"	"	"	"		
2-10	3	I	"	16	17	51	329	FM	"	-30db	17	52004	
2-11	"	II	"	14	47	55	325	"	"	"	"	52002	
2-12	"	III	"	15	47	52	383	"	"	"	24	52003	
2-13	4	I	7/27	12	17	00	129	AM	OUT-42	50	30	19298	
2-14	"	II	"	14	32	02	865	"	"	52-59	"		
2-15	"	III	"	12	47	51	753	"	"	55-60	32		
2-16	5	I	"	12	17	00	129	G-33	OUT-47	30-41	25		
2-17	"	II	"	14	32	02	865	"	"	"	"		
2-18	"	III	"	12	47	51	753	"	"	"	"		
2-19	6	I	"	12	17	00	129	FM	"	-30db	24	52005	
2-20	"	II	"	14	32	02	865	"	"	-40db	18	52007	
2-21	"	III	"	12	47	51	753	"	"	-30db	20	52006	
2-22	7	I	7/28	17	17	52	916	AM	OUT-42	53-58	32	19306	
2-23	"	II	"	16	32	49	759	"	"	55-58	30	19305	
2-24	"	III	"	16	02	50	322	"	"	"	32	19304	
2-25	8	I	"	17	17	52	916	G-33	OUT-47	40-52	25		
2-26	"	II	"	16	32	49	759	"	"	"	"		
2-27	"	III	"	16	02	50	322	"	"	"	"		
2-28	9	I	"	17	17	52	916	FM	OUT-47	-30db	23	52010	
2-29	"	II	"	16	32	49	759	"	"	"	19	52009	
2-30	"	III	"	16	02	50	322	"	"	"	16	52008	
2-31	1	I	7/29	16	02	55	791	FM	OUT-47	-40db	16	52013	
2-32	"	II	"	13	02	52	920	"	"	-30db	19	52011	
2-33	"	III	"	14	02	53	876	"	"	-20db	23	52012	
2-34	4	I	"	16	02	55	791	AM	OUT-42	53-57	30	19309	
2-35	"	II	"	13	02	52	920	"	"	48-51	28	19307	
2-36	"	III	"	14	02	53	876	"	"	52	30	19308	
2-37	5	I	"	16	02	55	791	G-33	OUT-47	38-42	25		
2-38	"	II	"	13	02	52	920	"	"	38-50	"		
2-39	"	III	"	14	02	53	876	"	"	38-42	"		

Traverse Line 1

FM : PT100 + MR20
AM : G11 + PMR7

Record No.	Spread	Shot point	Date	Detonation time				Seismic equipment	Filter	Gain	Amp	Tape No.	Re-marks
				Hour	Minute	Second							
1- 1	12	I	7/16	17	17	57	700	FM	OUT-47	-10db	25	37987	
1- 2	"	II	"	16	17	58	722	"	"	-20db	22	37986	
1- 3	"	III	"	15	32	04	252	"	"	-40db	18	37985	
1- 4	11	I	"	17	17	57	700	G-33	"	30-33	25		
1- 5	"	II	"	16	17	58	722	"	"	30-34	"		
1- 6	"	III	"	15	32	04	252	"	"	"	"		
1- 7	10	I	"	17	17	57	700	AM	OUT-42	40	30	19279	
1- 8	"	II	"	16	17	58	722	"	"	38-40	28	19278	
1- 9	"	III	"	15	32	04	252	"	"	"	"	19277	
1-10	9	I	7/17	16	47	50	234	FM	OUT-47	-20db	25	37989	
1-11	"	II	"	15	17	51	753	"	"	"	20	37988	
1-12	"	III	"	17	17	49	021	"	"	"	19	37990	
1-13	8	I	"	16	47	50	234	G-33	"	30-33	25		
1-14	"	II	"	15	17	51	753	"	"	30-32	"		
1-15	"	III	"	17	17	49	021	"	"	"	25-26		
1-16	7	I	"	16	47	50	234	AM	OUT-42	35	28	19281	
1-17	"	II	"	15	17	51	753	"	"	25-35	"	19280	
1-18	"	III	"	17	17	49	021	"	"	33-35	"	19282	
1-19	6	I	7/18	15	17	52	434	FM	OUT-47	-30db	25	37993	
1-20	"	II	"	13	32	59	342	"	"	"	20	37991	
1-21	"	III	"	14	17	50	562	"	"	"	25	87992	
1-22	5	I	"	15	17	52	434	G-33	"	30-31	25-30		
1-23	"	II	"	13	32	59	342	"	"	30-32	25		
1-24	"	III	"	14	17	50	562	"	"	"	"		
1-25	4	I	"	15	17	52	434	AM	OUT-42	40	28	19285	
1-26	"	II	"	13	32	59	342	"	"	33-40	"	19283	
1-27	"	III	"	14	17	50	562	"	"	30-40	"	19284	
1-28	3	I	7/19	12	32	52	446	FM	OUT-47	-30db	19	37994	
1-29	"	II	"	13	02	45	988	"	"	"	23	37995	
1-30	"	III	"	16	02	52	917	"	"	"	22	37996	
1-31	2	I	"	12	32	52	446	G-33	"	30-31	25		
1-32	"	II	"	13	02	45	988	"	"	"	"		
1-33	"	III	"	16	02	52	917	"	"	"	"		
1-34	1	I	"	12	32	52	446	AM	OUT-42	25-40	28	19286	
1-35	"	II	"	13	02	45	988	"	"	40	"	19287	
1-36	"	III	"	16	02	52	917	"	"	35-40	30	19288	
1-37	12	I	7/20	15	17	53	569	FM	OUT-47	180	25	37998	
1-38	"	III	"	14	17	57	518	"	"	-40db	18	37997	
1-39	11	I	"	15	17	53	569	G-33	"	28-45	25		
1-40	"	III	"	14	17	57	518	"	"	"	"		
1-41	10	I	"	15	17	53	569	AM	OUT-42	44	30	19290	
1-42	"	III	"	14	17	57	518	"	"	42	"	19289	
1-43	3	II	7/21	14	32	52	875	FM	OUT-47	-30db	20	37999	
1-44	"	III	"	16	02	53	308	"	"	"	23	51801	
1-45	2	II	"	14	32	52	875	G-33	"	31-32	25		
1-46	"	III	"	16	02	53	308	"	"	"	"		
1-47	1	II	"	14	32	52	875	AM	OUT-42	50	30	19291	
1-48	"	III	"	16	02	53	308	"	"	50-57	32	19293	

Traverse Line 3

Record No.	Spread	Shot point	Date	Detonation time				Seismic equipment	Filter	Gain	Amp	Tape No.	Remarks
				Hour	Minute	Second							
3- 1	12	I	7/8	15	47	58	177	FM	OUT-47	-30db	16-23	37973	
3- 2	"	II	"	15	03	53	368	"	"	"	"	37972	
3- 3	"	III	"	16	32	52	632	"	"	-40db	14-22	37974	
3- 4	11	I	"	15	47	58	177	G-33	"	30-35	25		
3- 5	"	II	"	15	03	53	368	"	"	"	"		
3- 6	"	III	"	16	32	52	632	"	"	"	"		
3- 7	10	I	"	15	47	58	177	AM	OUT-42	32-40	27-33	19302	
3- 8	"	II	"	15	03	53	368	"	"	36-41	27-34	19301	
3- 9	"	III	"	16	32	52	632	"	"	32-40	27-33	19303	
3-10	9	I	7/9	17	17	54	925	FM	OUT-47	-30db	20	37977	
3-11	"	II	"	13	02	55	021	"	"	-40db	"	37975	
3-12	"	III	"	17	02	56	483	"	"	-30db	"	37976	
3-13	8	I	"	17	17	54	925	G-33	"	30-35	25		
3-14	"	II	"	13	02	55	021	"	"	"	"		
3-15	"	III	"	17	02	56	483	"	"	"	"		
3-16	7	I	"	17	17	54	925	AM	OUT-42	40	28-30	19269	
3-17	"	II	7/9	13	02	55	021	"	"	"	"	19267	
3-18	"	III	"	17	02	56	483	"	"	"	"	19268	
3-19	6	I	7/10	17	17	50	617	FM	OUT-47	-30db	21	37980	
3-20	"	II	"	14	17	54	088	"	"	"	20	37978	
3-21	"	III	"	14	48	02	852	"	"	"	"	37979	
3-22	5	I	"	17	17	50	617	G-33	"	26-30	25		
3-23	"	II	"	14	17	54	088	"	"	"	"		
3-24	"	III	"	14	48	02	852	"	"	"	"		
3-25	4	I	"	17	17	50	617	AM	OUT-42	40-42	28	19272	
3-26	"	II	"	14	17	54	088	"	"	"	"	19270	
3-27	"	III	"	14	48	02	852	"	"	"	"	19271	
3-28	3	I	7/11	15	47	51	515	FM	OUT-47	-30db	19	37981	
3-29	"	II	"	-	-	53	033	"	"	-20db	20	37982	
3-30	"	III	"	17	02	56	004	"	"	"	21	37984	
3-31	2	I	7/11	15	47	51	515	G-33	"	35	25		
3-32	"	II	"	-	-	53	033	"	"	"	"		
3-33	"	III	"	17	02	56	004	"	"	"	24-25		
3-34	1	I	"	15	47	51	515	AM	OUT-42	20-34	28	19273	
3-35	"	II	"	-	-	53	033	"	"	40	"	19274	
3-36	"	III	"	17	02	56	004	"	"	42-47	30	19276	

Traverse Line 4

Record No.	Spread	Shot point	Date	Detonation time				Seismic equipment	Filter	Gain	Amp	Tape No.	Re-marks
				Hour	Minute	Second							
4- 1	1	II	6/29	13	56			AM	OUT-42	36-45	20-34	19251	
4- 2	2	II	"	13	56			G-33	OUT-47	30	25-26		
4- 3	3	II	"	"	"			FM	"	-40db	17-20		
4- 4	1	I	6/30	15	25			AM	OUT-42	20-40	28-30	19252	
4- 5	"	III	"	17	16	30	407	"	"	40	26-33	19253	
4- 6	2	I	"	15	25			G-33	OUT-47	30	20		
4- 7	"	III	"	17	16	30	407	"	"	"	"		
4- 8	3	I	"	15	25			FM	"	-30db	10-19	37956	
4- 9	"	III	"	17	16	30	407	"	"	"	"	37958	
4-10	4	I	7/1	14	32	51	206	AM	OUT-42	40	27-30	19254	
4-11	"	II	"	15	47	-	131	"	"	"	"	19255	
4-12	5	I	"	14	32	51	206	G-33	OUT-47	25-30	25		
4-13	"	II	"	15	47	-	131	"	"	"	"		
4-14	6	I	"	14	32	51	206	FM	"	-30db	10-19	37959	
4-15	"	II	"	15	47	-	131	"	"	"	"	37961	
4-16	4	III	7/2	13	17	52	640	AM	OUT-42	40	28-30	19258	
4-17	5	III	"	13	17	52	640	G-33	OUT-47	25-30	25		
4-18	6	III	"	13	17	52	640	FM	"	-20db	10-19	37964	
4-19	7	I	7/3	14	33	08	413	AM	OUT-42	40	25-30	19260	
4-20	"	II	"	14	02	44	722	"	"	"	23-30	19259	
4-21	"	III	"	17	33	13	460	"	"	"	"	19263	
4-22	8	I	"	14	33	08	413	G-33	OUT-47	30	25		
4-23	"	II	"	14	02	44	722	"	"	28	"		
4-24	"	III	"	17	22	13	460	"	"	30-35	23-25		
4-25	9	I	"	14	33	08	413	FM	"	-20db	10-19	37966	
4-26	"	II	"	14	02	44	722	"	"	"	"	37965	
4-27	"	III	"	17	33	13	460	"	"	-40db	"	37968	
4-28	10	I	7/4	14	47	52	000	AM	OUT-42	40-55	23-30	19265	
4-29	"	II	"	15	32	53	970	"	"	42-51	25-31	19266	
4-30	"	III	"	13	02	53	888	"	"	40-55	23-30	19264	
4-31	11	I	7/4	14	47	52	000	G-33	OUT-47	25-30	25		
4-32	"	II	"	15	32	53	970	"	"	"	"		
4-33	"	III	"	13	02	53	888	"	"	"	"		
4-34	12	I	"	14	47	52	000	FM	"	-20db	10-19	37970	
4-35	"	II	"	15	32	53	970	"	"	"	14-18	37971	
4-36	"	III	"	13	02	53	888	"	"	-30db	10-19	37969	

Table 11-1 Index of Play Back Records

Traverse Line 2

FM : PT100 + MR20
AM : G11 + PMR7

Record No.	Spread	Shot point	Date	Seismic equipment	Filter	Gain	Amp	Tape No.	Re-marks
2- 1-1	1	I	7/25	AM	OUT-27	25-30	30	19294	
2- 1-2	1	I	"	"	OUT-42	"	"	19294	
2- 3-1	3	I	"	FM	OUT-24	-40db	19	52001	
2- 4-1	1	I	7/26	AM	OUT-27	25-28	28	19297	
2- 4-2	"	I	"	"	OUT-42	20-28	"	19297	
2- 5-1	"	II	"	"	OUT-27	23-28	"	19295	
2- 5-1	"	II	"	"	"	18-23	25	19295	
2- 5-1	"	II	"	"	"	35-45	30	19295	
2- 6-1	"	III	"	"	"	23-30	"	19296	
2-10-1	3	I	"	FM	OUT-24	-40db	19	52004	
2-11-1	"	II	"	"	"	"	"	52002	
2-12-1	"	III	"	"	"	"	"	52003	
2-13-1	4	I	7/27	AM	OUT-27	18-27	28	19298	
2-19-1	6	I	"	FM	OUT-24	-40db	17	52005	
2-20-1	"	II	"	"	"	"	18	52007	
2-21-1	"	III	"	"	"	"	17	52006	
2-22-1	7	I	7/28	AM	OUT-27	18-25	21	19306	
2-23-1	"	II	"	"	"	"	"	19305	
2-24-1	"	III	"	"	"	18-26	22	19304	
2-28-1	9	I	"	FM	OUT-24	-40db	19	52010	
2-29-1	"	II	"	"	"	"	18	52009	
2-30-1	"	III	"	"	"	"	"	52008	
2-31-1	1	I	7/29	"	"	"	"	52013	
2-32-1	"	II	"	"	"	"	"	52011	
2-33-1	"	III	"	"	"	"	"	52012	
2-34-1	4	I	"	AM	OUT-27	18-28	25	19309	
2-35-1	"	II	"	"	"	"	"	19307	
2-36-1	"	III	"	"	"	"	"	19308	

Table 11-2

Traverse Line 1

Record No.	Spread	Shot point	Date	Seismic equipment	Filter	Gain	Amp	Tape No.	Re-marks
1- 1-1	12	I	7/16	FM	OUT-24	-40db	20	37987	
1- 2-1	"	II	"	"	"	"	"	37986	
1- 3-1	"	III	"	"	"	"	"	37985	
1- 7-1	10	I	"	AM	OUT-27	18-30	28	19279	
1- 8-1	"	II	"	"	"	20-30	25	19278	
1- 9-1	"	III	"	"	"	20-29	28	19277	
1-10-1	9	I	7/17	FM	OUT-24	-40db	21	37989	
1-11-1	"	II	"	"	"	"	"	37988	
1-12-1	"	III	"	"	"	"	18	37990	
1-16-1	7	I	"	AM	OUT-27	18-28	28	19281	
1-17-1	"	II	"	"	"	"	"	19280	
1-18-1	"	III	"	"	"	"	"	19282	
1-19-1	6	I	7/18	FM	OUT-24	-40db	20	37993	
1-20-1	"	II	"	"	"	"	19	37991	
1-21-1	"	III	"	"	"	"	21	37992	
1-25-1	4	I	"	AM	OUT-27	18-40	28	19285	
1-26-1	"	II	"	"	"	21-38	"	19283	
1-27-1	"	III	"	"	"	20-44	"	19284	
1-28-1	3	I	7/19	FM	OUT-24	-40db	18	37994	
1-29-1	"	II	"	"	"	"	"	37995	
1-30-1	"	III	"	"	"	-30db	"	37996	
1-34-1	1	I	"	AM	OUT-27	18-30	28	19286	
1-34-2	"	I	"	"	"	"	"	"	60C cut
1-35-1	"	II	"	"	"	25-45	"	19287	
1-36-1	"	III	"	"	"	18-30	30	19288	
1-37-1	12	I	7/20	FM	OUT-24	-40db	18	37998	
1-38-2	"	III	"	"	"	"	19	37997	
1-41-1	10	I	"	AM	OUT-27	18-28	30	19290	
1-42-1	"	III	"	"	"	"	"	19289	
1-43-1	3	II	7/21	FM	OUT-24	-40db	19		
1-47-1	1	II	"	AM	OUT-27	25-41	30	19291	
1-48-1	"	III	"	'	"	"	"	19293	

Table 11-4
Traverse Line 3

Record No.	Spread	Shot point	Date	Seismic equipment	Filter	Gain	Amp	Tape No.	Remarks
3- 1-1	12	I	7/8	FM	OUT-24	-40db	16-23	37973	
3- 2-1	"	II	"	"	"	"	16-20	37972	
3- 3-1	"	III	"	"	"	"	14-20	37974	
3- 7-2	10	I	"	AM	OUT-42	20-23	27-33	19302	
3- 8-1	"	II	"	"	OUT-27	"	27-34	19301	
3- 8-2	"	II	"	"	OUT-42	"	"	19301	
3- 9-2	"	III	"	"	"	"	27-33	19303	
3-10-1	9	I	7/9	FM	OUT-24	-40db	20	37977	
3-10-2	"	I	"	"	OUT-30	"	"	37977	
3-11-1	"	II	"	"	OUT-24	"	"	37975	
3-11-2	"	II	"	"	OUT-30	"	"	37975	
3-12-1	"	III	"	"	OUT-24	"	"	37976	
3-12-2	"	III	"	"	OUT-30	"	"	37976	
3-16-1	7	I	"	AM	OUT-27	20-23	28-30	19269	
3-16-2	"	I	"	"	OUT-42	"	"	19269	
3-17-1	"	II	"	"	OUT-27	"	"	19267	
3-17-2	"	II	"	"	OUT-42	"	"	19267	
3-18-1	"	III	"	"	OUT-27	"	"	19268	
3-18-2	"	III	"	"	OUT-42	"	"	19268	
3-19-1	6	I	7/10	FM	OUT-24	-40db	21	37980	
3-19-2	"	I	"	"	OUT-30	"	"	37980	
3-20-1	"	II	"	"	OUT-24	"	20	37978	
3-20-2	"	II	"	"	OUT-30	"	"	37978	
3-21-1	"	III	"	"	OUT-24	"	"	37979	
3-21-2	"	III	"	"	OUT-30	"	"	37979	
3-25-1	4	I	"	AM	OUT-27	20-25	28	19272	
3-25-2	"	I	"	"	OUT-42	"	"	19272	
3-26-1	"	II	"	"	OUT-27	"	"	19270	
3-26-2	"	II	"	"	OUT-42	"	"	19270	
3-27-1	"	III	"	"	OUT-27	"	"	19271	
3-27-2	"	III	"	"	OUT-42	20-28	"	19271	
3-38-1	3	I	7/11	FM	OUT-24	-40db	19	37971	
3-38-2	"	I	"	"	OUT-30	"	"	37971	
3-39-1	"	II	"	"	OUT-24	"	20	37982	
3-39-2	"	II	"	"	OUT-30	"	"	37982	
3-30-1	"	III	"	"	OUT-24	-30db	21	37984	
3-30-2	"	III	"	"	OUT-30	"	"	37984	
3-34-1	1	I	"	AM	OUT-42	18-24	28	19273	
3-34-2	"	I	"	"	OUT-27	"	"	19273	
3-35-1	"	II	"	"	"	20-23	"	19274	
3-35-2	"	II	"	"	OUT-42	"	"	19274	
3-36-1	"	III	"	"	OUT-27	20-25	30	19276	
3-36-2	"	III	"	"	OUT-42	"	"	19276	

Table 11-5
Traverse Line 4

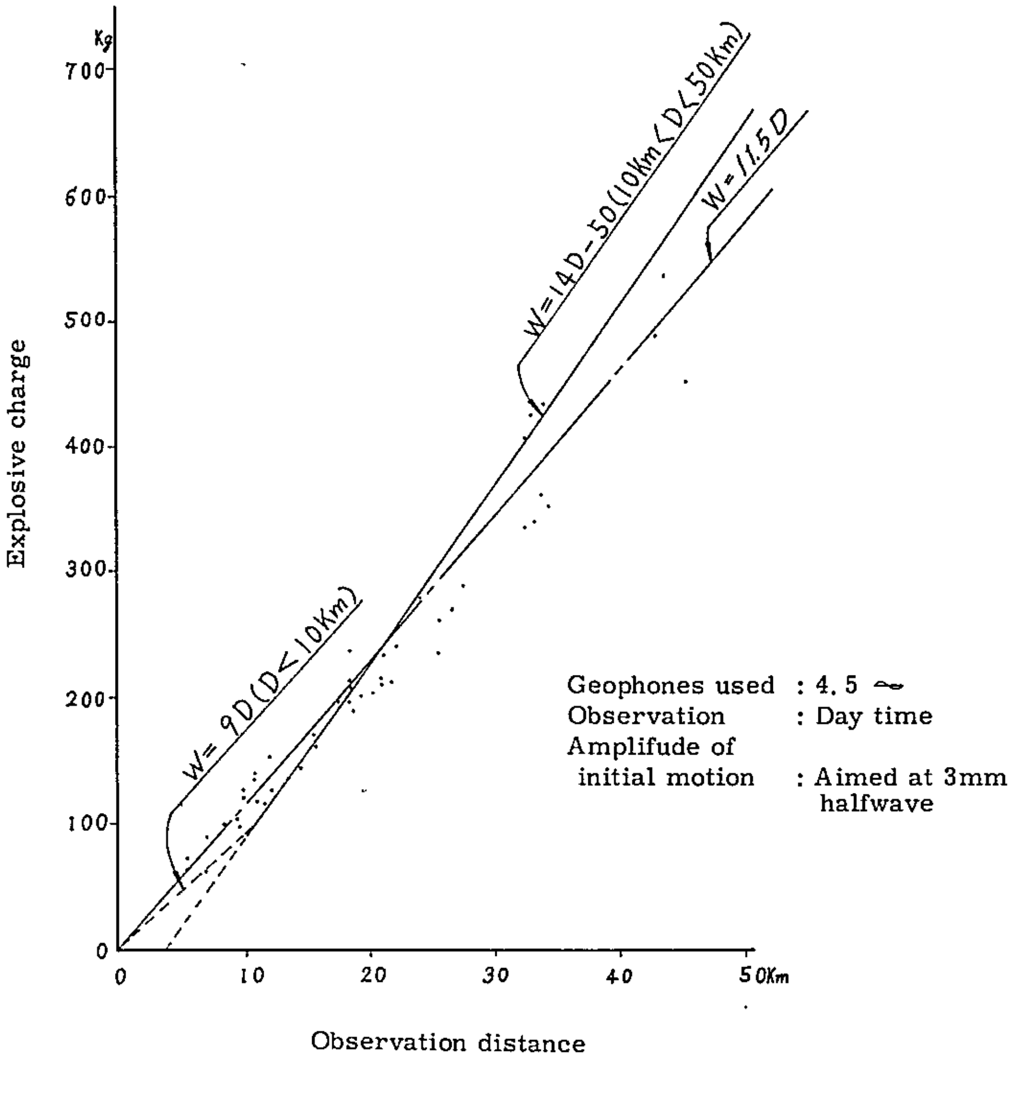
Record No.	Spread	Shot point	Date	Seismic equipment	Filter	Gain	Amp	Tape No.	Re-marks
4- 1-1	1	II	6/29	AM	OUT-27	20-30	20-34	19251	
4- 4-2	"	I	6/30	"	OUT-42	"	30-43	19252	
4- 5-1	"	III	"	"	OUT-27	"	26-33	19253	
4- 5-1	"	III	"	"	"	21-30	28	"	
4- 8-2	3	I	"	FM	OUT-47	-30db	10-19	37956	
4- 9-1	"	III	"	"	OUT-24	-40db	18	37958	
4- 9-2	"	III	"	"	OUT-30	-30db	"	"	
4-10-2	4	I	7/1	AM	OUT-42	20-30	28-30	19254	
4-11-2	"	II	"	"	"	"	"	19255	
4-14-2	6	I	"	FM	OUT-30	-40db	10-19	37959	
4-15-2	"	II	"	"	OUT-47	"	"	37961	
4-16-1	4	III	7/2	AM	OUT-27	20-30	28-30	19258	
4-18-1	6	III	"	FM	OUT-30	-40db	10-19	37964	
4-18-2	"	III	"	"	OUT-47	"	"	"	
4-19-2	7	I	7/3	AM	OUT-42	20-30	25-30	19260	
4-20-1	"	II	"	"	OUT-27	21-30	28	19259	
4-20-2	"	II	"	"	OUT-42	20-30	23-30	"	
4-21-1	"	III	"	"	OUT-27	"	"	19263	
4-25-1	9	I	"	FM	OUT-24	-40db	10-19	37966	
4-26-2	"	II	"	"	OUT-47	"	"	37965	
4-27-2	"	III	"	"	"	"	"	37968	
4-28-1	10	I	7/4	AM	OUT-27	21-30	28	19265	
4-28-2	"	I	"	"	OUT-42	20-30	23-30	"	
4-29-1	"	II	"	"	OUT-27	"	27-31	19266	
4-30-2	"	III	"	"	OUT-42	"	23-30	19264	
4-34-1	12	I	"	FM	OUT-24	-40db	10-19	37970	
4-34-2	"	I	"	"	OUT-30	-50db	"	"	
4-35-1	"	II	"	"	OUT-24	"	12-19	37971	
4-36-2	"	III	"	"	OUT-47	"	11-18	37979	

In this chapter, the operational stages shown in Figure 8 will be described.

3 - 2 - 1 Outline of record

One of the disadvantages of observation during the day is the interfering vibration caused by various sources. All efforts had been made to prevent the lowering of the S. -N. ratio. In the records of the earlier part of the survey, there are some detonations which are considered as somewhat insufficient in explosive charges, but in the later works the records are much im-

Fig. 9 Chart Showing Relation between Distance and Explosive Charge.



proved as explosive charges were increased and noises were eliminated fro detonations with long distance receiving points and for those considered to have low explosion effect because of the geological and topographic conditions. As a result, velocities and reflections of the after phases were detected near the shot points and the observation records were generally good.

The relation between the explosive charge and the distance was set at

$$W = 11.5\,D$$

W = explosive charge km

D = distance km (4.5 cycles)

from experiments in Tertiary systems. But the best explosive charge for day time observation in the present case was

$$W = 9\,D \qquad D \qquad 10 \text{ km}$$

$$W = 14\,D - 50 \qquad 10 \text{ km} \qquad D \qquad 50 \text{ km}$$

Records with relatively good phase velocity of second and third motions are listed in Table 12.

Traverse No.	Shot point	Spread
2	I	1, 2, 3 (Surface wave)
	II	1, 2
	III	1, 2, 3, 4
1	I	3, 4, 5, 6, 8
	II	2, 3, 9
	III	Generally poor
3	I	5, 2 (Reflection)
	II	2, 5, 11, 12, 8 (Large phase velocity)
	III	2, 3
4	I	4, 5, 6, 1 (Reflection), Z (Surface wave)
	II	5, 1 (Large phase velocity)
	III	4, 5, 6 (All large phase velocity)

Table 12

Characteristic records are as follows:

o Record from Shot point III of Traverse Line 2.

The 2nd and 3rd motions are clearly recorded in 1 - 4 spread, but they are almost extinct in 5 - 9 spread adjacent to the above.

8 spread record from shot point I, Traverse Line 1; 2 spread record from shot point II, Traverse Line 1.

Waves believed to be the repetition of 2nd and 3rd motions is recorded in several places.

Record from shot point III, Traverse Line 3.

This record shows relatively small S. -N. ratio near the initial motion, but the amplitudes of the 2nd and 3rd motions become larger, and the frequency lower, and waves believed to be the repetition of fast phases are recorded.

1 spread record from shot point II, Traverse Line 4, 4, 5, 6 spread record from shot point III, Traverse Line 4.

Waves believed to be the repetition of initial and 2nd motion are recorded in the former, and fast phase which are unusual for after phases are observed in the latter records.

These phase velocities of the 2nd and 3rd motions play important role in the analysis of multi-layered structures. The parts of the structures not shown in the initial motion are analysed experimentally by the travel-time curve constructed by parallel gliding of these phase velocities. There are many profiles in the present survey derived by these phase velocities.

As mentioned above, there are many wave surfaces which are considered to be multiple waves in the records of this survey. The reasons for inferring these wave surfaces to be multiple waves are that these wave surfaces have intervals and arrangement similar to multiple reflection waves, they are approximately of the same velocity and are lived symmetrically, the line up is similar to each other, and that the frequency gradually changes. But there are some doubts in inferring them to be similar to the multiple reflections which are observed in reflection method, because marked multiple reflections were not observed in the reflection seismic survey in this area, and also because they are observed in marine reflection surveys while the present survey is on land.

Local attenuation of the 2nd and 3rd motions, fast phase velocitions and other phenomenia are observed in the after phase of the records together with the multiple waves. These phenomena are considered from their distribution to be caused by the geology and geological structure of the area. The cause and the mechanism of the origin of these phenomena including multiple reflection, however, are all unknown, and thus the interpretation and application of the phenomena must be done with care.

3 - 2 - 2 Construction and calibration of the travel-time curve

As the scale of the travel-time chart and the analysed profile was prescribed at 50,000 : 1, the errors of calculation of real travel-time and the offset position of the receiving points, topographic correction of receiving and shot points, uphole time of shot points were all within corresponding limits (error $^1/100\sqrt{n}$ sec. n = number of measurements, so that the total error became $^1/100$ sec.)

It was necessary to establish the center line for of the traverse lines for the analytical calculations since many of the spread arrangements were irregular. Shot points I-II-III and shot points I - III were used as the center lines. Thus the arrangement of the receiving points and the traveltime were those projected to the center line. Therefore the analysed profile down to 2,000 m is that of the section of the line joining shot points I - II and II - III, profile deeper than 2,000 m is the section of the line joining shot points I - II. But the projection of the real travel-time and the receiving points are within the allowable errors and in practice they both show the same profile.

The maximum height difference within the traverses were 121 - 294 m. This results in errors on the assumed velocities of the travel-time and it was necessary to correct them for topography by setting analysing base level.

The correction was done by the following equation.

$$\Delta tn = \frac{h\cos\theta 1n}{V_1}$$

tn: topographic correction for travel time of nth layer when parellel layers are assumed.

h. receiving point height - analysing base level

$\theta 1n$: $\sin^{-1} \frac{V1}{V_n}$

V1 : seismic wave velocity of the first layer

V_n : " " " " nth "

In this method the correction Δtn becomes larger for travel-time from lower formations and the maximum is $\frac{h}{V_1}$. These corrections were done also for the shot points. The analysing base levels for each traverse is shown in Table 13.

3 - 2 - 3 Annalytical calculations

Zero-travel-time method was used for the analytical calculations, and 1107 UNIVAC computer computer was used. The process of the work is shown in Figure 10.

Fig. 10 Process Analysis for Travel - Time Curve

Manual Operations (1 - 8):

1. Record reading
2. Travel-time calibration (receiving point location, topography, surface layers, detonation depths etc.)
3. Plotting travel-time curves.
4. Adjustment of travel-time curves.
5. Travel-time reading of corresponding seismic velocity layers of each receiving point.
6. Calculation of zero-travel-time of each seismic velocity layer at each receiving point.
7. Preparation of data sheet (imput data)
8. Preparation of punch cards.

Computer (9 - 10):

9. Electronic computer
10. Automatic printing of calculated results (output data)

Playback center (7 - 10)

Manual Operations (11 - 13):

11. Drawing the depths of the velocity layers from the receiving points on the base level by compass.
12. Obtaining the profiles of velocity layers as circular envelope.
13. Check the velocity layer structures by pass calculation.

Table 13 Datum Lines of Traverse Lines

Traverse No.	Base level of analysis	Remarks
2	+ 150 m	
1	0 m	
3	+ 40 m	Land surface was used as base level for spreads 1, 2, 5 - 12
4	+ 35 m	Land surface was used as base level for spreads 1 - 6

Generally the up hole time of the shot points are measured by the receivers set at each shot hole, but in the present survey, the measured values at the spread including the shot holes were corrected proportionally to the depth to the explosive surfaces, and these values were used.

The data used in these calculations are listed in the attached tables.

The adjustment and analysis of travel-time curves were done by applying "The selection of refraction travel-time and the analysis of refraction travel-time curve at zero-travel-time" by Kurihara.

The following conditions were satisfied for the adjustment of the travel-time curve,

- the same terminal travel-time between both shot points,
- parallel travel-time curve for curves with identical direction from a single refracting layer,
- same zero-travel-time for one refracting layer at a single shot point.

This adjustment of the travel-time curve is the most important work in the refraction analytical process, and it is usually done with great care.

The equation used in the present survey is the one which seek the layer depth (vertical depth), inclination, and seismic wave velocity from the receiving distance, zero-travel-time, and the apparent velocity at the receiving point.

The recurrence formula of the k-th layer used in programming for UNIVAC computer is as follows.

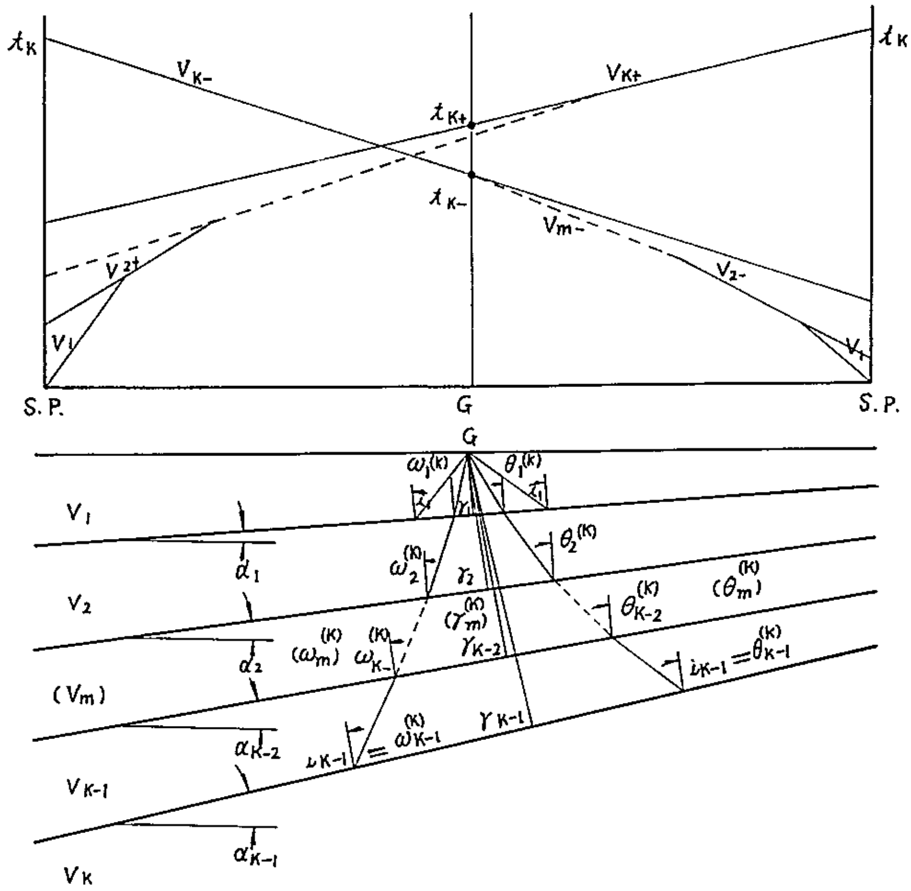
Input data sheets were prepared for these calculations. In these sheets there are columns for number of layers (n), V1, V2+, V2-, V3+, V3- ...... Vn+, Vn-, 2GO, 3GO, ... nGO, and these values were to be punched in the punch card.

A card will be made for each receiving points, but the computing output can be in table form when these cards and the computing program are fed to the computer. The computing time is approximately 2 min. 20 sec. for one travers (6 layered structure with 12 spreads), and about 0. 5 sec. for one raceiving point.

Examples of input data sheets and the output of the refraction calculations are listed in Tables 14 and 15.

The structural profile of the refracting layers under the traverse lines can be obtained as the envelope by drawing an arc with radius of the output and the center at the receiving point. These structural profiles were checked by graphic analysis.

Fig. 11 Illustration of Path and Angles of Refraction Ray through multilayered Structure



$$\alpha_1 = 1/2\,(\sin^{-1}\frac{V1}{V2-} - \sin^{-1}\frac{V1}{V2+})$$

$$i_1 = 1/2\,(\sin^{-1}\frac{V1}{V2-} + \sin^{-1}\frac{V1}{V2+})$$

$$\gamma_1 = 1/2\ V1\,t\,2GO\ \mathrm{Sec}\ i\ 1$$

$$V_2 = V1\ \mathrm{COSEC}\ i\ 1$$

$$\theta_1^{(K)} = \sin^{-1}\frac{V1}{Vk-} - \alpha\ 1$$

$$\omega_1^{(K)} = \sin^{-1}\frac{V1}{Vk+} + \alpha\ 1$$

$$\theta_1^{(K)} = \sin^{-1}(\frac{Vm}{Vm-1}\sin\theta\frac{(k)}{m-1}) - \alpha\ m + \alpha\ m-1$$

$$\omega_m^{(k)} = \sin^{-1}\left(\frac{Vm}{Vm-1} \sin \omega \frac{(k)}{m-1}\right) + \alpha m - \alpha m-1$$

$$Vk = Vk_{-1} \operatorname{cosec} i\ k-1$$

$$\alpha k-1 = 1/2 \sin^{-1}\left(\frac{Vk-1}{Vk-2} \sin \theta \frac{(k)}{k-2}\right) - 1/2 \sin^{-1}\left(\frac{Vk-1}{Vk-2} \sin \omega \frac{(k)}{k-2}\right) + \alpha\ k-2$$

$$i\ k-1 = 1/2 \sin^{-1}\left(\frac{Vk-1}{Vk-2} \sin \theta \frac{(k)}{k-2}\right) + 1/2 \sin^{-1}\left(\frac{Vk-1}{Vk-2} \sin \omega \frac{(k)}{k-2}\right)$$

$$\gamma\ k-1 = \frac{Vk-1}{2} \sec i\ k-1 \Big[t\, KGO + \sum_{m=2}^{k-1} \frac{m-1}{Vm} \Big\{\cos\left(\theta_m^{(k)} + \alpha m - \alpha m-1\right)$$

$$+ \cos\left(\omega_m^{(k)} - \alpha m + \alpha m-1\right) \Big\} - \sum_{m=2}^{k-2} \frac{m}{Vm} \left(\cos \theta \frac{(k)}{m} + \cos \omega \frac{(k)}{m}\right)\Big]$$

The travel-time curves and analysed profiles shown in Figures 12, 14, 16, 18 were obtained by the above processes. The zero-travel-time calculation sheets, input data sheets, calculation output are listed in the attached sheet.

Table 15 Example of Out-put of Computor

```
                   (V1)  (t2GO)(t3GO)(t4GO)(t5GO)  (V2-) (V2+)(V3-) (V3+) (V4-) (V4+)(V5-) (V5+)
DATA... 20103  5  1900.0 33.0 70.0 104.0 137.0  -.02500.02350.03100.02900.03800.03600.04500.04200.0 -.0 -.0
          |  |  |
          |  |  └ Formation     * 20103          N 5              V1  1900.
          |  └──── Receiving
          |          Point No.  t2GO  .330       V2-  2500.        V2+  2350.
          └─── Spread No.       T30   .700       V3-  3100.        V3+  2900.
        └──── Traverse          T40  1.040       V4-  3800.        V4+  3600.
                                T50  1.370       V5-  4500.        V5+  4200.
                                GAMMA1 (γ1) 505.9   ALPHA1 (α1)-2.24   I1 (i1) 51.71   V2   2420.8
                                GAMMA2     1098.5   ALPHA2     -1.11   I2      53.92   V3   2995.2
                                GAMMA3     1643.6   ALPHA3       .12   I3      54.15   V4   3695.2
                                GAMMA4     2420.8   ALPHA4      -.43   I4      58.31   V5   4342.8


DATA... 20104  5  1900.0 34.0 69.0 105.0 138.0  -.02500.02350.03100.02900.03800.03600.04500.04200.0 -.0 -.0
                                * 20104            N5             V1  1900
                                T20   .340       V2-   2500.       V2+  2350.
                                T30   .690       V3-   3100.       V3+  2900.
                                T40  1.050       V4-   3800.       V4+  3600.
                                T50  1.380       V5-   4500.       V5+  4200.
                                GAMMA1      521.2   ALPHA1      -2.24   I1      51.71   V2   2420.8
                                GAMMA2     1067.6   ALPHA2      -1.11   I2      53.92   V3   2995.2
                                GAMMA3     1676.6   ALPHA3        .12   I3      54.15   V4   3695.2
                                GAMMA4     2440.7   ALPHA4       -.43   I4      58.31   V5   4342.8
```

Table 14 Example of Zero-Travel-Time Sheet

SRM2 (Seismic Refraction Method2) Data Sheet

Note (1) △ : Position of decimal poine (2) unit of t : 1/100 sec (3) L : No of Layer

No. 1

Line No. Station No.	L	V_1	t_2 go	t_3 go	t_4 go	t_5 go	t_6 go	V_2 −	V_2 +	V_3 −	V_3 +	V_4 −	V_4 +	V_5 −	V_5 +	V_6 −	V_6 +
1 2 3 4 5	6 7	8 9 10 11 12	13 14 15 16	17 18 19 20	21 22 23 24	25 26 27 28	29 30 31 32	33 34 35 36 37	38 39 40 41 42	43 44 45 46 47	48 49 50 51 52	53 54 55 56 57	58 59 60 61 62	63 64 65 66 67	68 69 70 71 72	73 74 75 76 77	78 79 80 81 82
		△	△	△	△	△	△	△	△	△	△	△	△	△	△	△	△
20101	5	1900	34	71	104	139		2500	2350	3100	2900	3800	3600	4500	4200		
20102	5		34	70	104	138											
20103	5		33	70	104	137											
20104	5		34	69	105	138											
20105	5		35	69	105	137											
20106	5		35	69	106	138											
20107	5		36	70	106	136											
20108	5		36	70	107	137											
20109	5		36	70	106	137											
20110	5		35	70	108	138											
20111	5		36	71	106	139											
20112	5		37	69	107	138											
20113	5		37	70	107	139											
20114	5		37	71	106	140											
20115	5		38	70	107	139											
20116	5		38	70	106	140											
20117	5		38	71	106	139											
20118	5		39	72	107	140											
20119	5		38	71	107	140											
20120	5		38	72	107	140											
20121	5		39	72	108	139											
20122	5		40	72	106	140											
20123	5		39	72	107	140											
20124	5		40	71	107	141											

Ⅳ Analytical Results Interpretation

IV Analytical Results Interpretation

The seismic wave velocity distribution of the three areas of western Taiwan, namely, northern (Traverse Lines 2 and 1), central (Traverse Line 3), and southern (Traverse Line 4), obtained from CPC velocity log data is listed in Table 16.

Table 16. Comparison of Seismic Wave Velocities in the Western TAIWAN

Age			Formation	Seismic wave velocity by velocity log: Northern area (Traverse 2&1) m/s	Contral area (Traverse 3) m/s	Southersn area (Traverse 4) m/s
Plio-Pleistocene			Toukoshan Formation	1,980-2,500	2,600-2,700	2,500(1,730-2,740) (Erhchungchi F.)
Tertiary	Pliocene		Cholan Formation	2,200-3,000	3,000-3,700	2,800-3,600 (Kanhsialio F.) (Upper Gutingkeng F.) (Liuchungchi F.) (Lower Gutingkeng F.) (Yunshuichi F.)
Tertiary	Pliocene		Chinshui Shale	2,100-3,800	3,800	
Tertiary	Miocene	Upper	Kueichiulin Formation	3,500-4,100		
Tertiary	Miocene	Upper	Nanchuang Formation	3,100-4,300		(Kengnei F.) 2,500-3,800(Ailiaochiao F.) 3,200 (Changchihkeng F.)
Tertiary	Miocene	Upper	Nankang Formation	3,700-3,800 (Nankang, Shihti, Taliao, Mushan Formations)		
Tertiary	Miocene	Lower	Shihti Formation			
Tertiary	Miocene	Lower	Taliao Formation			
Tertiary	Miocene	Lower	Mushan Formation			
Tertiary	Miocene	Lower	Wushishan Formation			
Mesozoic Cretaceous					3,500-5,300	

The average seismic wave velocities of western Taiwan calculated from the above data are as follows.

Geology		Velocities
Pleistocene series		2,100 - 2,300 m/s
Pliocene series		2,800 - 3,300
Miocene series	upper	3,600 - 4,000
	middle lower	3,800 (±)
Mesozoic formations		4,400 - 5,300

Generalized from velocity data of CPC

The figures for Mesozoic and Pleistocene rocks are not much different from the data obtained from other areas, but the velocities of the Neogene Tertiary system are approximately 1,000 m/s larger than those of Japan which are shown in Table 17.

Table 17 Summarized of Seismic Wave Velocities of Cenozoic Formations and its Basement Rocks on Coal Field in Japan.

Locality		Seismic wave velocities: Tertiary (m/s)	Seismic wave velocities: Basement (m/s)	
Hokkaido	Kushiro district	1,700-3,100	3,800-3,900	Cretaceous Sedimentary rocks
	Ishikari district	2,000-3,800		
Eastern Honshu	Joban district	2,000-3,800	4,400-5,500	Mesozoic, Paleozoic Sedimentary rocks Schists
Western Honshu	Ube district	2,200-2,700	over 4,200	Schists, Mesozoic Granites, Metamorphic rocks
Northern Fukuoka	Kokura district		over 4,500	Granites,Volcanic rocks
	Chikuho district		over 4,500	Granites,Paleozoic
	Kasuya district		over 4,500	Granites, Metamorphic rocks
	Fukuoka district		over 4,500	Granites
	Miike district		over 4,500	Granites Schists

According to Table 16, the velocity variation with the age of the strata is evident in this area, and it was anticipated that the stratigraphic velocity layers would be drawn relatively clearly in the travel-time curve. Also the formations were thick and the observations were carried out at long distances, these conditions contributed to the clear description of the phases of the 2nd, 3rd, and further motions in the travel-time curve.

4 - 1 Analysis and interpretation of the traverses.

4 - 1 - 1 Traverse Line 2.

(1) Seismic wave velocity layers and analysed profile.

The velocity layers and the distribution of the seismic wave velocities of this traverse can be divided into the five groups listed in Table 18. These groups were interpreted to be the formations listed on the right column of the table from velocity log data of wells KY-1, PC-1 and PS-6.

Seismic wave velocity layers	Seismic wave velocities (from analysed profiles) Southern area m/s	Northern area m/s	Correlated major formations	
1st layer	1,700	1,700-1,900	Plio-Pleistocene	Tokoshan Formation
2nd " } 3rd "	2,400-3,200	2,420-2,800	Pliocene	Cholan Formation Chinshui Formation
4th "	3,390-3,840	2,990-3,400	Miocene	Kueichiulin Formation
5th "	4,380-4,430	3,690-4,200	Miocene	Nanchuang Formation Nankang Formation
6th "	4,940-5,040	4,340-4,820	Miocene	Shihti Formation Taliao Formation

Table 18 Relation between Velocity Layers and Strata in Traverse Line 2.

The subsurface structure of this traverse is shown in the analysed profile, it is seen that the seismic wave velocities and the thicknesses of the formations increase from north to south.

These velocity layers show irregular thickness variation near faults, but as a whole they become thicker to the south. The 1st layer increases from 450m to 600m, the 2nd and 3rd from 500m to 1,350m, the 4th from 600m to 1, 600m, the 5th from 700m to 1, 700m, they all have thickness in the order of 1, 000m in the southern part of the traverse. As the result of the thickness variation, the lowermost 6th layer in the profile is 2, 300m deep in the north and 5, 000m deep in the south. This layer is interpreted as lower Miocene formation lower than Shihti Formation, but since this is based on insufficient data, it needs further investigation.

Also the existence of 5, 660 m/s and 5, 800 m/s layers which were observed in Traverse 3 was assumed under this traverse as the Mesozoic velocity layer. The upper limit of these layers is inferred from KY-1 well and gravimetric data to be about 6, 000m deep in area between shot points I and II, 8. 000m deep at shot point II, and to dip southward monoclinically.

The velocities of Neogene Tertiary system, namely those below 2nd and 3rd layers (Cholan Formation) are somewhat faster than the values generally obtained. This tendency is especially evident in the southern areas where the velocities are approximately 1, 000 m/s greater than the usual Tertiary system.

This is also fairly clearly observed in the velocity log of drill wells KY-1 in north, PC-1 in central area, and PS-6 in southwest.

KY-1	$V = 1,900 + 0.65Z$ ($Z < 2,800$m)
PC-1	$V = 2,200 + 0.505Z$ ($Z < 3,300$)
PS-6	$V = 2,330 + 0.625Z$ ($Z < 3,100$)

It is seen that the velocity of the southern PS-6 is several hundred meters/second greater than the other northern two.

The results of geological and seismic surveys indicate that this increase of velocity in the south occurs in the area east of the Miocene Hukou hinge line.

The horizontal and vertical velocities of this area obtained by refraction seismic and velocity logging are as follows.

Velocity layer	Refraction seismic	Velocity log
1st	1, 700 - 1, 900 m/s	2, 000 - 2, 500 m/s
2nd and 3rd	2, 420 - 3, 200	2, 400 - 3, 300
4th	3, 000 - 3, 840	3, 600 - 4, 100
5th	3, 690 - 4, 430	
6th	4, 340 - 5, 040	

It is seen that horizontal velocities are higher by approximately 1.1 fold. This velocity ratio is similar to those measured in Japan.

(2) Geological interpretation map

(a) Anticlinal structures

The major anticlinal structures of this area are Pingchen, Hukou, and Tungkeng anticlines.

Hukou Anticline extends in east-west direction near Shot Point II, and in the northern wing it is associated with fractured Hukou Fault which is parallel to the anticline axis. The dip of both wings of this anticline is very gentle in the analysed profile compared to that of the geological survey. This is believed to be the result of analysis with weight on the travel-time from Shot Point II, because the records of 2nd and 3rd motions from Shot Points I and III were insufficient. Thus the anticlinal structures of the geologic interpretation map were made by analysis with heavier weight on the velocity layers of vertical physical conditions (compression, weathering, depth, porosity, water content) rather than stratigraphic velocity layers.

Tungkeng structure near No. 20 of Spread 8 also has anticlinal axis in east-west direction and its northern wing is cut by east-west trending Hsinchu Fault. The existence of this structure was predicted by geological survey, but this present survey was reconnaissance in nature and the structure could not be confirmed by the analysis. Pingchen Anticline near No. 14 of Spread 4 is a small structure, but is fairly clearly observed in the deeper parts. This structure is hardly observed in other traverses and thus it is a notable structure in this traverse.

(b) Fault structures

The faults clearly observed in the travel-time curve of this traverse are Hukou Fault near Shot Point II and Hsinchu Fault north of Shot Point III. The geologic interpretation map shows that both faults displace Cholan Formation in the upper part and are marked reverse faults with southward dip and displacement of 200 - 300m. It is also inferred that Hukou Fault is associated with other faults and fractured zone or fault zone.

The structure of the deeper parts of Hsinchu Fault at south of the Hukou Fault is not clear, this is because we lack travel-time curve extending in this region. More detailed structure can be obtained from long distance detonation data of south of Shot Point III. There is also a zone between Spread 2 and Spread 3 where the seismic wave velocity changes abruptly.

The S-N ratio of reflection seismic method decreases in this zone, and this seems to suggest bending or other notable structure in formations below Nanchuang Formation 1,700m deep. This structure needs further geological and geophysical investigation.

These results of analysis agree well with the results of reflection seismic and gravimetric surveys carried out previously in this area.

(3) Basement

Velocity layer considered to be the basement could not be detected in this traverse. The length of this traverse was 33.7 km, and considering the velocity distribution it was foreseen that it would not be possible to detect the basement by the present conditions. The basement shown in the analysed profile is the upper limit of the basement based on the assumption that the velocity of the basement be equal to that of Traverse Line 3 and the dip of the Neogene Tertiary system to be paralleled to that of the upper parts. The shallowest calculated depth with the above assumption is 4,500m. This agrees with the geological inferrence that the basement of Kuanyin area is 4,000m. If the above basement depth is correct, the lower Miocene and the lower formations are developed to thicknesses in the order of 5,000m.

4 - 1 - 2 Traverse Line 1

(1) Seismic velocity layers and analysed profile

The seismic wave velocity distribution was inferred to be as follows. (Table 19) The interpretation of this distribution based on CTH-2 and TCS-2 well data drilled on both wings of this traverse is listed in the right column of the table.

Seismic wave velocity layers	Velocities (from analysed profiles)	Correlated major formations	
1st layer	1,900 m/s	Plio-Pleistocene	Toukoshan Formation
2nd "	2,100 - 2,300	Pliocene	Cholan Formation
3rd a "	2,690 - 2,940		
3rd b "	3,270 - 3,550	Pliocene	Chinshui Formation
4th "		Miocene	Kueichiulin Formation
5th "	3,920 - 4,200	Miocene	Nanchuang Formation
6th "	4,720 - 5,190		Nankang Formation
			Shihti Formation

Table 19 Relation between Velocity Layers and Strata in Traverse Line 1.

Fig. 12 Travel-Time Curves and Seismic Refraction Profile of Traverse Line 2

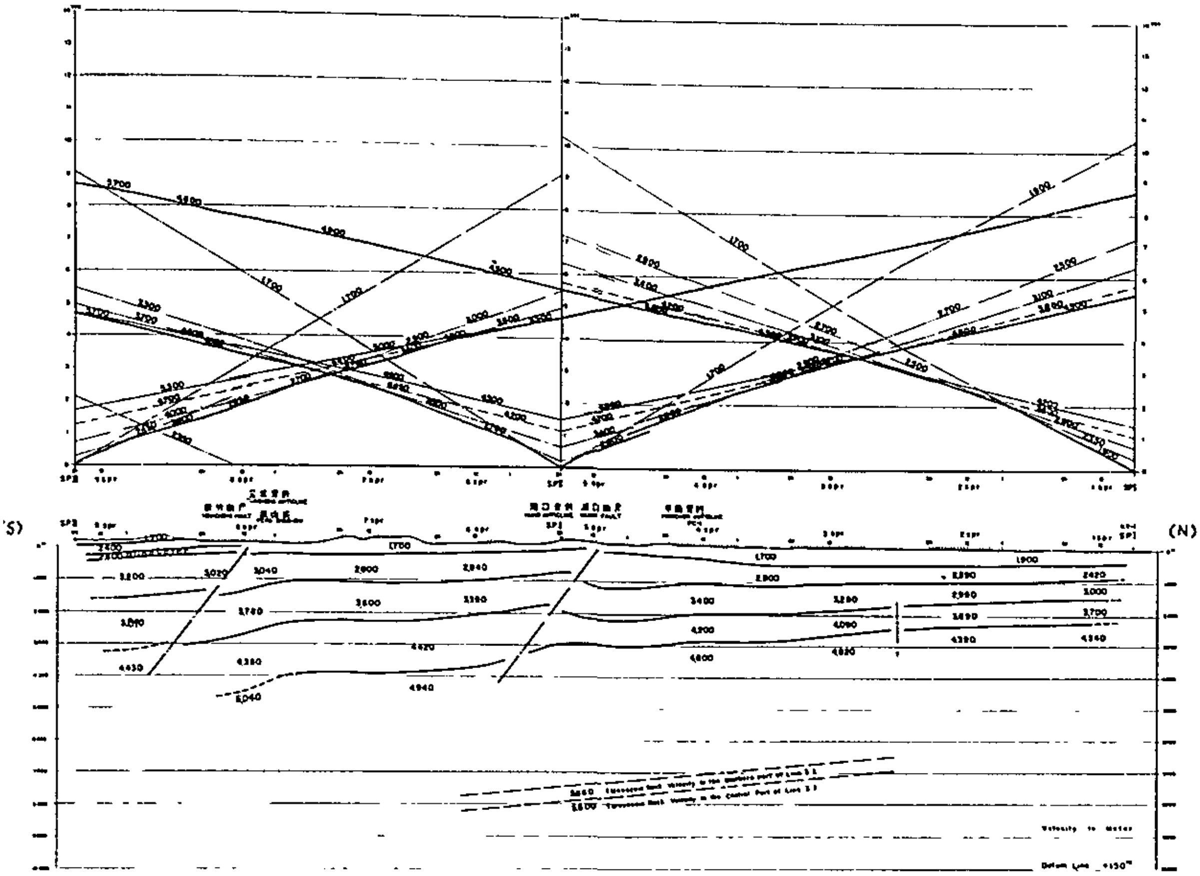
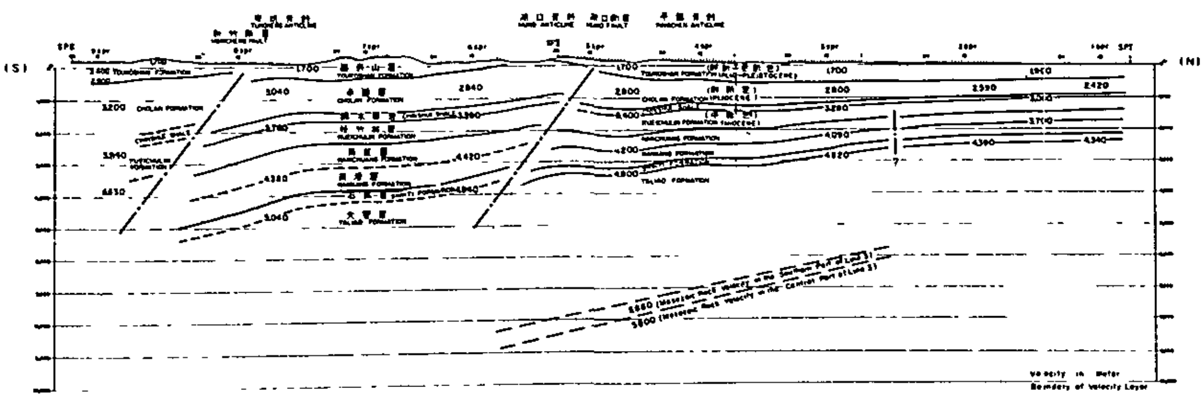


Fig. 13 Geologic Interpretation on Seismic Refraction Profile of Traverse Line 2



The subsurface structure of this traverse is deep in the central part and gently rises at both wings. It is generally a simple structure, but there are some faults and other structures.

The thicknesses of the velocity layers of the analysed profile are as follows.

Seismic wave velocity layers	Thickness
1st layer	50 - 400m
2nd layer	250 - 550
3rd layer	400 - 600
3rd b and 4th layers	400 - 900
5th layer	1,000 - 1,700

This table shows that the thickness generally increases in the lower parts. This tendency is more conspicuous near the 5th layer corresponding to Nangkang and Nanchuang formations and is about 1700 m. Also the velocity layers are mostly well developed in the central parts with the maximum between Houlung-chi and Chungkang-chi. But 3rd b and 4th layers which are correlated to Kueichiukin Formation is the thickest between Tiechenshan and Tunghsiao in the southern part of the traverse and is somewhat different from other formations. The uplift at both ends of the traverse is of Tiechenshan Tunghsiao Anticline in the western part and the anticline of Shingtsaopu and in the eastern wing there seems to be a rise eastward. The lowermost layer of the analysed profile is the 4, 720 - 5, 190 m/s layer correlated to the Shihti Formation. This layer is calculated to be 3, 700m thick in the central part of the traverse and 2, 800m at both ends.

One characteristic of this traverse is that there are no large horizontal variation of the velocity distribution. This tendency continues and the velocity distribution of the formations as shown in Table 19 is very similar to those observed in Traverse Line 2 in the north. This is also fairly well observed by velocity log of CTH-2 well in the north and TCS-2 well in the southern part of this traverse.

QTH-2	$V = 2,035 + 0.8\ Z\ (Z \leq 4,000\ m)$
TCS-2	$V = 2,285 + 0.57\ Z\ (Z < 3,600\ m)$

These data show that the seismic wave velocity near Traverse Lines 2 and 1 has somewhat larger rate of increase near CTH-2 well at the northern part of the traverse, but as a whole it is similar to that of the southern part (south of 3 Spread) of Traverse Line 2.

These results indicate that the seismic wave velocities of the Tertiary system near this traverse are similar to those near Traverse Line 2 in that they are about 1,000 m/s faster than that of the Tertiary system of Japan, and the horizontal velocity distribution is about 10% higher than the vertical velocity distribution.

(2) Geological interpretation map

The interpreted profile of this traverse was made by referring to the drilling data of CTH-2 well in the north, TCS-2 well in the south, and of Tiechenshan-Tunghsiao Anticline in the southern part of the traverse.

It is seen from the profile that the subsurface structure of the area is concave with the subsided central part and somewhat uplifted ends. The uplift is of Tiechenshan Anticline in the west and Shingtsaopu anticline in the east, with rising tendency to the east. These anticlinal structures on both ends of the traverse have different form and thicknesses and each has its own characteristics. These differences are believed to reflect the different process of formation of the anticlines. The fact that 3rd-b and 4th layers are the only thick layers at Tiechenshan-Tunghsiao Anticline in the west and that the strata on the Shingtsaopu anticline in the east is generally thinner than those on the anticline in the west seem to represent the difference in the formation process. Detailed investigation of these structures will provide the basic geological concept concerning the exploration of this area.

(a) Anticlinal structures

The complete structure of Tiechenshan-Tunghsiao Anticline in southern part of the traverse is known through many deep drillings. In this survey, these data and the result of the analysis were compared with the following consideration.

1. The 1st layer (1,900 m/s) corresponds well with the thickness of the Plio-Pleistocene Toukoshan Formation.

2. The thicknews of 2nd and 3rd-a layers (2,100 m/s - 2,940 m/s) coincides fairly well with that of Pliocene Cholan Formation.

3. 3rd-b and 4th layers (3,270 m/s - 3,550 m/s) are correlated to Miocene-Pliocene Chinshui Shale and Kueichiulin Formation

4. The depth of 5th layer (3,920 m/s - 4,200 m/s) is close to that of Miocene Nanchuang and Nankang Formations.

5. The upper limit of the 6th layer (4,720 m/s - 5,190 m/s) corresponds to lower Miocene Shihti Formation.

These divisions of the velocity layers agree fairly well with the stratigraphic division by drilling data. This is considered to be the result of favorable conditions of the geology, formation thicknesses, structure for refraction seismic method; the good selection of the traverse location and various other factors.

The above results also agree well with the results of gravimetric survey.

Thus the analytical results of this traverse are in good agreement with the actual structure. These results will be most useful after detailed correlation with drilling data of the area and further study of the profile itself. Therefore, the velocity profile of this traverse will serve as basic data for the survey of land and offshore areas of Western Taiwan.

(b) Faults structures

There are a fault with downward displacement of the southern block north of Chungkang-chi (near No. 15 Spread 3), a fault with downward displacement of the northern block north of Houlung-chi (near No. 20 Spread 6), and a fault with downward displacement of the northern block south of Shot Point II (between Spread 7 and 8) in the area of this traverse. The fault near Shot Point II is considered to be Tungshihwo Fault from surface geological survey. These faults have displacements of about 100 m in the shallower parts and about 200 m in the deeper parts. These structures, however, were calculated from small amount of travel-time data, and further study on the dip and other factors of these faults is necessary.

The Neogene Tertiary system of this traverse show significant change of velocity between the fault to the north of Houlung-chi and Chungkang-chi. This velocity change is especially large in the velocity layers below Nanchuang Formation where the velocity decreases in the range of 200 - 250 m/s. This decrease of velocity is considered to be caused by the lithological distribution, the lowering of the velocity layers in this area by the Houlung-chi Fault, and other factors. The increase of the displacement and the increase of velocity change in the deeper parts are considered to be associated phenomena.

(3) Basement

The Mesozoic system of this traverse was calculated on the basis of seismic wave velocity of 5,660 m/s - 5,800 m/s which is that of the Mesozoic formations of Traverse Line 3. The analytical results indicate that the depth of the basement in this area is more than 8,800 m or 9,500 m.

Fig. 14 Travel-Time Curves and Seismic Refraction Profile of Traverse Line 1

scale 1 : 200,000

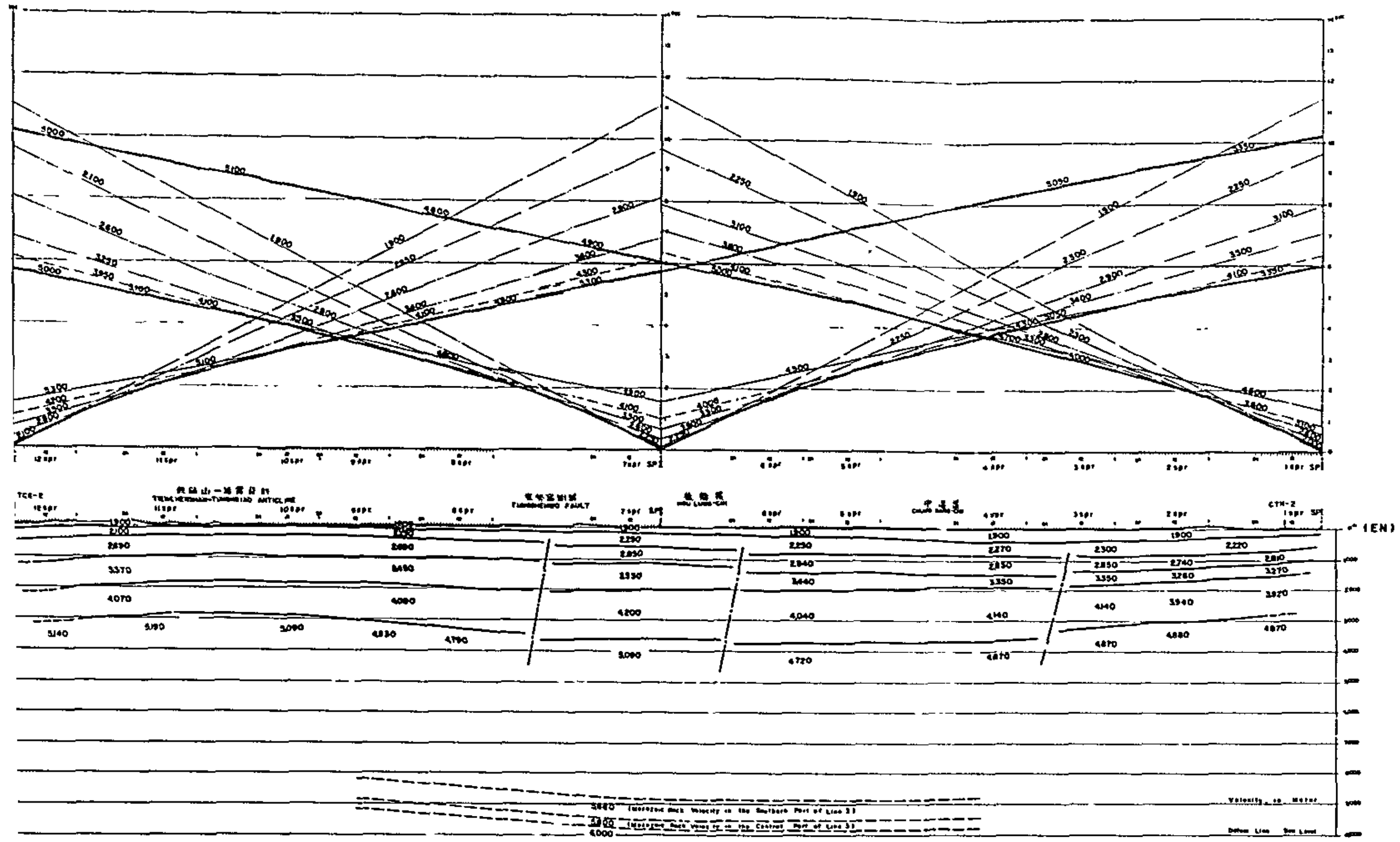
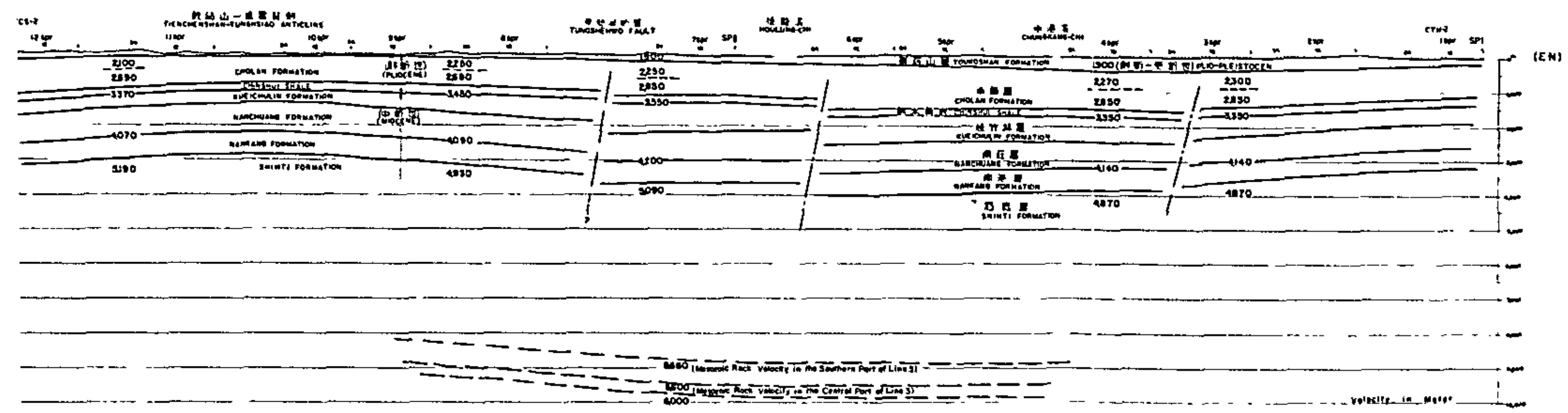


Fig. 15 Geologic Interpretation on Seismic Refraction Profile of Traverse Line 1



This depth is a little larger than the inferred depth of the Mesozoic strata in the southern part of Traverse Line 2 which is 8,000 m or 9,000 m. This result indicates that the basement in the area of Traverse Lines 1 and 2 gradually subsides from the southern part of Traverse Line 2 towards Traverse Line 1. This tendency is also observed in gravimetric and other data. But the basement shown in the analysed profile is based on the velocity and the dip of the basement of Traverse Line 3, and the velocity and the dip varies a little with the assumption of analysis. The analysed profile shows that there are formations of lower Miocene or older with thickness of about 5,000 m in the upper part of the basement. This thickness is the largest observed in this survey and do not occur in other traverses. This is based on the assumption that the upper part of the basement is similar to the 6th layer and thus if there are intercalated layers with larger velocity than the 6th layer, it will be thicker than 5,000 m.

4 - 1 - 3 Traverse Line 3

(1) Seismic velocity layers and analysed profile

The inferred distribution of the velocity layers and the seismic wave velocities are shown in Table 20.

Seismic wave velocity layers	Velocities (from analysed profiles) Southwest of fault	Northeast of fault	Correlated major formation
1st a layer	1,500 m/s	None	Plio-Pleistocene
1st b "	1,950-2,000	"	Plio-Pleistocene
1st c "	2,200-2,550	2,300 m/s	Plio-Pleistocene Toukoshan Formation
2nd " 3rd "	2,850-3,540	3,220	Pliocene Cholan Formation Chinshui Shale
4th " 5th " 6th "	3,800-4,160	4,330	Miocene: Kueichiulin Formation, Nanchuang Formation, Nankang Formation
7th "	5,230-5,240	5,460	Miocene lower - middle Miocene series
8th "	5,620-5,860		Mesozoic

Table 20 Relation between Velocity Layers and Strata in Traverse Line 3.

The velocity layers of this traverse are divided into two parts by the fault between Spread 4 and 5 at south of Pakuanshan Anticline. The velocity layers of this traverse have 7 layered structure in the area southwest of the fault and 4 layered structure in the area northeast of the fault lacking the low velocity layers (1-a and 1-b layers) of the southwest area.

(a) Seismic wave velocity layers in the area northeast of the fault

The results of the analysis and surface geological survey in the area near Tiechenshan shows that the velocity layers in the area northeast of the fault lacks 1st-a and 1st-b layers which are distributed in the southwest area, and 1st-c layer (2, 300 m/s) of the southwest area is developed. This layer has a thickness of 1, 200 m - 1, 800 m and is inferred to be Toukoshan Formation from the nearby drilling data.

The 3, 220 m/s layer underlying 1st-c layer corresponds to 2nd and 3rd layer of the area southwest of the fault, and is correlated to Pliocene Cholan and Chinshui Shale Formations. This layer is 1, 250 m - 1, 400 m thick and is considered to dip northward.

The velocity of the 4th, 5th and 6th layers is 4, 330 m/s. These correspond to the 4, 000 m/s ($\pm$) layer in the area southwest of the fault, and is interpreted to be middle-upper Miocene Kueichiulin, Nanchuang, and Nankang formations. The thickness of these layers increases from the south northward and is 2, 400 m in the area north of the fault.

The lowermost layer in the northeastern part is the 7th layer (5, 460 m/s). This is 5, 000 m deep and corresponds to the 5, 620 - 5, 860 m/s layer of the southwestern area, but the velocity is somewhat lower. The dip of these velocity layers of the northeastern area was calculated from the reflection of Spreads 1 and 2 to be 5° north.

(b) Seismic wave velocity layers in the area southwest of the fault

There are seven velocity layers from 1-a to 8 in the southwestern area. Their velocities are listed in Table 20, and their thicknesses are from up downwards, about 200 m, 300 m - 500 m, 650 m - 1, 200 m, 600 m - 1, 500 m, 700 m -2, 000 m. All the layers are thicker and their velocities are greater northward and as a whole they dip monoclinically northward. But these layers rise gently in the area northeast of the fault and forms an anticline near Pakuanshan. The 1-a and 1-b layers of the southwestern area thins out near the fault.

The velocity layers were numbered for correlation purposes in the table. The layers 4, 5, 6 and 7, 8 (Miocene) generally have small velocity variation and is thinner than in other traverses, and thus resulted in the division of the table. The reason for the blind layer seems to be the very thin thickness of the layer.

The upper limit of the lowermost 7th and 8th layers is 2,500 m deep in the southern part of the traverse and 6,000 m at the southern side of the fault, calculated from the thickness of the overlying velocity layers.

These layers have velocity of 5,620 m/s - 5,860 m/s in the southern half of the traverse while it is 5,240 m/s at the southern side of the fault in the north. This velocity change can be considered as the result of the velocity decrease by the fractured lowermost layer near the southern Pakuanshan Fault, but since the velocity is not so low where the upper layers are in contact with the faults, it can be better explained as due to newly intercalated low velocity layer.

The velocity layers in the southwestern part of the fault of this traverse are generally of higher velocity compared to those of other traverses. This high velocity is especially conspicuous in the 7th layer which has the highest velocity in the analysed profile. This velocity layer is interpreted to be Mesozoic strata on the basis of nearby drilling data. The seismic wave velocity of this Mesozoic strata is also somewhat higher than that measured in Japan.

(c) Velocity logging data and seismic wave velocity near the traverse.

The velocity log data of HL-1 well in the north, PT-1 well in the east, and PC-1 and PK-2 wells in the southern part of this traverse are as follows.

HL-1	$V = 2,700 + 0.3Z$	$(Z < 2,750$ m$)$
PT-1	$V = 2,520 + 0.42Z$	$(Z < 3,500)$
PC-1	$V_1 = 1,650 + 0.8Z$	$(Z < 1,600)$
	$V_2 = 4,835$	$(1,600 < Z < 2,000)$
PK-2	$V_1 = 1,800 + 0.5Z$	$(Z < 1,400)$
	$V_2 = 3,550 + 0.2Z$	$(1,400 < Z < 2,300)$

These velocity log data indicate that the vertical seismic velocity of this area is somewhat larger in the eastern part of the fault which is inferred to be hinge line. This is similar to the results seen in Traverse Line 2, and is noteworthy, but in this traverse the tendency is weaker and there are layers with reverse tendencies. This difference is believed to be caused by the variation of the fault fracture, lithological distribution and others. Also the velocity layers of this traverse are generally larger than that of Traverse Lines 2 and 1. This is considered to be due to the fact that velocity layers of this traverse are stratigraphically higher than those of Traverse Lines 2 and 1.

(2) Geological interpretation map

The analysed profile of this traverse agrees well with nearby drilling data. This is probably due to the fact that the lowermost velocity layer of this area coincides with the basement, and also the interpreted profile also agrees well with the analysed profile.

The interpreted profile shows that the velocity layers of this traverse can be divided into 7 layers. They are interpreted to be Pliocene - Pleistocene, Miocene, and Mesozoic strata, and they are all stratigraphically well developed.

The velocity layers corresponding to Pliocene - Pleistocene series are divided into three layers from 1-a to 1-c. The uppermost 1-a layer is considered to be weathered Pliocene - Pleistocene series or alluvium, 1-b and 1-c to be lower Pliocene - Pleistocene series.

The lowermost 5,620 m/s - 5,860 layer is believed to be the basement of this area on the basis of the depth, velocity, and nearby drilling data. The depth of this layer is 2,500 m in the southern end and 6,000 m at the southern side of Pakuanshan and dips monoclinically northeastward at 5° - 9°. But a different layer with lower velocity (5,240 m/s) is intercalated in the upper part of this basement near the southern side of Pakuanshan. The strata of Pakuanshan and in the northern side of the mountain forms Pakuanshan Fault in the southern side, and Pakuanshan Anticline in the lower part following the structure of this lower velocity layer.

The formations stratigraphically higher than the basement dip monoclinically northeastward in the area between the southwest end of the traverse to the northeast end conforming to the structure of the basement and the 5,240 m/s layer.

The geology of the northeastern part of this traverse was surmised from the drilling data of Tiechenshan area in the north.

(a) Anticlinal structures

The existence of anticlinal structure is expected near Pakuanshan. This anticline is confirmed by surface geological survey and is considered to be of comparatively large scale with a width of 9 km.

This anticline is stratigraphically interesting as thick formations corresponding to Pliocene - Pleistocene, Pliocene, Miocene series are developed.

But this anticline is associated with the fault inferred to be hinge line in the southern wing which is cut off diagonally by the reverse fault. Thus this fault plane extends near the anticlinal axis in the vicinity of the lower Miocene series where it is assumed to be fractured by the fault. Therefore, it is considered that this anticline was formed in relation to the hinge line of the southern wing.

(b) Fault structures

The fault in the southern wing of the Pakuanshan Anticline is interpreted to be northward dipping steep reverse fault from travel-time curve and analysed profile. The seismic velocity layers of this traverse have 4 layer structure in the northeastern area and 7 layer structure in the southwestern area with this fault as the boundary. The formations of the northern and southern areas show different velocity distribution. In the southern area, the velocity increases in conical section wise downwards while in the northern area it increases linearly.

This fault seems to be located in the area where the 3-shaped hinge line inferred to exist in western Taiwan from drilling data and surface geological survey passes.

(3) Basement

The lowermost layer of the southwestern half of the interpreted profile is believed to be the basement (Mesozoic) from the seismic wave velocity and nearby drilling data. It is 2, 500 m deep in the southwestern end, 6, 000 m in the northern part and dips northeastward at 5° - 10°. The rise of the basement in the southwestern end corresponds to the northern slope of the Peikang Shelf which is determined by geological survey and drilling.

The basement of this traverse dips monoclinically northeastward along this Peikang Shelf and extends to the southern side of Pakuanshan. There is a different 5, 240 m/s velocity layer (7th layer) in the upper part of this basement in the southern part of Pakuanshan. This velocity layer is of somewhat lower velocity than the 5, 860 m/s layer observed in the southern part of the traverse and it can be considered to be the fractured zone by the fault as in the case of the 4, 020 m/s layer developed above.

It is possible, however, to correlate this layer to a pre-Miocene formation different from the basement in the southern part, because 1-c, 2nd, and 3rd layers of the southern side of the fault do not show fractured zone characteristics and also because the lowermost layer of the Yuanlin area south of the fault has velocity of 5, 240 m/s and is considered to be stratigraphically lower than the lower Miocene series.

If the 5, 240 m/s layer is thus interpreted, the basement is developed in the depth indicated by the broken line part of the interpreted profile, and forms a pocket structure.

With the above hypothesis, the basement of this traverse will be more than 6, 000 m deep in the northern part.

4 - 1 - 4 Traverse Line 4

(1) Seismic velocity layers and analysed profile

The velocity layers and the seismic wave velocity distribution are inferred to be those shown in Table 21.

Table 21 Relation between Velocity Layers and Strata in Traverse Line 4.

Seismic wave velocities (from analysed profiles)

Seismic wave velocity layers	Shot point-Chungchou structure	Chungchou structure-Shot point III	Correlated major formation		
Surface layer	1, 430 m/s	None	Recent Taiwan Formation		
1st a layer	1, 810-1, 850	1, 850 m/s	Plio-Pleistocene	Erchungchi Formation	
1st b layer	2, 050-2, 080				
2nd layer	2, 420-2, 560	2, 430-2, 540 2, 900-3, 080, 3, 070	Pliocene	Upper Gutingkeng Formation	
3rd layer	3, 630-3, 810	3, 660-3, 670, 4, 850		Lower Gutingkeng Formation	
4th layer	4, 000	4, 000	Miocene	Kengnei Formation	
5th layer					
6th layer	4, 440-4, 530	4, 310-4, 570, 4, 730			

Fig. 16 Travel-Time Curves and Seismic Refraction Profile of Traverse Line 3

scale 1 : 200,000

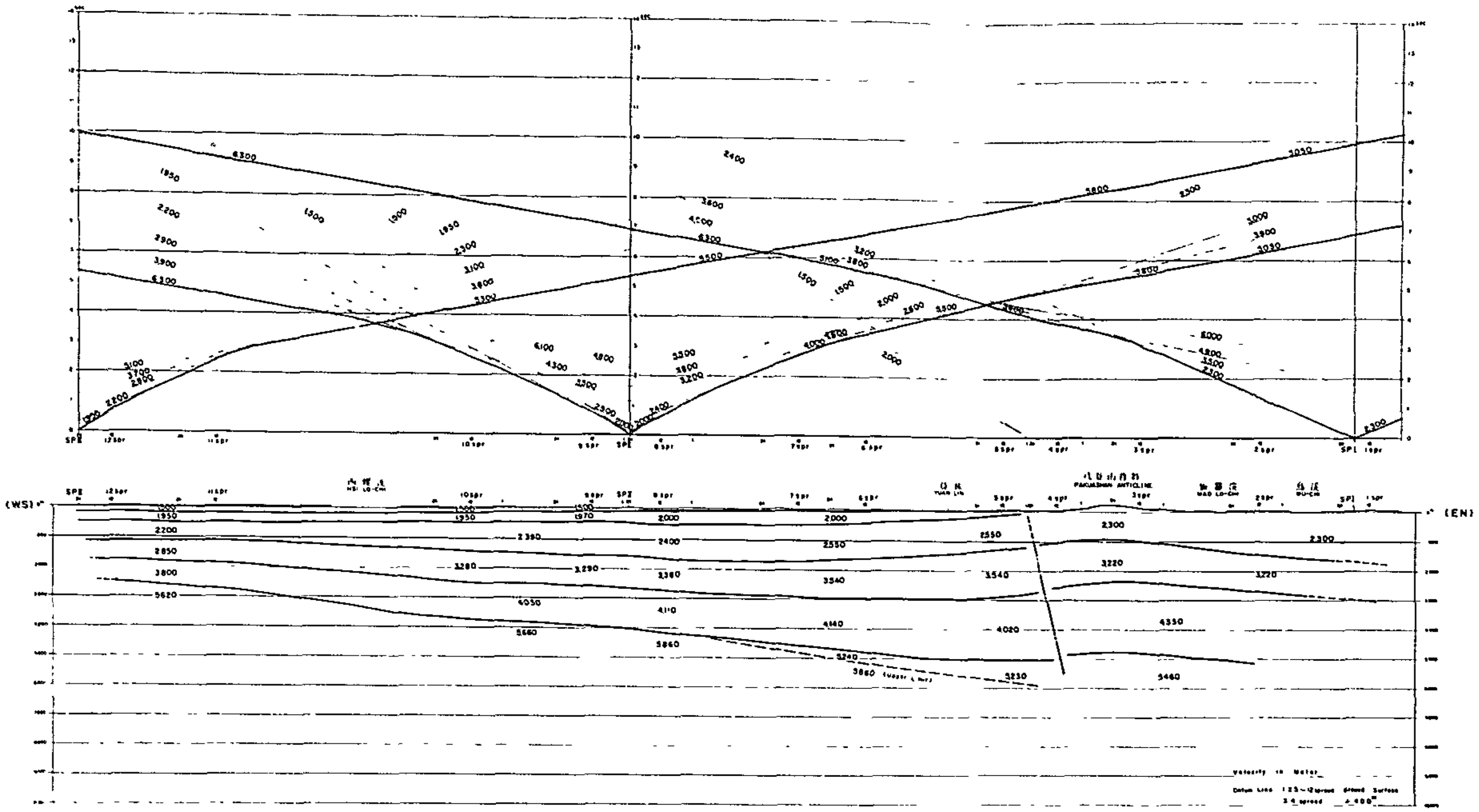
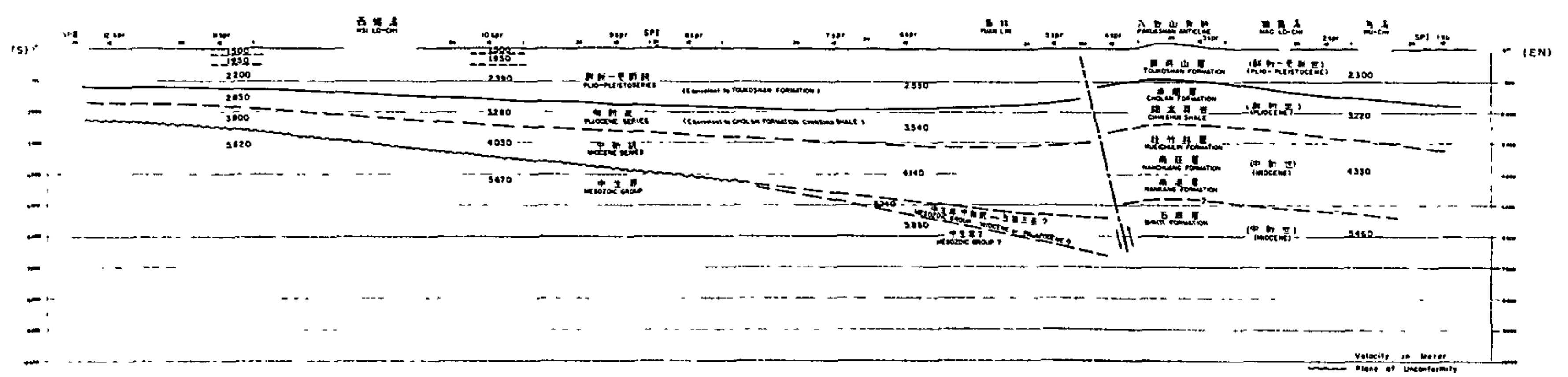


Fig. 17 Geologic Interpretation on Seismic Refraction Profile of Traverse Line 3

scale 1 : 200,000



The velocity layers of this traverse consist of 6 layers from the 1st to the 6th layer. They are correlated to the formations listed in the right column of the table.

The velocity layers are subdivided and their thicknesses are calculated as follows.

West of Chungchou Anticline	(thickness)	Chungchou Anticline	East of Chungchou Anticline	(thickness)
m/s layers	m		m/s layers	m
1,430	(100-150)			
1,810-1,850	(200-400) }			
2,050-2,080	(200-500) }		1,850	(100-450)
2,420-2,560	(900-1,050)		2,430-2,540	(250-400)
3,630-3,810	(1,450 ±)		2,900-3,080	(650-1,000)
4,000 (?)	(1,700-1,800)		3,660-3,850	(1,500 ±)
4,430-4,530			4,000 (?)	(1,700 ±)
			4,310-4,730	

The velocity variation of the layers of this traverse is very irregular both horizontally and vertically. The geological units near this traverse are known to be almost all mudstone from geological survey and drilling data, and thus the brittleness of the formations rapidly increases by structural change caused by crustal movement and other factors, and the seismic wave velocity decreases to a greater extent. The irregular velocity variation is believed to be caused by the poor bedding of the mudstone in this area, the unusual brittleness, the effect of faults and folds, and others. The velocity layers of this traverse show a large change of velocity between the areas east of and west of the Chungchou Anticline in the central part. One example of this change is the 1,430 m/s - 2,560 m/s velocity of the 3rd layer in the western area and 2,430 m/s - 3,080 m/s in the eastern part.

This velocity variation is believed to be due to the extinction of the 1st and 2nd layers of the western part near the Chungchou Anticline and the uplift of the 2nd layer (2,430 m/s - 2,540 m/s) in the eastern part. This velocity layer of the eastern area, however, contains in its lower part a layer (2,900 m/s - 3,080 m/s) which does not exist in the western area.

Thus the velocity layers show different velocity distribution in the eastern and western areas both horizontally and vertically. The analysed profile shows that the velocity layers in the eastern area have more or less linear variation to the lowermost layer, but those in the western area have a discontinuity between the 2nd (2,420 m/s - 2,560 m/s) and 3rd (3,630 m/s - 3,810 m/s) layers. In spite of this discontinuity, the velocity distribution of the lower layers of the western area is similar to that of the eastern area. In general, the upper layers of the eastern area of this traverse have higher velocity than those of the western areas.

It is inferred from these data that there is a steep slope or a fault between Chungchou Anticline and Kuanmiao. If such a fault exists in this area, there should be relationships among the velocity layers of east and western areas as shown by the arrows in the preceding table, and there should be a fault or a steep slope shown in the figure.

This tendency is observed to the 3rd layer of the analysed profile and not observed in layers below the 4th (4,000 m/s) layer. This fact is interpreted as due to fracturing of the deeper velocity layers by the Lungchuan Fault.

A 4,000 m/s velocity layer was assumed to exist under the 3rd layer (3,700 m/s). This is because such velocity was observed above the lowermost layer and such layer was reasonably expected by Mirage phenomenon due to the thick 3rd layer. The 4,000 m/s layer in the eastern area corresponds to the lowermost layer (4,500 m/s) of the western area, it was uplifted and the velocity decreased in the eastern area.

Under these assumptions, the velocity increases, and the depth also increases rapidly from east to west in this traverse. These structural assumptions are believed to be valid considering the many faults, uplifts, and other structural features; the rapid decrease of the seismic velocity of the mudstones with these faults and uplifts; and other geological conditions of the area.

Also the velocity (5,000 m/s and 5,660 m/s) of the lowermost layer of the Traverse Line 3 was assumed for the Mesozoic strata of this traverse. Assuming that the Mesozoic strata of this traverse are developed parallel to the lowermost 4,430 m/s - 4,530 m/s layer, the Mesozoic formations will be 7,500 m to 8,500 m deep.

The velocity logging data and the seismic velocity data of refraction seismic observation all show greater velocity to the east of the Mesozoic hinge line inferred to exist in north to central areas of west Taiwan. This velocity distribution is the general tendency in northern and central areas, and in the velocity log of CC-2 well south of Traverse Line 4, this velocity is expressed as

$$V = 2,150 + 0.56Z \ (Z < 2,500 \text{ m})$$

This is considerably lower than the results of the velocity logging and analysis of the Traverse Lines 2 and 1 which also exist to the east of the hing line. This is believed to be caused by the different behavior of the geological units of the southern area and the northern and central areas.

(2) Geological interpretation map

The velocity layers of this traverse consist of 6 layers and they are interpreted as listed in the right hand column of Table 21.

The general geologic structure of this area is the eastward rising thrust structure to the east of the Chungchou Anticline and the folded westward dipping inclined structure to the west of the above anticline. The interpreted profile of this traverse has a fault at the Chungchou Anticline or on the east side of the said anticline because of the above two structures.

The velocity layers of the interpreted profile form Lungchuan Fault and Tainan Anticline at the northern tip of the steep incline in the eastern area, and at the central part of the gentle slope of the western area. The Lungchuan Fault in the east is a conspicuous thrust fault as mentioned above but the Tainan Anticline in the west is a uplifted structure with gentle inclination.

(a) Anticlinal structures

The Chungchou Anticline to the west of the Lungchuan Fault is smaller in scale compared to the fault, but their forms are of the same nature in that the anticline is asymmetrical with the western wing being much lower than the eastern wing, the dip is steep near the anticlinal axis, and a fault with an eastern rising fault is expected to exist at the eastern side of the axis.

The velocity layers of this traverse have two structural forms to the east and west of this anticlinal structure. The western blocks are lower by maximum of 1,000 m and this forms a large stratigraphic difference. The formations fo this traverse are inferred from the interpreted profile and logging data in the southern part of the traverse to be from up downwards, A-B Formations, upper Gutingkeng Formation, lower Gutingkeng Formation, and Kengnei Formation. The lowermost Kengnei Formation is calculated to be about 5,000 m deep, and it is thicker in the western wing.

There is the Tainan Anticline 10.5 km west of the Chungchou Anticline in the central part of this traverse. The layers which dip gently westward at the western wing of the Chungchou Anticline are uplifted again here and forms a weak anticline. This anticline has the same geologic column as the Chungchou Anticline and the lowermost layer has approximately the same depth. But the depth of the upper Pliocene series differ and that of the Tainan Anticline is about 2,700 m deeper.

The anticlinal structure of the analysed profile of this traverse has lower dip compared to the results of geological survey and reflection seismic survey, and also the scale of the anticline becomes smaller in the deeper parts. The explanation of the latter feature must await further investigation, but the gentle dip is considered to be caused by the observation with emphasis on the stratigraphy by vertical depth (depth by weathering, compression, water content, fracturing and etc.), and because of the poor bedding of the mudstone formations.

(b) Fault structure

The Lungchuan Fault at the eastern end of the traverse seems to have an anticlinal structure associated with thrust fault from the analysed and interpreted profiles. At both the eastern and western sides of the fault there are steep velocity stratigraphy and low velocity distribution over a wide area which indicate the large scale of the structure.

The western side of this fault consists of 2,540 m/s layer and the eastern side of 3,000 m/s layer, and the western block was displaced downward. The velocity layers on the eastern side consist of 1,850 m/s, 3,070 m/s, and 3,850 m/s layers and all incline steeply to the east.

The structural form of the Lungchuan Fault is typically represented by the subsurface structure of the western wing. The strata on the western side of the fault dip westward near Kuanmiao, and are almost vertical at the immediate west of the fault. Thus the Lungchuan Fault is considered to have a western wing with anticlinal structure with more than 10 km in width.

Fig. 18 Travel-Time Curves and Seismic Refraction Profile of Traverse Line 4

scale 1 : 200,000

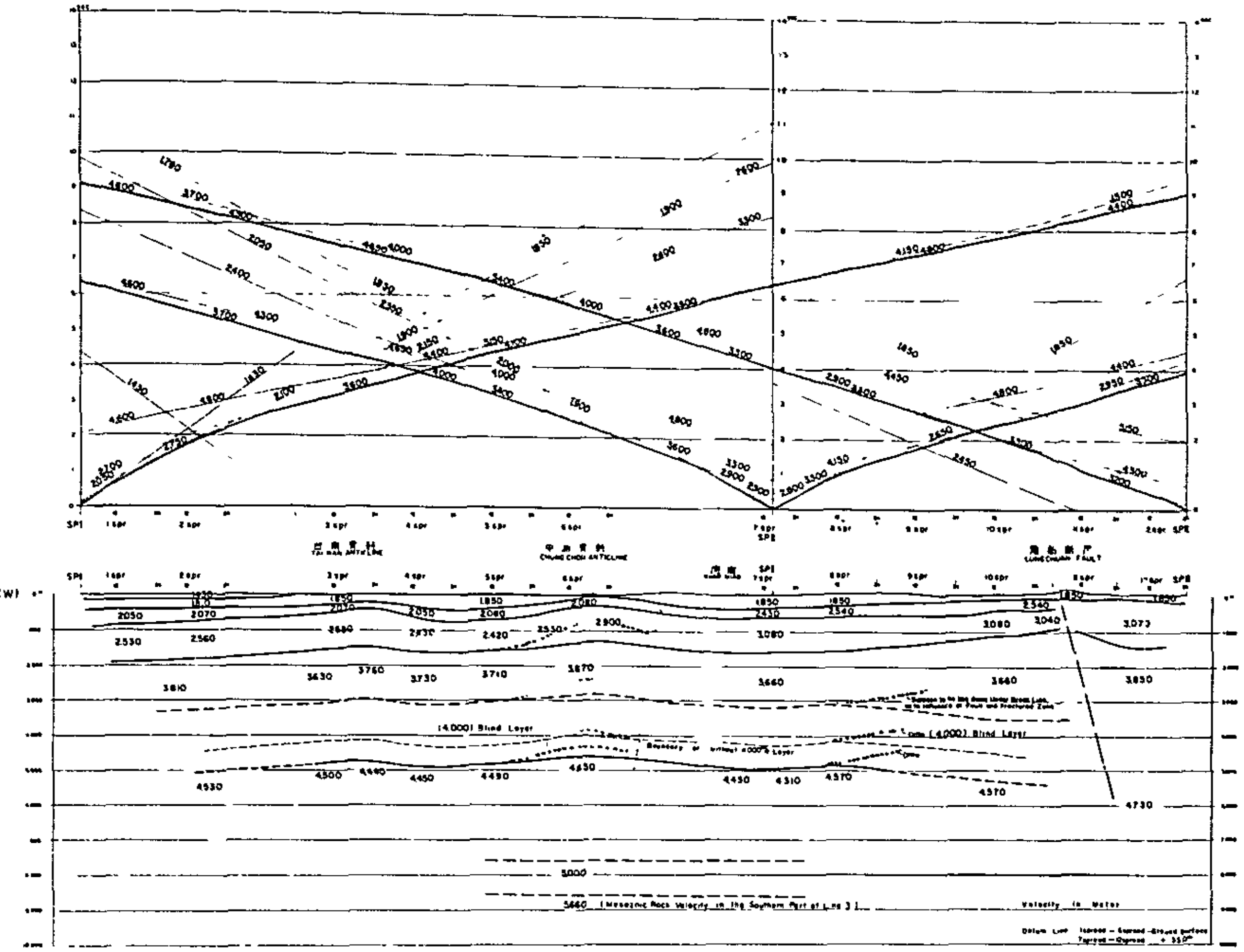
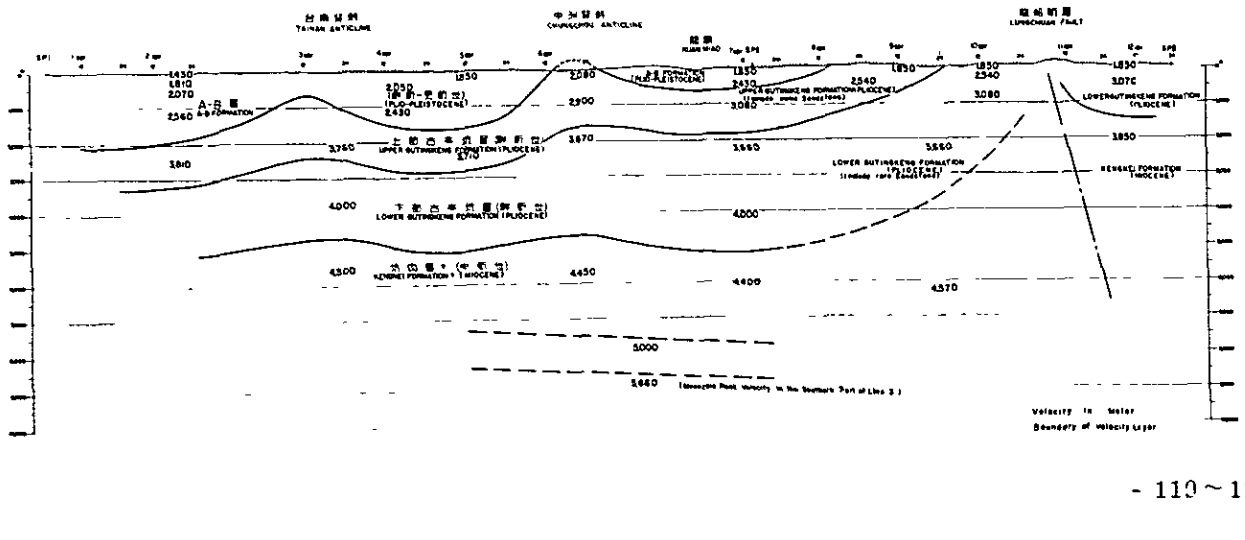


Fig. 19 Geologic Interpretation on Seismic Refraction Profile of Traverse Line 4



(3) Basement and the lowermost layer of the analysed profile

The lowermost layer of the analysed profile is believed to be Miocene Kengnei Formation. The lowermost Miocene series east of the Chungchou Anticline seems to be somewhat older than the Miocene series to the west of the anticline by comparing the two in the interpreted profile and the table. The western Miocene series is inferred to be 5,000 m $\pm$ deep in the southern part of the traverse and 4,800 m $\pm$ deep in the central part, and 2,000 m - 4,000 m deep in the eastern part (southern side of the Lungchuan Fault). Thus there should be another Miocene series of 4,310 m/s - 4,730 m/s under the extension of the above formation.

The depth of the basement under the lowermost layer was calculated under the assumption that it has the same velocity as that of Traverse Line 3. The depth is calculated to be 7,500 m - 8,500 m in the central part. The depth of this basement from the upper limit of the Miocene series is approximately the same as the depth of the Mesozoic strata calculated from the basement depth of Traverse Line 3.

The tendency of the velocity layers of this traverse with eastern uplift and western subsidence is the opposite to the results obtained by the gravimetric survey in western Taiwan. This is believed to be caused by the following factors.

1. The gravimetric survey was more affected by layers 1,500 m - 3,000 m deep (these layers have higher velocity in the west) or
2. The basement is shallower to the west or
3. The seismic wave velocities of this area do not necessarily reflect the density of the formations of this area or
4. There are formations on the surface which affect the gravity in the western part or
5. High gravity structure exists in the deeper parts in the western part.

4 - 2 Geological consideration of the survey results

4 - 2 - 1 Traverse Line 2

The interpreted map shows that the analytical results generally agree with the geological sections prepared by Tang and others using previous data. Especially, the structures in the area between Kuanyin Shelf and Pingchen Anticline, namely the Pingchen and Hukou Anticlines, and Hukou Fault were traced very well in the deeper parts, this confirmed the validity of the previous works. The inclination of the wings of the above anticlines, however, are lower in the analysed results than the actual values. The cause for this has already been mentioned. Tungkeng Fault did not appear in the analysed profile and the faults parallel to the Hukou Fault was represented as the fractured zone of the Hukou Fault in the analysed profile. These results, however, are often encountered in structurally disturbed areas.

The depth of the basement could not clearly be determined in this survey. The existing data indicates, however, that the basement of the Kuanyin Shelf is Mesozoic strata like that of the Peikang Shelf. Thus we obtain the depth of the basement at 7, 500 m - 8, 000 m under the Hukou Anticline by applying the velocity (5, 660 m/s) of the Mesozoic formations at the Peikang Shelf. It is not clear which direction this hypothetical layer is dipping. It is, however, quite certain from existing data that the basement becomes shallower to the north, and the 5, 660 m/s layer is drawn approximately parallel to the inclination of the Miocene series in the analysed profile. The extension of this layer to the north will produce depth of 5, 500 m - 6, 000 m under the KY-1 well near the Kuanyin Shelf. This is considerably deeper than the depth conjectured by Tang (1963) and Schreiber (1965) which is 3, 500 m - 4, 000 m. From this fact, the following considerations are possible when the 5, 600 m/s layer is assumed to be the basement.

a. The basement depth of this area is generally about 1, 000 m deeper than the previous assumption.

b. The basement depth is about 4, 000 m near KY-1 well, but is 7, 500 m - 8, 000 m under Hukou Anticline, and thus it subsides to the south with steeper inclination than the Miocene series.

Bent structure accompanied by inferred faults are shown in the analysed profile to the north of Pingchen Fault at the point where the Miocene series changes to monoclinic shelf structure from very gentle synclinal structure. This structure is more apparent in the deeper parts and it may be reflecting the form of the basement surface.

Schreiber (1965) reports that the middle and lower Miocene formations generally becomes thicker northward as the mudstone facies increase. It can be that the variation of the thickness and lithology in the north-south direction is greater near the above bend. If this assumption holds, this area will also be noteworthy for oil and gas accumulation together with Houkou and

Pinchen Anticlines.

4 - 2 - 2 Traverse Line 1

The analysed profile agrees well with various previous survey results. Almost horizontal structure is shown in the analysed profile from the southern end of the traverse to Tungshihwo Fault because the traverse is almost parallel in the south to the Tienchenshan - Tunghsiao Anticline axis. As mentioned before, the strata in the area between Tungshihwo Fault and Chungkang-chi form a gentle and broad basin structure in the analyse profile. This structure is believed to represent the surface semi-basin structure near Houlung-chi in deeper underground. The strata becomes shallower to the north from Chungkang-chi, and this is believed to be the reflection of the structure near Shingtsaopu.

A fault along Houlung-chi with downward displacement of the northern block is shown in the analysed profile between Tungshihwo Fault in the south and Chungkang Fault in the north. This fault is not apparent on the surface and is not shown in the existing geological maps. The fault with east-west trend along Houlung-chi is inferred to exist from the result of this survey.

Definitive results could not be obtained concerning the depth of the basement. This area is located between the Peikang and Kuanyin Shelves, and from the geological conditions, it is not unreasonable to assume the basement to consist of Mesozoic formations, then the 5,660 m/s layer can be interpreted to be the basement as in the case of Traverse Line 2. The 5,660 m/s layer is not recorded in the travel-time curve, but if it does exist, it will be about 8,000 - 9,000 m deep as shown in the analysed profile. This depth is deeper than the previously inferred depth of the basement. Schreiber (1965) and other data indicate that this area near the Tiechenshan - Tunghsiao Anticline is the so-called Miaoli swell where the formations of the Miocene series become very thin, and since the depth of the basement and the thickness of the Miocene series are related throughout western Taiwan, the basement may be shallower than the 5,660 m/s layer of the analysed profile. This problem needs further investigation.

The central part of the analysed profile has a basin structure and the possibility of oil and gas production is small.

4 - 2 - 3 Traverse Line 3

The area of Traverse Line 3 includes the structural transition from Peikang Shelf to Hsinchu Sedimentary basin and there are difficult problems related to sedimentary and structural interpretation. The geological conditions of the northeastern and southwestern parts of the traverse are believed to differ, and it is not possible to extend the velocity layers through the whole traverse. The existing data indicate that an inferred fault between Pakuanshan and Yuanlin is the boundary between different geological conditions on both sides. Therefore, geological data of the Peikang Shelf area are used for the southwestern part of the traverse and those of Tiechenshan-Tunghsiao Anticline are used for correlating the velocity layers and geologic formations of the northeastern part of the traverse.

The basement is quite clearly traced as a 5,620 m/s - 5,860 m/s layer in the area from the southwestern end of the traverse to Yuanlin, it dips northeastward at 5° - 7° and suddenly increases its depth at 5-6 km west of Yuanlin. This analysed profile agrees fairly well with the previous inferrence of the underground structure on the basis of gravimetric, reflection seismic survey, and geological cross section of Sun (1965). But it was not possible to subdivide the Miocene series by velocity and the detailed stratigraphy of the series. This will be carried out by drilling operations in the future.

The 5,230 m/s layer overlies the 5,860 m/s layer which is considered to be the basement near Yuanlin, and this is considered to be either lower Miocene or lower Tertiary strata.

It is also seen in the analysed profile that the large fault observed by reflection seismic method does not exist in the analysed profile.

On the other hand, the velocity layers of the northeastern part of the traverse are faster and thicker than those of the southwestern part of the traverse. By using the geological and geophysical data of Tiechenshan - Tunghsiao and Chinshui Gas Fields for reference, the correlation of the velocity layers and geologic formations shown in the interpreted map are obtained. The problem here is the 5,460 m/s layer correlated to Shihti Formation, this velocity is unusually fast for a middle Miocene strata, and this may be suspected to be a lower Miocene formation. However, throughout the Miocene series of western Taiwan, the layer with abrupt change of velocity lies between Shihti and Tailiao Formations which is between middle and lower Miocene series. If the Shihti Formation of the interpreted profile were lower than Tailiao Formation, the Miocene strata above Shihti Formation will be thinner than previous inferrence resulting in somewhat different interpretation, and the thickness and lithological variation on the two sides of the inferred fault between Yuanlin and Pakuanshan will be different, and also the bend of the hinge line will be more gentle than the previous inference.

The higher velocity of the formations in the northeastern part of the traverse compared to other areas is related to the increase of thickness and the depth, but also lithological conditions must affect the velocity to a large degree.

The Pakuanshan Anticline observed on the surface is confirmed in the deeper parts and the location of the axis coincides very well with that on the surface.

Promising area for oil and gas production in this area is the Pakuanshan Anticline. If orthoquartzite or protoquartzite such as the sandstone of middle Talu Shale or Shihti Formations are found in this anticlinal area, it will be a very promising gas structure.

Concerning strutigraphic trap, the lower Tertiary system or lower Miocene series in the deeper parts of Yuanlin and its vicinity to southwest is the possible area for oil and gas producing structure. For this, it will be necessary to survey the hinge line near Peikang Shelf regionally.

4 - 2 - 4 Traverse Line 4

This area is divided geologically into the eastern and western parts. The east is a folded area with steeply inclined folds associated with large faults, while the western part consists of relatively gently folded area under the coastal plains. In the analysed profile, the structure of both areas are shown to be almost flat. This is caused by the difficulty of analysing the details of the geological structures with steep inclination in large scale refraction surveys, and by the tendency to result in more gentle inclination in the analysed profile than the actual values as pointed out in the interpretation of Traverse Line 2. There are, however, very large discrepancies between the geological structure of the shallower parts and that of the velocity layers of the analysed profile in the eastern part of the traverse. One explanation for this is the large amount of the cracks and fractures in the disturbed zone to the west of the Lungchuan Fault and along the fault itself, and the intense fracturing within the formations, which caused abnormal seismic wave velocities.

Also the boundaries of the velocity layers are not clearly observed in the deeper parts of the Lungchuan Fault. If this phenomenon is caused by the same factors as above, the geophysically ambiguous parts to the west of the Lungchuan Fault will be of use for geologic interpretation as indicating the area of structural disturbance.

In the western part of the traverse, on the other hand, Chungchou and Tainan structures are expressed quite clearly in the analysed profile. The dip of the wings is again expressed much lower than that inferred from reflection seismic, gravimetric, drilling, and other data, and the reasons for this have already been mentioned. This is the first confirmation, however, of the anticlinal structure at depth of 4, 000 - 5, 000 m. The lower limit of 4, 000 m/s layer is 4, 500 - 5, 000 m deep and this was correlated as the base of the lower Gutingkeng Formation. Thus the Kengnei Formation which contains fair amount of sandstone intercalations is inferred to be 4, 500 - 5, 000 m deep at the axial part of the Chungchou Anticline.

The basement again could not be confirmed in this traverse. In the analysed profile, the depth of the 5, 660 m/s layer is hypothetically shown under the assumption that the 6th layer (4, 310 - 4, 570 m/s) has a homogeneous velocity. Thus if the 6th layer is subdivided into some velocity layers, the 5, 660 m/s layer will be deeper.

The following geological interpretations are possible from the above observation.

(a) Kengnei Formation (upper Miocene series) is about 2, 500 - 3, 000 m thick, and the basement with the same velocity as the Peikang Shelf directly underlies it.

(b) If a 5, 000 m/s layer exists under the 6th layer as shown in the analysed profile, it probably is a member of the middle - lower Miocene series. The reason for this being the inferrence that formations lower than middle Miocene series will have high velocity because the Pliocene and Miocene series of the southern part have high velocities and the formations become thicker in this area with finer grained rocks predominating. In this case, the 5, 600 m/s layer will be deeper than shown in the analysed profile.

It is not easy to judge which of the above two interpretations has higher possibility. From the gravimetric map, however, (isogravity values gradually decrease from west to east), (a) seems to be more reasonable. In this case, the basement of this area is about 8,500 m deep near the Chungchou Anticline and dips gently eastward, the disturbance of Kengnei and upper and lower Gutingkeng Formations (observed in the cores of TN-1, CC-2 wells) overlying the basement is interpreted as the result of different movement of the Miocene series and the basement brought about by pressure from east to west.

It may be that the eastern inclination of the 6th layer expressed in dotted lines in the interpreted profile under the western side of the Lungchuan Fault reflect the inclination of the basement.

4 - 3 Geophysical and geological consideration of the surveyed area.

The present refraction seismic survey was carried out along the four traverse lines covering the whole area of western Taiwan. The major purpose of the survey was to determine the general outline of the deeper structure of Neogene Tertiary system and the depth and structural form of the basement in order to provide data for the understanding of the geological structure of the oil and gas field areas of western Taiwan. The writers consider that the above purpose was achieved.

Here, the geophysical and geological aspects of the whole area will be discussed.

The observed velocity layer distribution of each travers? is as follows.

Formations	Seismic wave velocity layers	Velocities (m/s) Northern ares	 Central area	 Southern area
Pliocene - Pleistocene series	1st layer	1,700-1,900	1,500 1,950-2,000 2,200-2,555	1,810-1,850 2,050-2,080
Pliocene series	2nd "	2,100-2,300	2,850-3,540	2,420-2,560 2,900-3,080 3,630-3,850 4,000(blind layer)
	3rd "	2,400-3,200		
Miocene series	4th "	3,000-3,840	3,800-4,330	4,000(blind?) 4m310-4m730
	5th "	3,690-4,430		
	6th "	4,340-5,190		
Mesozoic(?)	7th "		5,230-5,460	
	8th "		5,620-5,860	

The velocity layers of the surveyed area have the following characteristics under the above division and correlation.

(1) The velocity layers are divided into eight layers from the 1st to the 8th and all show higher velocities than the formations of the same age of Japan. Therefore, it is necessary to establish longer traverse lines in order to determine accurately the depth of the basement in western Taiwan.

(2) The surveyed area is divided into north, central and southern parts, and the Miocene series are divided into three velocity layers of 4th, 5th, and 6th layers. The 4th layer is correlated to Kueichiulin Formation, the 5th to Nanchuang and Nankang Formations, and the 6th to Shihti and Taliao Formations. On the other hand, in the central and southern parts, the Miocene series cannot be divided into three divisions, but only into one or two velocity layers.

(3) The seismic wave velocities in the central and southern parts are generally higher than those of the corresponding layers of the northern part. This increase of velocities in the central and southern parts are believed to be caused by the greater depth and other geological conditions.

(4) The divisions of the velocity layers are distinct, and each layer has sufficient thickness for accurate analysis. This velocity distribution and the structure of the velocity layers are the main factors for the effectiveness of seismic refraction method in analysing the geologic structure of western Taiwan, and also for the relatively clear records of 2nd, 3rd motions and later phases. The velocity layers of this area were analysed and interpreted with the above division and correlation, and there are also the following general structural features in the analysed profile.

(5) There are velocity logging data obtained from drilling wells near the surveyed area. In general, the velocity data observed in the seismic refraction survey are higher than the logging data, and the rate of velocity increase is somewhat higher than the log data. This is believed to be caused by the geological structure of the area which is relatively flat with smaller number of faults.

(6) The inclination of the anticlinal structures expressed in the velocity profiles of Traverse Lines 4 and 2 are smaller than those measured on the surface. Lithological change, compression of the strata, and the degree of weathering are considered to be the major of factors for this difference. The wings of the anticlinal structures analysed by refraction methods, is

represented with lower dip because the layer surfaces are drawn in the direction of the composition of the velocity changes normal to the bedding and vertical direction. The existing data indicate that the areas in the vicinity of Traverse Lines 4 and 2 contain large portion of mudstone and thus the profile is affected more by the velocity variation due to the depth than to lithological variation.

In the area consisting mostly of physically weak mudstone to the west of the fault in the eastern part of Traverse Line 4, the horizontal velocity is especially stressed because of the lack of bedding in the mudstone layers.

Therefore the wings of the structures such as the Chungchou structure in the Traverse 4 area, were drawn with dotted lines in the interpreted profile with inclination exaggerated than the velocity layers of the analysed profile.

In surmising the basement of each traverse, the velocity of Traverse 3 was applied and also it was assumed that the velocity of the lowermost layer was homogeneous. It is necessary to further investigate the geological conditions of the related areas in order to check the validity of the above assumptions. Next, structure and other features of the analysed or interpreted basement will be critically discussed.

(7) The analysed depths of the lowermost velocity layers and the interpreted possible upper limit of the basement of the surveyed area are as follows.

Traverse	Depth of the lowermost layer	Interpreted possible upper limit of basement
2	4, 200 m	7, 000 m (near Pingchen Anticline)
1	3, 700 m	8, 000 - 9, 000 m (central part)
3	5, 000 m	5, 000 m (near Yuanlin)
		2, 500 m (southwest end)
4	5, 000 m	7, 500 - 8, 500 m

In this survey the basement was observed and analysed only in Traverse Line 3. The basement under Traverses 2, 1, and 4 of the above table are the shallowest possible depth with the assumption that the velocity of the basement is 5, 660 m/s. If the velocity is lower than the above value, the depth will be shallower. Under the above hypothesis, the basement is 2, 500 - 9, 000 m deep and inclines northeastward with a high peak at Peikang Shelf area in the southern end of Traverse Line 3, and in Traverse 2, it inclines southeastward with Kuanyin Shelf area as the highest peak. This tendency agrees fairly well with the structure surmised from the results of the gravimetric survey.

With the exception of Traverse 1, the hypothetical depth of the basement is deeper where the Miocene series is thick. The reason for the greater depth of the basement under Traverse Line 1 compared to other traverses is believed to be that the traverse was established parallel to the strike of the basement surface.

It is clear that in areas where the inferred depth of the basement is large, there should be thick Miocene or older formations under the analysed Miocene series.

In the present survey, the depth of the basement of the Neogene Tertiary system was assumed to be in the order of 6,000 m in setting the traverse lengths at about 40 km, but if the inferred depths of the basement are 7,000 - 9,000 m, the lengths of 70 km or more would have been better.

(8) There is the following general tendency concerning the velocity distribution of the Tertiary system of western Taiwan. The velocity layers of this survey and the logging data indicate that the same geological formation has higher velocity in the area east of the hinge line than in the western side.

Geophysical consideration concerning the total area of the present survey has been discussed. From the above discussion, several geologically common features are deduced by general geological consideration of the entire area.

a. Reliable information concerning the basement could not be obtained with the exception of the southwestern part of Traverse Line 3. This is caused by the insufficient length of the traverse because of the basement depth was greater than the predicted values, and the contrast between the velocities of the lower Miocene series and the basement was ambiguous, these factors are believed to have contributed to the lack of information concerning the basement of the area.

b. When the velocity of the basement Mesozoic layer of the Peikang Shelf is taken as the standard, the hypothetic 5,660 m/s layer is 7,500 - 9,000 m deep in the central parts of Traverses 1, 2 and 4.

c. The geological structural situation of the area under Traverses 2, 3 and 4 are similar in spite of their distances. For example, the Pingchen and Hukou Anticlines in Traverse 2 area are correlated to the Tainan and Chungchou Anticlines of Traverse 4. The Pakuanshan Anticline of Traverse 3 is correlated to Pingchen and Tainan Anticlines. There is a gentle syncline to the north of the Pingchen Anticline and a gentle monoclinic structure continuing to the Kuanyin Shelf further north. This is very similar to the structural variation from southwest of Pakuanshan to the Peikang Shelf in the Traverse 3 area.

d. When the argument of (b) is applied to Traverse 4 area, there is a gentle syncline to the west of Tainan Anticline and there is a possibility of a third shelf existing to the west of this syncline in the southeastern part of Taiwan Straights.

In Traverse 1 area, Tiechenshan-Tunghsiao Anticline continues to the Pakuanshan Anticline, but the geologic structural situation indicate that it corresponds to Hukou and Chungchou Anticlines.

If the above folds, it is not unreasonable to assume the existence of a gentle anticline corresponding to the Pingchen Anticline to the west of Tiechenshan-Tunghsiao Anticline in the Taiwan Straits.

The above consideration gives rise to the following inferrence. The surface of the basement in the area from Taiwan Straits to western Taiwan in general, inclines gently eastward with some small undulations, and protrusions such as the Peikang Shelf in east-west direction are aligned in north-south direction with certain intervals. In other words, the intersection of the basement with a horizontal plane would be a wave formed curve extending along the western coast of Taiwan in north-south direction.

The pattern of the folding of the Neogene Tertiary system with decreasing degree of folds to the west is not only caused by the decrease of pressure from the east but is controlled by the mutual relationship of the decrease of the pressure and the shape of the basement.

5 CONCLUSION

The main purpose of the present survey in western Taiwan was to determine the deep structure of the Miocene series which constitute the oil and gas layers and at the same time determine the depth and shape of the basement. Although it was generally not possible to obtain the depth of the basement accurately with the exception of one area, the deeper structure of the Neogene Tertiary system was analysed and also it became clear that the basement was deeper than hitherto believed, thus satisfactory results were obtained from this survey. Also various physical data such as the correlation of the velocity layers and geologic formations will be extremely useful for future oil and gas exploration.

The results of this survey shows that it is necessary to determine the reliable depth of the basement for future oil and gas exploration. When the depth and the shape of the basement are determined, the areas with relatively shallow basement will be the target area for oil and gas accumulation structures such as the Tiechenshan-Tunghsiao and Tainan Anticlines, and the coastal areas of the Taiwan Straits are most probably the promising areas in this respect.

In order to determine the basement structure, large scale refraction seismic and deep electric surveys are necessary.

APPENDIX

APPENDIX

THE VELOCITY AND SPECIFIC GRAVITY OF THE ROCKS AND DRILLING CORES OF TAIWAN

Table of contes

1. Introduction

There are a large number of data concerning the relationship between the geological formations and velocities in Taiwan, these are from the velocity logging carried out by the Chinese Petroleum Corporation, part of which has already been published. During the course of the present survey, rock specimens of the representative geological formations were collected, and the velocities and apparent specific gravities of these specimens were measured in Japan in order to check the relationship between the velocities and the formations.

2. Localities of rock specimens

Rock specimens collected from outcrops and from the drilling cores of the Chinese Petroleum Corporation were used.

Most of the specimens were collected from the northern side of the Peikang Shelf.

The localities of the specimens are shown in Figure 1.

3. Stratigraphy and lithology of the rock specimens

The stratigraphic horizons of the collected specimens are shown in Table 1.

Table 2 is a list of the lithology, formation names, localities, distinction of outcrops or cores of the collected specimens. The number of the specimens is in the order the measurement.

The total number of the measured specimens is 48.

Specimen 46 consists of two rock samples they are numbered 46-1 and 46-2.

Table 1. The Stratigraphic Horizons of Rock Samples from the Neogene Strata in the Western Taiwan.

Southern Area

Age	Traverse Line 4: Formation	Sample №	Traverse Line 4 - 3: Formation	Sample №
Plio-Pleistocene				
Plio-Pleistocene	"B" Formation		LIUSHUANG F.	
Plio-Pleistocene	"A" Formation	①	ERHCHUNGCHI F.	
Pliocene	Upper GUTINGKENG F.		KANHSIALIAO F.	
Pliocene	Lower GUTINGKENG F.	② ③	LIUCHUNGCHI F.	
Pliocene		④	YUNSHUICHI F.	
Pliocene		⑤ ⑥	NIAOTSUI F.	⑪
Pliocene		⑦	CHUNLUN F.	
Miocene	KENGNEI F. (MUCHA Formation)	⑧ ⑨	CHUTOUCHI F.	⑫
Miocene			MAUPU Shale	
Miocene			AILIAOCHIAO F.	
Miocene			YENSHUIKENG Sh	
Miocene			TANGENSHAN S.S.	
Miocene			CHANGCHIHKENG F.	
Miocene			HUNGHUATZU F.	
Miocene			SHUILIKENG F. (SHANMIN F.) (HOSHE F.)	⑬
Miocene			TAKENG F.	
Miocene			TSUKENG F.	⑭
Miocene			PEIHANG Bore Hole	⑮
Miocene			Miocene Series	⑯
Early Cretaceous Period			Cretaceous System	⑰
Early Cretaceous Period			Basement Rock	⑱

Northern Area

Age	Traverse Line 1 - 3: Formation	Sample №	Traverse Line 2: Formation	Sample №
	LH.		LH.	
	LT.		LT.	
Plio-Pleistocene	TOUKOSHAN F.: HUOYENSHAN Facies		TOUKOSHAN F.: HUOYENSHAN Facies	
Plio-Pleistocene	TOUKOSHAN F.: HSIANGSHAN Facies		TOUKOSHAN F.: HSIANGSHAN Facies	
Pliocene	CHOLAN Formation	⑩ ㉚	CHOLAN Formation	
	CHINSHUI Shale	㉛ ⑲	CHINSHUI Shale	㉜
Upper Miocene	KUEICHULIN F.: TAWO Siltstone	㉝	KUEICHULIN Formation	
Upper Miocene	KUEICHULIN F.: SHINLIUFEN Sh.	⑳		
Upper Miocene	KUEICHULIN F.: KUANTAAO-SHAN S.S.			
Upper Miocene	SHANGFUCHI S.S.		NANKANG F.: NANCHUANG F.: SHANGFUCHI S.S.	
Upper Miocene	TUNGKENG F.	㉟	NANKANG F.: NANCHUANG F.: HOPAI Formation	㊷
Upper Miocene	KUANYINSHAN S.S.			
Middle Miocene	TALU Shale	㉑ ㉒ ㉓	NANKANG F.: TALU Shale	㊸
Middle Miocene	PEILIAO S.S. / PEILIAO F.	㊱ ㉔	NANKANG F.: PEILIAO F.	㊹ ㊺
Middle Miocene	CHUHUANGKENG F. / SHIHTI F.	㊲ ㊳ ㊴ ㉕ ㉖	SHIHTI Formation	㊻-1.2
Lower Miocene	TALIAO KUNGKANG F.	㉗	TALIAO KUNGKANG F.	㊼
Lower Miocene	MUSHAN Formation	㉘ ㊶	MUSHAN Formation	
Lower Miocene	WUCHISHAN F	㊵ ㉙	WUCHISHAN F.	
Early Cretaceous Period				

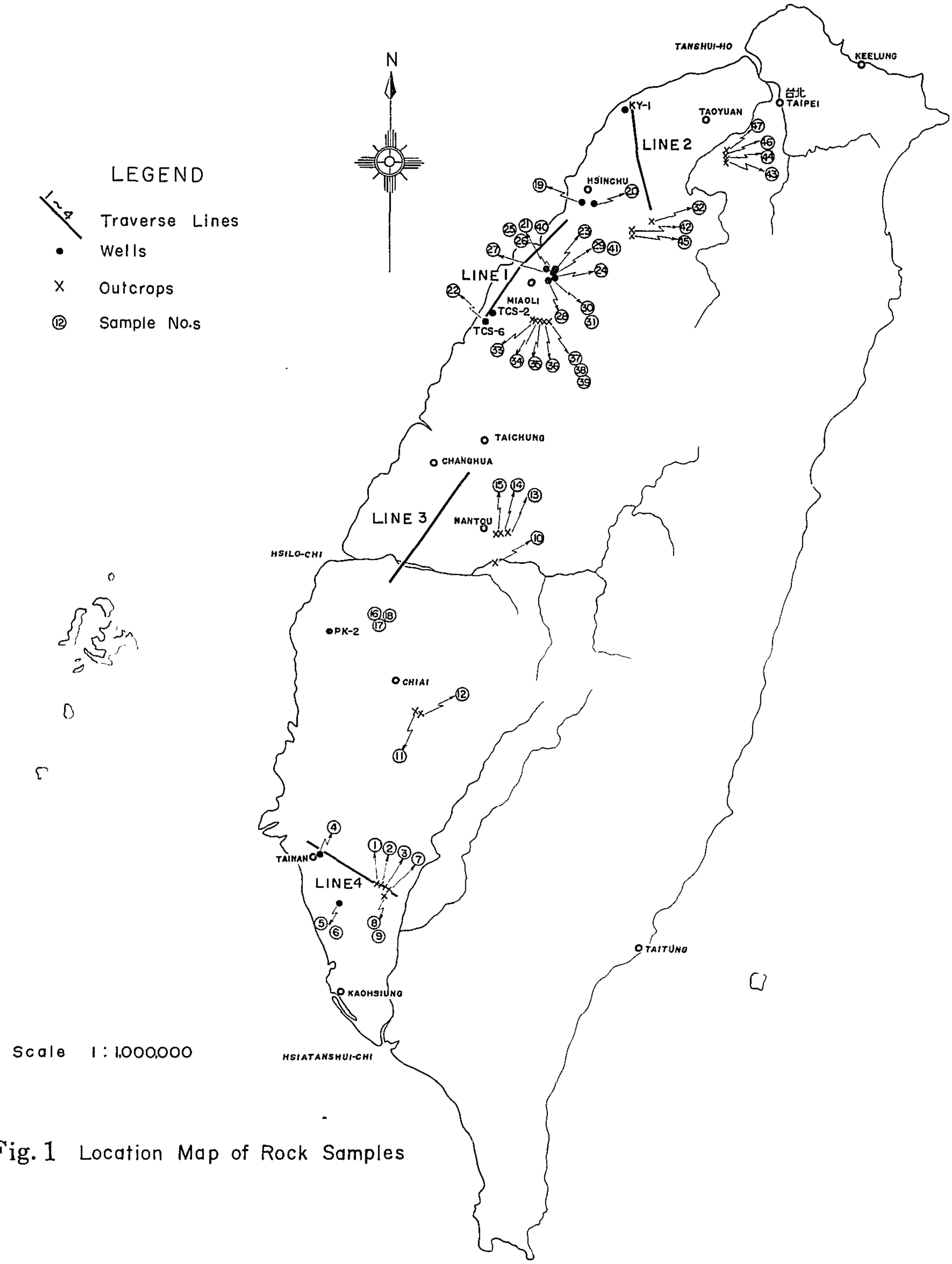


Fig. 1 Location Map of Rock Samples

Table 2-1. The List of Specimens for Measurement.

Sample №	Rocks	Formation	Location of Sample	Outcrops and Core	Remark
1	Mudstone	"A" Formation	between CHISHAN-KUANMIAO East 1.7Km of CHITING	Outcrop	
2	Calc S.S.	Upper CHITINGKENG F.	between CHISHAN-KUANMIAO East about 3Km of CHITING	"	
3	Mudstone	Upper part of Lower GUTING-KENG F.	North West 8.2Km of CHISHAN	"	West of LUNGCHUAN Fault
4	"	" ?	TAINAN TN-1 Well 533m	Core	
5	"	Lower part of Lower GUTING-KENG F. ?	CHUNGCHO CC-2 Well 3,182m	"	
6	"	" ? "	" 3,290m	"	
7	"	Lower part of Lower GUTING-KENG F.	North West 6.5Km of CHISHAN	Outcrop	East of LUNGCHUAN Fault
8	Sandstone	KENGNEI Formation	North West 7Km of CHISHAN	"	LUNGCHUAN Fault
9	Muddy S.S.	"	"	"	"
10	Sandstone	CHOLAN Formation	Near opposit bank of CHICHI at the Southern Shore of the HSILO-CHI	"	"
11	"	NIAOTSUI Formation	East of CHIAYI, YUNSHUI-CHUNLUN	"	Western wing of CHUNLON Anticline
12	"	?CHANGCHIH-KENG F.	"	"	East of LIUCHUNG-CHI Fault
13	"	SHUILIKENG-TAKENG F.	NANTOU PING-LINCHITSUKENG	"	
14	"	Lower part of TAKENG F.	"	"	
15	"	TSUKENG Formation	"	"	Anticline A x is
16	Volcanic Detrital Sandstone	PEIHANG Formation	PEIKANG PK-2 Well 1,525 m	Core	
17	Shale	Lower Cretaceous System	" 1,644 m	"	Basement Rock
18	Sandstone	"	" 2,076 m	"	"
19	Mudstone	SHINSHUI Shale	HSINCHU SHING-TSAOPU 5 Well 1,544 m	"	
20	"	KUEICHULIN F. (SHINLIUFEN Sh.)	" 2,031 m	"	
21	White S.S.	TALU Shale	CHINSHUI CS-64 Well 2,407 m	"	
22	"	"	TIENCHENSHAN TCS 6 Well 2,782 m	"	Anticline Top

Table 2-2. The List of Specimens for Measurement. (continued)

Sample №	Rocks	Formation	Location of Sample	Outcrops and Core	Remark
23	Shale	TALU Shale	CHINSHUI 32 Well 2,373m	Core	
24	Sandstone	PEILIAO Sandstone	" CS59 Well 2,381m	"	
25	"	SHIHTI Formation	" CS64 Well 3,418m	"	
26	Shale	"	" CS64 Well 3,342m	"	
27	Sandstone	TALIAO Formation	" CS61 Well 3,516m	"	
28	"	MUSHAN Formation	" CS53 Well 4,040m	"	
29	"	WUCHISHAN F.	" CS69 Well 4,519m	"	
30	Mudstone	CHINSHUI Shale	CHINSHUI	Outcrop	CHINSHUI Anticline Top
31	Sandstone	"	"	"	"
32	Mudstone	"	7Km East of CHUTOUNG	"	Near Fault
33	Shale	KUEICHULIN F. (SHINLIUFEN Sh.	CHUHUANGKENG	"	Western wing of CHUHUANG-KENG Anticline
34	Sandstone	KUEICHULIN F. (KUANTAOSHAN SS)	"	"	"
35	"	NANKANG F. (KUANYINSHAN SS)	"	"	"
36	"	PEILIAO Formation	"	"	"
37	White S.S.	SHIHTI Formation	"	"	"
38	"	"	"	"	
39	"	"	"	"	
40	Sandstone	WUCHISHAN F.	CHINSHUI CS-64 Well 4,701m	Core	
41	"	"	" CS-69 Well 4,581m	"	
42	"	Upper parts of NANGHUANG F. (HOPAI Formation)	TSOUHO Arer	Outcrop	
43	Shale	TALU Shale	"	"	
44	Sandstone	PEILIAO Formation	"	"	
45	"	"	"	"	
46-1	"	SHIHTI Formation	"	"	
46-2	White S. S.	"	"	"	
47	Sandstone	TALIAO Formation	"	"	

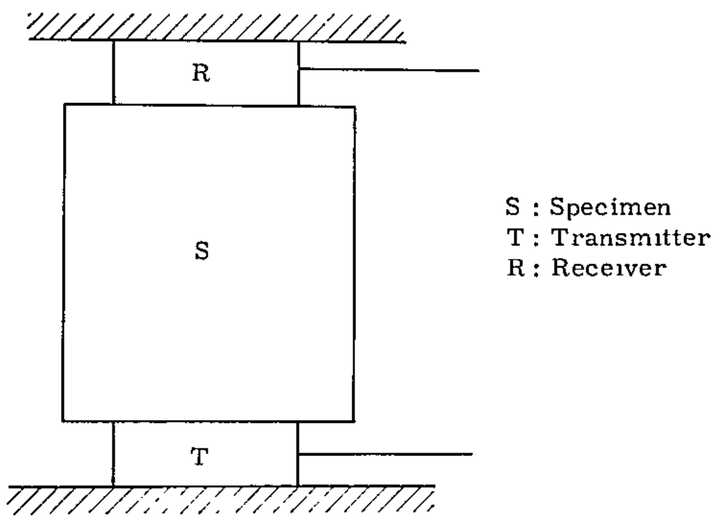
4. Method of measurement

The rock specimens were cut into cubes with sides of 3 cm to 6 cm but some of the specimens could not be cut parallel and were not possible to polish.

Rocks with distinct bedding such as shale were cut normal to the bedding plane. The velocities of waves travelling normal to the bedding were designated as V_a and those travelling in the direction within the plane were designated V_b and V_c.

Many of the specimens were mudstone or sandstone. Thus the bedding planes of these rocks are not necessarily clear, and the grain distribution was used as criterion for cutting.

Fig. 2 The Schematic Representation of the Method of Ultrasonic Wave Velocity Measurement under Normal Condition

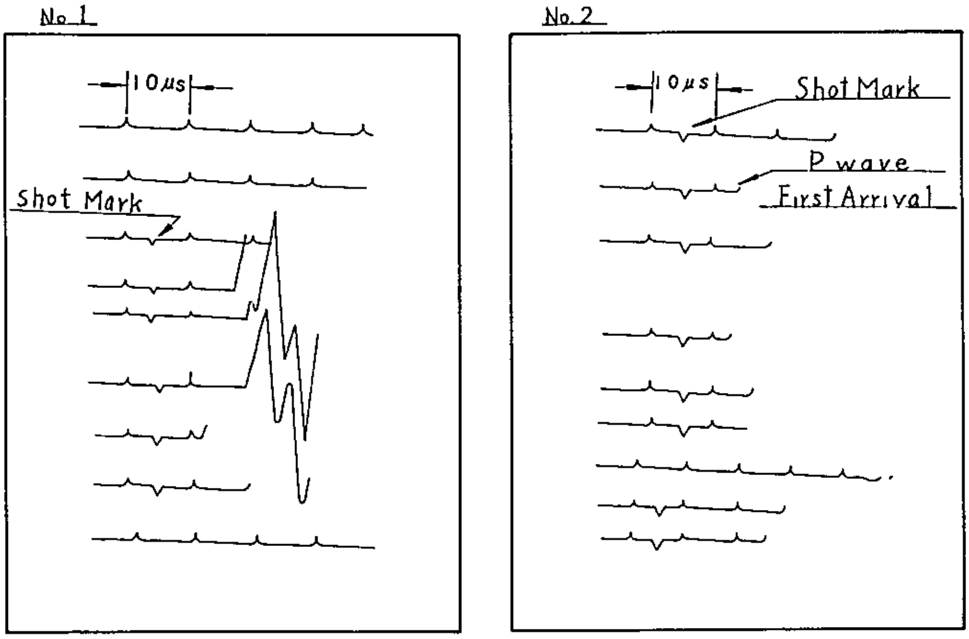


Ultrasonic wave velocity measurement apparatus was used for the measurements.

Barium titanate transducers were used for the velocity measurement. The specimen was fixed between two transducers as shown in Figure 2, and the vibration from the transmitter (500 KC) was caught by the receiver after transmission through the rock sample.

An example of the records of the measurements is shown in Figure 3 The transmitting time of the vibration is read from these records and the velocities are obtained.

Fig. 3. An Example of Seismic Records



The apparent specific gravities of the rock samples were measured. The values were obtained from the following equation.

$$Pa = \frac{WAD}{WAD - WAW}$$

WAD : weight in air

WAW : weight in water

These measurements of the velocities and apparent specific gravities were all done under naturally dried conditions.

5. Results

The velocities and the apparent specific gravities of the 48 rock specimens are laid out in Table 3.

The above results were compiled into a table of geological horizons and velocities and apparent specific gravities (Table 4).

This is graphically shown in Figure 4.

As seen in Tables 1 and 4, most of the Miocene specimens were collected from north of the Peikang Shelf while those of the Pliocene series come from the southern areas. Thus the sampled localities may seem unbalanced, but this inevitable due to the characteristics of the geology of Taiwan. This does mean, however, that the average velocities and apparent specific gravities of the collected samples cannot be used uniquely as the velocities and specific gravities of the geological units of western Taiwan.

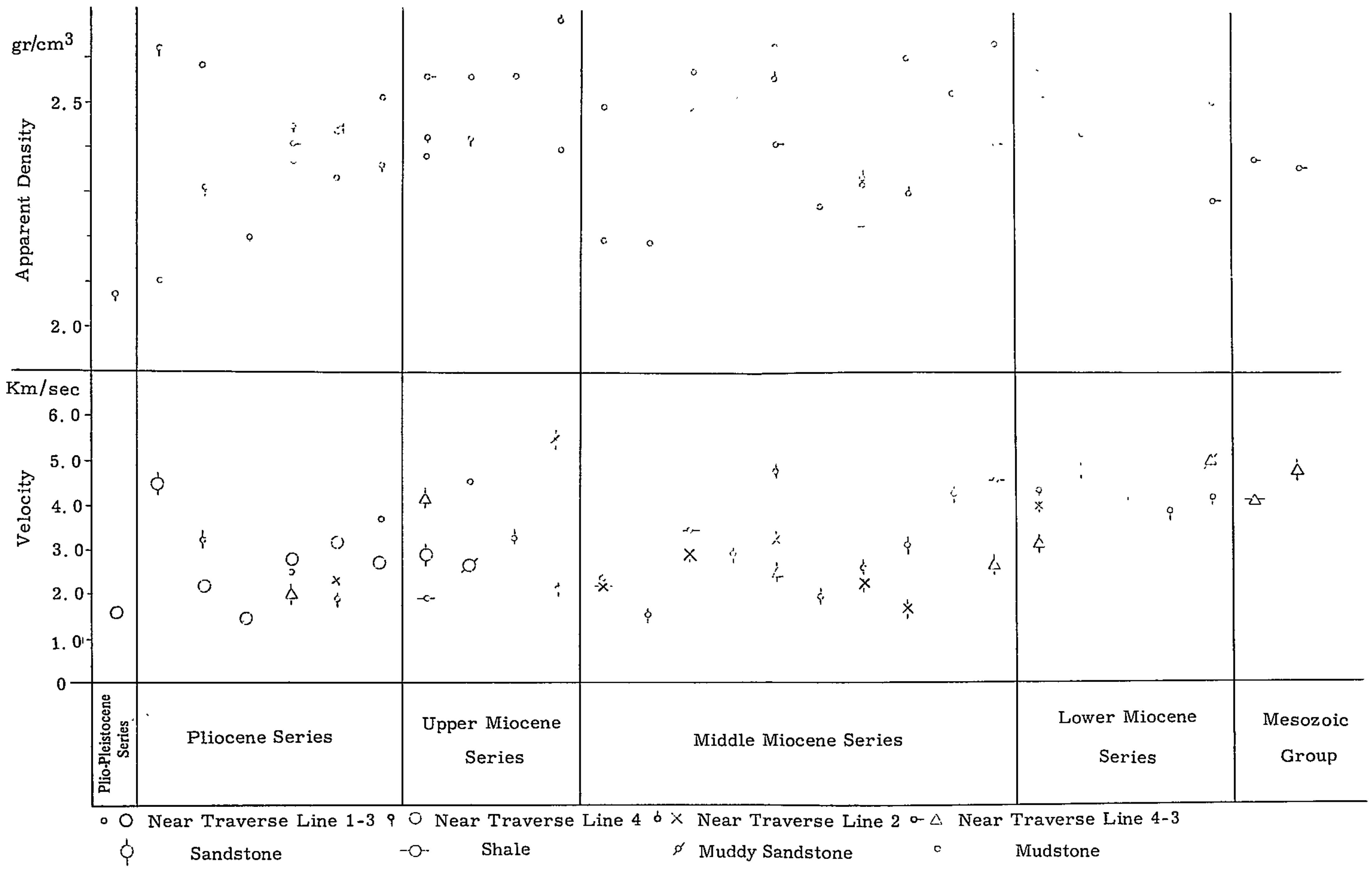
Table 3 Measuring Results of Seismic Velocity.

Rock No.	Vz	Vy	Vx	Va	Density
1	1, 638	1, 415	1, 546	1, 533	2. 072
2		5, 125	3, 944	4, 535	2. 623
3	1, 947	2, 174	2, 376	2, 166	2. 315
4	1, 539	1, 718	1, 036	1, 431	2. 206
5	2, 295	3, 351	2, 986	2, 877	2. 453
6		3, 061	3, 324	3, 193	2. 455
7		2, 617	2, 885	2, 751	2. 369
8	2, 715		3, 133	2, 924	2. 430
9	2, 672	2, 690	2, 492	2, 615	2 427
10	3, 246	3, 019	3, 300	3, 188	2 585
11	1, 959	1, 959	2, 006	1, 975	2 412
12	4, 151	4, 220		4, 186	2. 565
13	2, 479		2, 694	2, 587	2. 411
14		2, 628	2, 713	2, 675	2. 407
15	3, 201		3, 082	3, 142	2. 510
16	5, 250	4, 861	4, 910	5, 007	2. 288
17	3, 980		4, 211	4, 096	2. 375
18		4, 758	4, 771	4, 765	2. 355
19	3, 387	4, 014	3, 918	3, 773	2 517
20	4, 465	4, 474	4, 745	4, 561	2. 565
21	2, 667	2, 093	2, 130	2, 297	2. 198
22	1, 492	1, 317	1, 597	1, 469	2. 190
23		3, 402	3, 672	3, 537	2. 571
24	4, 900	4, 530	5, 045	4, 825	2. 634
25	4, 297	3, 938	4, 618	4, 284	2 518
26	3, 198	5, 344	5, 261	4, 601	2. 625
27	4, 327	4, 353		4, 340	2. 577
28	4, 544	4, 792	4, 902	4, 746	2. 430
29	3, 671	4, 533	4, 439	4, 214	2. 504
30		2, 448	2, 732	2, 590	2, 379
31	1, 963	1, 833		1, 898	2. 339
32	2, 599	2, 557	1, 994	2, 383	2 444
33		1, 942		1, 942	2. 386
34	3, 338	3, 393	3, 168	3, 300	2 565
35	2, 142	2, 176		2, 159	2 401
36	2, 846	2, 820	3, 111	2, 929	2 521
37	1, 818	1, 849	2, 213	1, 960	2 269
38		2, 573	2, 577	2, 575	2. 314
39		3, 170	2, 953	3, 062	2 598
40	3, 832	4, 167	3, 571	3, 857	2 424
41	5, 024		3, 689	4, 357	2. 634
42		5, 661	5, 591	5, 626	2 690
43	long 1, 668	short	2, 759	2, 214	2 495
44		3, 104	2, 812	2, 958	2, 482
45	3, 126		3, 371	3, 249	2 561
46-1	2, 280	1, 870	2, 793	2, 314	2 322
46-2	1, 809	1, 641		1, 725	2 295
47	3, 939	3, 873	4, 183	3, 998	2, 498

Table 4 Comparison of Seismic Velocity, Apparent Density and Stratigraphy

		Northern Area										Southern Area									
		Near Traverse Line 1 - 3					Traverse Line 2					Traverse Line 4 - 3					Traverse Line 4				
		Rock№	Va	ΣVa/n	Density	ΣD/n	Rock№	Va	ΣVa/n	Density	ΣD/n	Rock№	Va	ΣVa/n	Density	ΣD/n	Rock№	Va	ΣVa/n	Density	ΣD/n
Plio-Pleistocene Series																	1	1, 533	1, 533	2. 072	2 072
																	2	4, 535	2, 825	2. 623	2 404
Pliocene Series		10	3, 188	2, 862	2. 585	2. 455											3	2, 166		2 315	
																	4	1, 431		2. 206	
		30	2, 590		2 379							11	1, 975	1, 975	2. 412	2 412	5	2, 877		2. 453	
		31	1, 898		2. 339		32	2, 383	2, 383	2. 444	2 444						6	3, 193		2. 455	
		19	3, 773		2. 517												7	2, 751		2 369	
Miocene Series	Upper Miocene	33	1, 942	2, 991	2. 386	2. 479						12	4, 186	4, 186	2 565	2 565	8	2, 924	2, 770	2 430	2 429
		20	4, 561		2. 565												9	2, 615		2 427	
		34	3, 300		2. 565																
		35	2, 159		2. 401		42	5, 626	5, 626	2. 690	2 690										
	Middle Miocene	21	2, 297	3, 154	2. 198	2. 444	43	2, 214	2, 492	2 495	2 431										
		22	1, 469		2. 190																
		23	3, 537		2. 571		44	2, 958		2. 482											
		36	2, 929		2. 521																
		24	4, 825		2. 634		45	3, 249		2. 561		13	2, 587	2, 631	2. 411	2. 409					
		37	1, 960		2. 269																
		38	2, 575		2. 314		46-1	2, 314		2. 322											
		39	3, 062		2. 598		46-2	1, 725		2. 295											
		25	4, 284		2. 518																
		26	4, 601		2. 625							14	2, 675		2 407						
	Lower Miocene	27	4, 340	4, 303	2 577	2 514	47	3, 998	3, 998	2. 498	2. 498	15	3, 142	4, 075	2. 510	2. 399					
		28	4, 746		2. 430																
		41	4, 357		2. 634																
		40	3, 857		2. 424																
		29	4, 214		2, 504							16	5, 007		2. 288						
Mesozoic Group												17	4, 096	4, 431	2. 375	2. 365					
												18	4, 765		2. 355						

Fig. 4 Seismic Velocity and Apparent Density of Rock Sample in Western Taiwan



And the values of the samples in one area does not represent the values of the geologic formations of the area.

However, the rock samples were collected from the representative formations of western Taiwan as shown in Figure 1 and Table 1, and the values laid out in Figure 4 and Table 4 statistically reflect the tendency of the velocity and apparent specific gravity of the formations.

The following are the points inferred from the figures of Table 4 and Figure 4.

(1) Velocity Stratigraphy

The rock samples were collected densely stratigraphically in the areas of Traverses 1 - 3. The inferrence of the velocity stratigraphy from the results of the above areas show the mean velocity to be 2, 862 m/s for Pliocene strata, 2, 991 m/s for upper Miocene strata, 3, 154 m/s and 4, 303 m/s for middle and lower Miocene formations respectively. Velocity stratigraphy is observed and the correlation with geologic stratigraphy is possible. The increase of velocity from the upper layer downwards is one of the reasons for the effectiveness of the refraction seismic method.

(2) The velocity of the Miocene series similar to that of the basement

The mean velocity of lower Miocene series is 4, 303 m/s, 3, 998 m/s, and 4, 075 m/s as seen in Table 4 and Figure 4 On the other hand, that of the pre-Miocene (Cretaceous) series in the lower part of the area is 4, 431 m/s. The figure of the Crataceous system was obtained from the drilling core of Peikang No. 2 well, and coincides very well with the velocity logging data of Chinese Petroleum Corporation and supports the accuracy of the measurements.

This similarity of the velocities of the Cretaceous basement and the lower Miocene series must be taken into consideration in the geological interpretation of the velocity layers.

From the above points, the geological interpretation of the analytical results of Traverse Line 3 of this survey is of interest. And it will be necessary to consider the matter with further survey data in the future

(3) The velocity variation within one formation (Formation pressure and velocity variation)

The middle Miocene samples Nos. 24, 25, 26 collected from Peiliao, Shihti, and Taliao Formations are deep drilling cores as shown in Table 2 and Figure 1. On the other hand, specimens 36, 37, 38, 39, 44, 45, 46-1, 46-2 were collected from the exposures of the same formations.

Study of the measured results of these rock specimens with different depth and areas reveal interesting facts.

The difference of average velocities by localities of the Peiliao Formation is 2, 929 m/s, 2, 958 m/s, 3, 249 m/s for samples 36, 44 and 45 respectively. These figures are actually quite similar. Also specimens 37, 38, 39, 46-1, 46-2 were all collected from Shihti Formation and their mean velocities are 1, 960 m/s, 2, 575 m/s, 3, 062 m/s, 2, 314 m/s, and 1, 725 m/s respectively. These indicate that the velocities closely resemble each other as in the case of Peiliao Formation.

It can be concluded from these results that there are small differences in velocities within the same formation of different areas, unless they are affected by faults and fractured zones.

Next is the variation of the velocity by the depth of the specimens.

Sample 24 was collected from Peiliao Formation at the depth of 2, 381 m and the average velocity is 4, 825 m/s

Samples 25 and 26 were collected from Shihti Formation at depths of 3, 418 m and 3, 342 m, their average velocities are 4, 284 m/s and 4, 601 m/s respectively.

These data show that the velocity of geologic formations is closely associated with the depth of the formation from the surface, in other words the pressure applied to the particular formation.

This fact is important in that the velocities of the layers are controlled and varies by the structure This point has been examined from the results of the velocity logging data of the Chinese Petroleum Corporation as follows

Figure 5 shows the results of the comparison of the velocity logging data of Kuanyin well 1 and Tiechenshan well 2.

Concerning Peiliao Sandstone and Shihti Formation, the results of this velocity logging do not contradict the considerations above.

It is also of interest to note that the depth and the velocity of the sample from Peikang well 2 are intermediate values of the two well samples.

The result of the velocity logging of Tiechenshan well 2 shows that the average velocity of the lower layer of Peiliao Sandstone is approximately 5, 000 m/s which is similar to the velocity of the Cretaceous basement, and this is noted in the interpretation of the velocity layers of the northern part of Traverse Line 3.

(4) The anisotropism of the velocities

Generally the bedding is distinct in shales. Samples 17, 23, 26, 33 were shales, but the measurements suited for the consideration of anisotropism were those of samples 17 and 26

It is seen from Table 24 that in two rock specimens the velocities of the waves transmitted in direction normal to the bedding plane Va are smaller than the velocities of the waves travelling in directions within the bedding plane Vb and Vc.

Sample 17 is lower Cretaceous shale and the anisotropism of the velocities is expressed as Vb or Vc/Va = 1. 1.

Sample 26 is shale from Shihti Formation and Vb and Vc are 5, 344 m/s and 5, 261 m/s respectively and are close to each other, but the anisotropism is Vc/Va = 1. 6 and is abnormally large.

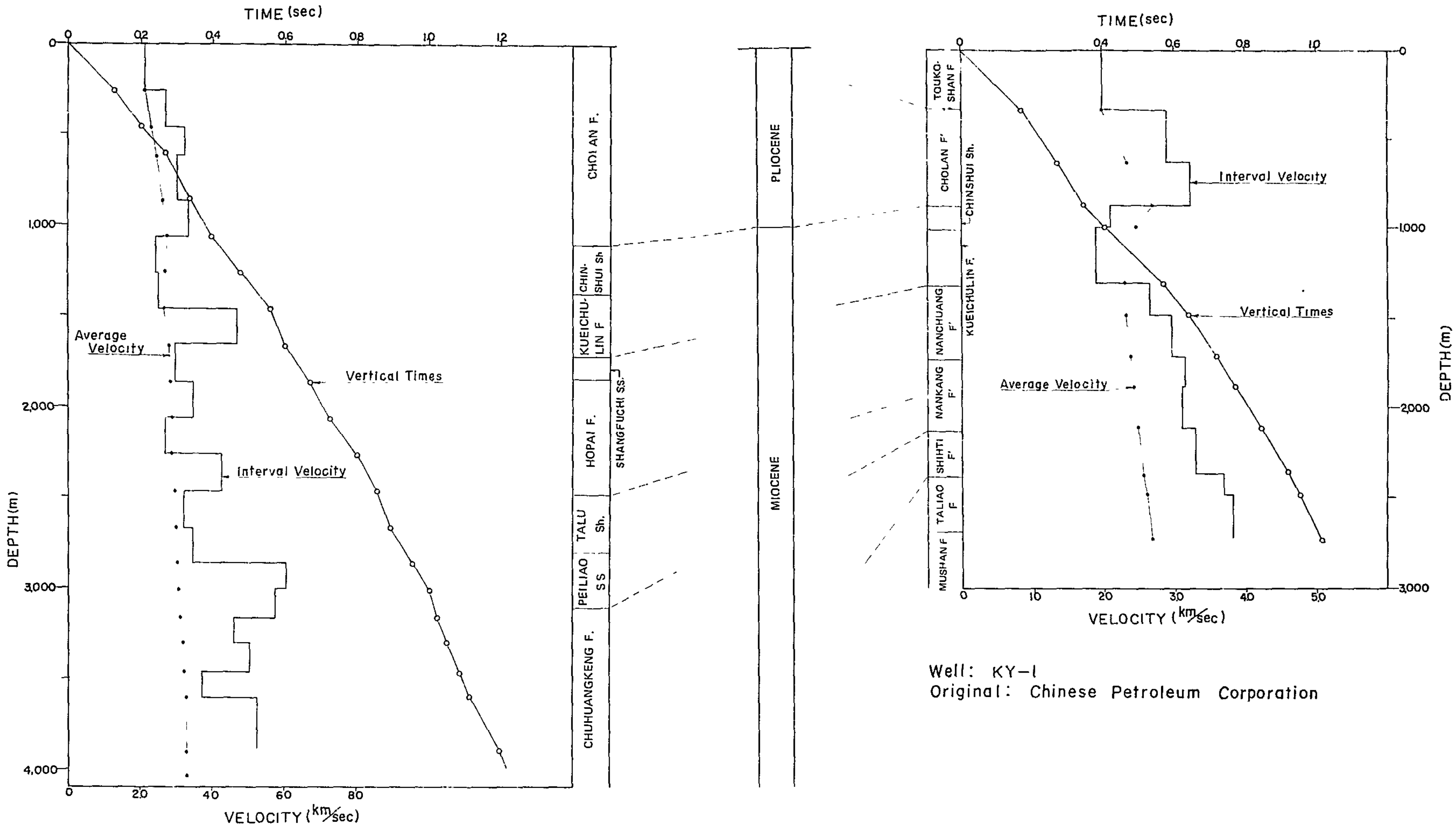
Generally the velocities of shales are anisotropic, and Vb and Vc are larger than Va. The above results agree with this general tendency.

This anisotropism of the velocities means that the velocities obtained by the refraction method does not necessarily coincide with those of the velocity logging.

Appendix 2. Statistics of the Survey Operations

Period of Survey	From June 3, 1968 to August 12, 1968					
Duration of Survey	71 days					
Survey Team						
Number of personnel Days in Taiwan Man-days in Taiwan Total man-days	Chief	Geophysics Party	Geophysics Party	Administrative Party	Advance Party	Withdrawal Party
Traverse Lines	Traverse 2 1 3 4	Length	Spread	Observation Points	Maximum difference of elevation	Remarks Survey & establishment of the traverse lines were done by Chinese Petroleum Corporation
Shot Holes	Traverse	Shot Points	Shot holes	Shot hole diameter	Drilled length	Remarks All casing. The drilling was done by CPC.
Major Equipment Used	Seismic equipment	SIE Seismic equipment PT 100 + PMR 20 SIE " " GA 11 + PMR 7 SIE " " G 33 (CPC)				car borne equipment
	Receivers	Mark Product 4. 5 cycle				90 units
	Com-munication equipment	Yaesu Musen FT-50SSB Transceiver National 1W Microwave Radio " 0. 1 - 0. 5W 27MC band Transceiver Kikusui Denki JJY Receiver				6 units 5 units 10 units 5 units
Explosives	Traverse 2 Total	Number of Shots 13	Explosive charge 2, 933 kg	Average charge 225. 6 kg	Maximum charge 433. 0 kg	Electric detorator caps used 35

Expendable items, workers, and vehicles were provided by the Chinese Petroleum Corporation



Well: TCS-2
Original: Chinese Petroleum Corporation

Well: KY-1
Original: Chinese Petroleum Corporation

Fig. 5 Comparison of Well Shooting Data, TCS-2, KY-1