Carboniferous, Permian, Triassic, Jurassic, Cretaceous, Paleogene, and Neogene.

According to the old theory of the continental drift championed by Wagener and Suess, there was neither the Atlantic nor the Indian ocean as we know them today. Before and during the Carbo-Triassic period, areas covered by these oceans today were actually incorporated in the Gondwana. Where then, were all the mass of water?

3.1.2.2. Mid-oceanic ridges

According to the theory of Isostasy, the crust of the mid-oceans are nearer to the effects of the mantle. Mantle pressure forces the floors of the oceans to bulge upwards or force some of its assimilated materials to make through the cracks and overflow to make or form the ridges. Mid-oceanic ridges exist in all the major oceans and make a continuous interlinking structure between them. It appears as though that the ridges had a close link with the Alpine type orogeny and that during the orogensis, the ridges had saved as safety valves to allow heat, gases, and lava to escape from the interior of the earth due to over heating resulting from the mechanical movement of the land masses. The ridges have also saved as buffers between the plates. Some of the mid-oceanic ridges are supposed to expand from the crater like openings in the middle of the ridge; for example, the Atlantic ridge (Fig. 5); others have attained mound like structures like the southern Pacific ridge (Fig. 4).

3.1.2.3. The fold mountains

Basic concepts of geology assume that the orogery that had built up the formidable fold mountains to have effected from the large depressions embedded with the large sedimentary accumulations, which had suffered vertical and compressional forces within the crust. Supposing the vast and the ancient geosynclines were taken to be similar to the basins of the present seas and oceans do, then, the mid-oceanic ridges represent unaccomplished process of fold mountaineering?

Similarities of physical processes taking place along the fold

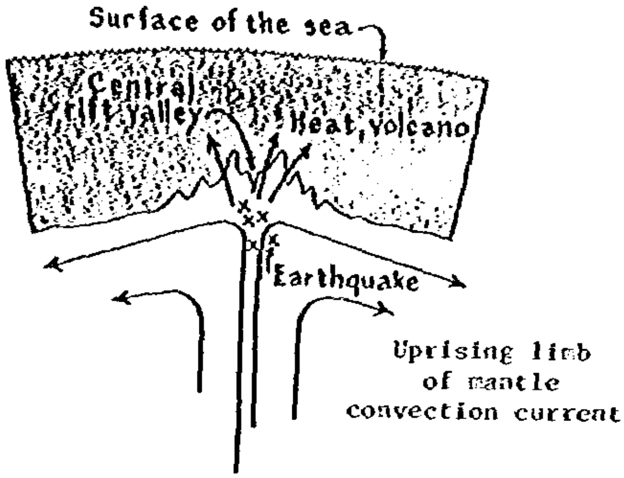

Fig. 4 Schematic drawing illustrating a possible mechanism of the formation of a mid-oceanic ridge by mantle convection currents.

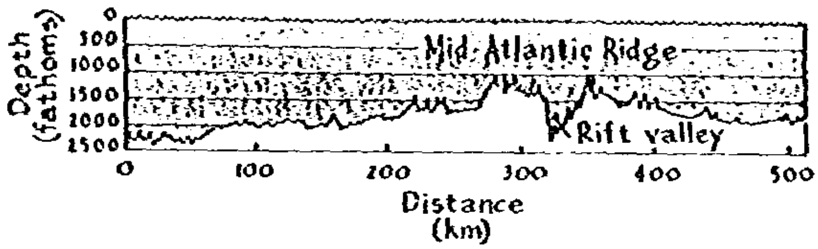

Fig. 5 Profile of the Mid-Atlantic Ridge. (After S. K. Runcorn, 1962)

mountains and along the mid-oceanic ridges; like the volcanic eruptions, lava flow, earthquakes, fumeroles, etc., give good point to contend that the mechanism of the physical processes taking place in the interior of the earth along the fold mountains and along the mid-oceanic ridges, are essentially similar.

3.1.2.4. The convectional currents

The subject of the convectional currents have been introduced to serve the explanation of the physical processes taking place in the interior of the earth, some of which could be correlable on the surface. Seismic observation of the interior of the earth

(Fig. 1-a) which coinsides with the gravimetric data (Fig. 1-b) and physical observations through volcanic eruptions, lava flow, fumeroles, etc., all indicate the existance of the solid crust, the fluid like mantle and the heavy inner core. Some authors agree that between the crust and the mantle, there could be free movement of the relatively solid crust navigating on the mantle.

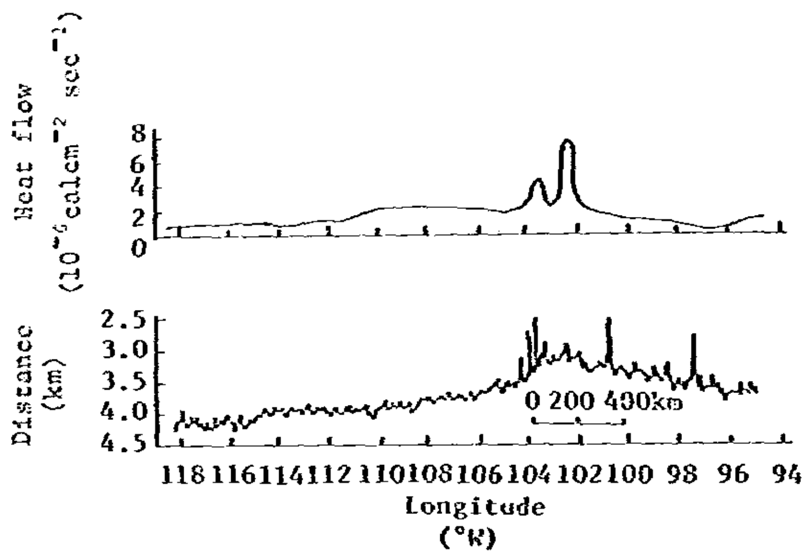

Fig. 6 Profile of heat flow and topography across the East Pacific Rise. After R. P. Von Herzen and S. Uyeda, 1963.

According to the geothermal gradient (Fig. 6), the temperature in the mantle should be extremely high: enough to generated convectional currents responsible for the physical processes as land movements, volcanic eruptions, mountain and ridge building, subduction of lands and continents, earthquakes, etc. (Fig. 7).

3.1.2.5. Ocean floor expansion

Observations made in the Atlantic mid-oceanic ridge revealed an apparent cross expansion of between 2-3cm per annum all over the peak length of the ridge. This expansion is made up of the lava flow across the crater like extension of the ridge. It is assumed, therefore, that such a phenomenon of ocean floor spreading

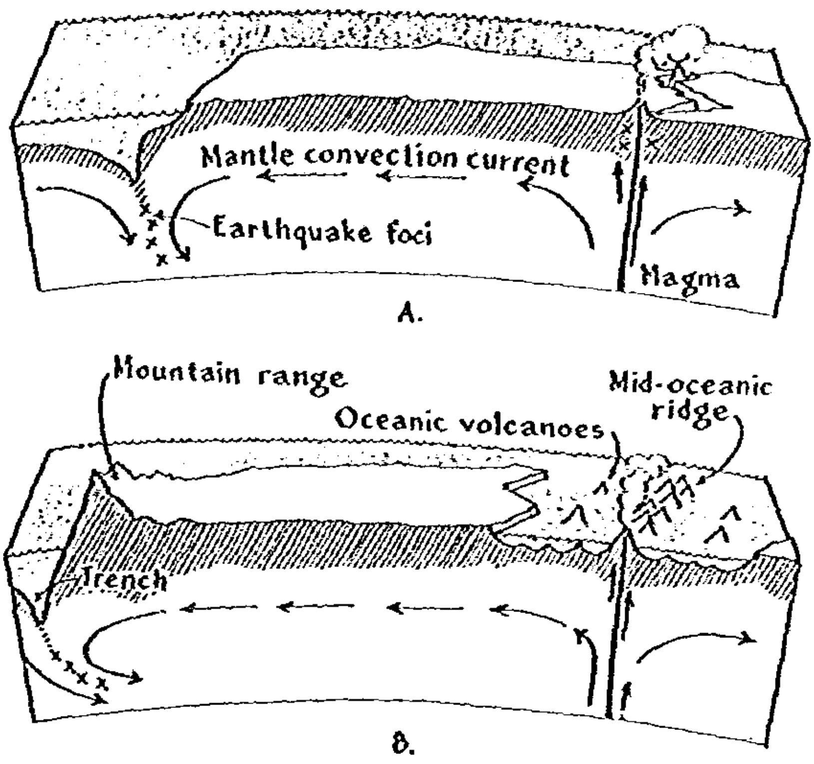

Fig. 7 Schematic drawing illustrating Wilson's interpretation of the formation of mid-oceanic ridges and continental drift by mantle convection. (After J. T. Wilson)

might also be taking place all over other areas of the mid-oceanic ridges, like in the Indian Ocean and the Pacific Ocean.

In other places, ocean floor expansion is caused by the mid-oceanic rise as in the south Indian and south east Pacific mid-oceanic ridges.

3.1.2.6. Plate subduction

Subduction of plates in a large scale in known in the Pacific region. A ring of the Alpine type of the fold mountains across the western side of the American continent and the island arcs of the east Asia are accompanied by the deep trenches off their coasts, through where the plates of the Pacific submerges over them. The Australian plate is also known to submerge into the Java - Suamtra peninsula, through the Java trench. Elsewhere, local subductions are known, for example, in the Carribean region, Mediteranean region, along the Rift Valley of east Africa, in the Sea of Japan, etc.

In Norway and Sweden, the inverse of subduction has been recorded and acknowledged as continental rise. Impact of subduction on continental movements could be decisively tremendous and very important.

3.1.2.7. Earth's magnetism

Among the most important application of the discovery made in England during the 1950's of the earth's reversed magnetic property found in some rocks, has been the confirmation of the drift of the Indian Sub-continent away from south of the equator during Jurassic to where it is now in the northern hemisphere. The search for the reversed magnetic phenomenon in rocks has been continued in many other areas of the world.

3.1.2.8. Radioactive dating

Application of the radioactive dating method to non-fossiliferous rocks, which are usually associated with paleo or remanent magnetism, solved the problem of age determination of rocks found with queer magnetic polarity. Some rocks found with extreme reversed magnetic polarity in the Deccan plateau were found to have ages corresponding to the Jurassic-Cretaceous period; that implied the time at which India began to drift north wards from the southern hemisphere.

3.1.2.9. Plate tectonic in the modern concept

The interest on the continental drift survived when such data as the reversed paleomagnetism and ideas on the convectional currents were added to explain the nature of the mid-oceanic ridges. Continental drift got a new face-lift through plate tectonics which tended to uphold in a way that crater moved due to compressional forces exerted by ocean floor spreading as exemplified by the mid-oceanic ridges. The view that America parted away from Euro-African continent was still upheld and that India, Australia, Antarctica, had also moved away from each other. Subduction of plates in the Pacific region had been acknowledged even though its impact on the whole set up of the plate tectonics has not been very seriously treated.

It is important to mention, however, that the re-structure of plates under-went important changes during the Alpine type orogeny, when such fantastic continents of, say, Pangeea or Gondwana in that matter, split up or reunited with other land masses to form the fold mountains and other crustal characteristics.

3.1.3. The now concept of the drifting of the continents

The central focus of the now concept of the drifting of continents place the mid-oceanic ridges in major role. It had been argued and fairly accepted as from the results of the detailed studies on the Coama Atlantic, that there appears an apparent expansion of around 2-6cm. per annum on the ridge which could sufficiently part South America from Africa, all way off the present distance during the period from Jurassic to the present. The progressive increase in the ages of the volcanic island rocks from the middle of the ridge towards the continents tended to support ocean floor spreading ideas (fig. 8).

It is, therefore, important that we take a critical look at the ridge question (fig. 5). A cross section of the Atlantic ridge reveals an active crater like depression, a few maters wide, from where lava and volcanic materials guts and beef up along sides and edges of the ridge in a continuous structure known as the Rift Valley. In this way ocean floor speading is presumably accomplished. But, in the Atlantic floor, only about 1000-1500km is covered by the ridge material out of over 300km of ocean floor distance.
It appears, therefore, quite questionable if at all the South American or for that matter the American continent had percussed all the way that distance under the influence of the ocean floor spreading.

A close analysis of events, connected to mantle convectional currents, appears to bracket the emergence of the mid-oceanic ridges with the Alpine type folding. It appears, therefore, that during the process of orogeny; when the crustal masses were either compressed or moved away, heat produced due to the resultant mechanical action exercised on the crust was valved away though the crater like openings

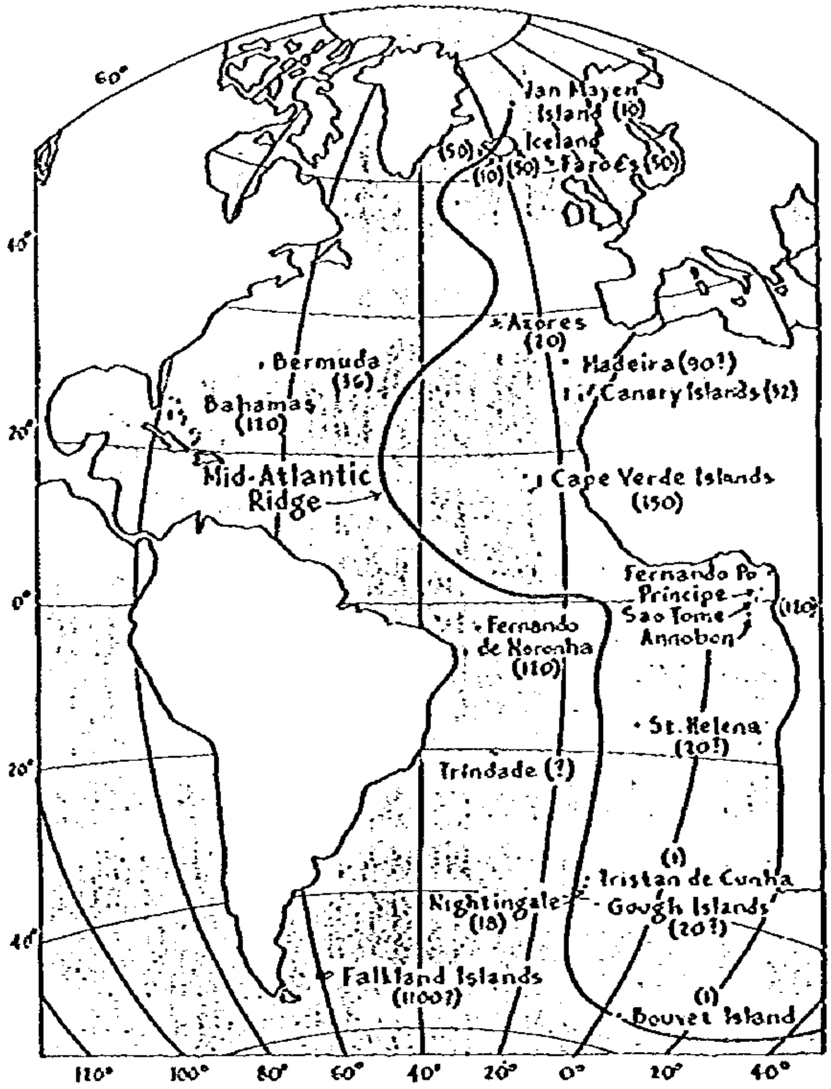

Fig. 8 Age of Atlantic islands, as indicated by the age of the oldest rocks found in them. The numbers associated with the islands give ages in millions of years. (After J. T. Wilson, 1963)

along the ridge. Besides acting as the safety valves during the orogenesis and continental or plate collisions, the mid-oceanic ridges stuffed by fluid-like lava at the crater like middle had acted as buffer zone; preventing continental crumbling and breakages as a result of plate collission and friction.

Mid-oceanic ridges and bulges are closely associated with mantle activity which have their links due to the close proximity of the mantle to the ocean floor, postulated by the principle of Isostasy

(Veining - Meinnez principle). But, supposing that there was Atlantic even before the start of the induced Alpine type crustal movements, then, the mid-oceanic ridge could very easily by evolved out of the thin crust and contribute to balancing the orogenic forces. It appears, therefore, quite questionable if the American or rather South American continent ever actually parted off from Africa, however, it appears quite likely that it might have been quite nearer than where they are actually situated now.

Sometimes we are led to wonder and yield to support the idea of the parting off of the South American continent from Africa, from the luring observation of the succesive increase in age of the volcanic island rocks away from the centre of the mid-oceanic ridge towards the continent: as in the case of the succession of St. Helena, Sao Tome and Fernando Po, towards the west African continent; and Ascension, St. Peter and St. Paul, and Fernando de Noronha, towards the east of the South American continent. These islands are in fact representing parts of the succesive episodes of the orogenic activity associated with the Alpine type folding and land movements. Of course, lava would first consolidate earlier and firmer in the cracks and openings situated nearer the continents from where the crust is progressively thinner towards the ridge.

The massive presence of the great Himalaya mountain range and Hindukush-Altai-Sanyan ranges, in the central part of Asia affirms that during the Alpine type orogeny, however, much activity must have been centred here and that the convectional currents must have been very active that an eventual link was established between the depositional convectional currents below the fast rising Himalaya's and the transporting currents from the south Indian oceanic ridge which later became responsible in dragging India a long way off. The south Indian mid-oceanic ridge shifted its link with the Mid-Atlantic oceanic ridge somewhere at the Mozambique and Prince Edward cross faults in the south east of south Africa, and the Amsterdam cross faults in the south west of western Australia; to eventually establish its link with the Red Sea rift and then the great east African continental Rift Valley system in the Tertiary. Some rocks from the Deccan plateau of the Indian subcontinent show the property of the reversed remanent magnetism typical of parts of the southern hemisphere. Radioactive dating give the ages of rocks to range from Jurassic to

Tertiary. Storanger contrast was attributed to the older rocks which in turn must have been dragged all way off from the southern hemisphere.

Conséquent to the Indian sub-continental drift, some lands got re-oriented, like Madagasy, Sychelles plateau, Arabian peninsula, Ninty east ridge, and even partial subduction of the Sustralian plate into the Java trench, took place. The south Indian mid-oceanic rise in conjuction with the south east Pacific mid-oceanic rise, probably has helped push up the Australian plate into the Java trench, and partly helps push the (Z) Continent north eastwards.

As the Antarctica appears to have been sorrounded by the ring of the ridges, it is, therefore, temptiful to assume that this continent had not moved away very much from its present positioning.

3.2. Drifting in View of the (Z) Continent

General information about the Pacific region way previously discussed in connection with the (Z) Continent. However, it is important to also acknowledge some facts which could be of help in elucidating the drift in the area, in the course of the explanations.

It is first of all necessary to pin point out about the existance of the Paleo-Pacific Ocean, curved out of the deep oceanic basin situated between the (Z) Continent and the western margin of the American continent. Most probably the extent of this basin or the Paleo-Pacific Ocean could have been larger than the areas covered by it now. However, roughly estimating, the Pacific mid-oceanic ridge used to pass through in the middle of this basin, in a way quite similar to the Atlantic mid-oceanic ridge. The Mid-Pacific oceanic ridge has had consequently longer cross faults especially in the north and in the South where it bends to link with the south Indian mid-oceanic ridge. These cross faults indicate the far greater movements the Pacific plate has experienced due to extensive ocean floor spreading. In the south and south east, the Paleo-Pacific basin is shallower and manifests a bulged shaped ridge which is associated with the mid-basinal rise, but in the north the oceanic water in the Paleo-Pacific basin is deeper and the mid-oceanic ridge is idented with many large cross faults but appearing calmer in activity as compared to the southern ridge. In central Pacific there is a distinct shift or dislocation of the ridge between the Clipperton cross fault and the Galapagos cross fault where the transitional continuation of the south east Pacific rise finds a new direction across the Galapagos fault to the state of California in the U. S., through the gulf of California. This ridge shifting movement across the Galapagos fault tends to remind the like phenomenon in the south Indian mid-oceanic rise at the Amsterdam cross faulting zone or the most dramatic and the drastic one at the Prince Edward - Malagasy fault. This observation tends to suggest that there has been crustal movement across this displacement area. If the extent of the cross faults is to indicate the extent of the area of the ocean floor spreading, then ocean floor spreading has been three to six fold more on the Pacific floor than in the Atlantic (fig. 9).

The process of the mountain building in the Pacific regoin has been accompanied by the subjection of the (Z) Continent and in general the Pacific plate. The Pacific oceanic ridge got spread compressing consequently some lands which were uplifted by vertical movements during the creation of the fold mountains. Episodes of the orographic activity in the north Pacific had helped produce the Rocky range of mountains and the Cascade range - cast mountains in North America, and in the South American continent, the Andes were formed. There appears to have existed a link between the Alpine type fold mountains of central Asia and the American mountain chain of the Pacific region. The activity of the ocean floor spreading and the covectional currents might also have brought about the alignment of the fold mountains, and extensive ridges and trenches especially in the (Z) Continent and the island arcs. Viewed from central Asia, the Alpine type orogeny has been descending down in the Pacific in steps (fig. 10). The highest step is between the Hindukush-Tienshan-Altai-Sayan mountains and the greater Khingan range in the Mongolian plateau. After that, it is between the greater Khingan range and Sikhote Alun range in the Manchurian and the north China plain; then it's between the Sikhote and the island arcs - Kamcheatka range in the continental seas of the Okhotsk - Japan - China, then, it's between the island arcs and the Emperor in the oceanic plateau of the (Z) Continent, the last step is beyond the Emperor seamounts range in the Paleo-Pacific trough.

Subduction of the (Z) Continent and the Pacific plate in general could best be explained by taking into consideration of the convectional currents theory. In the Pacific, the convectional currents seem to

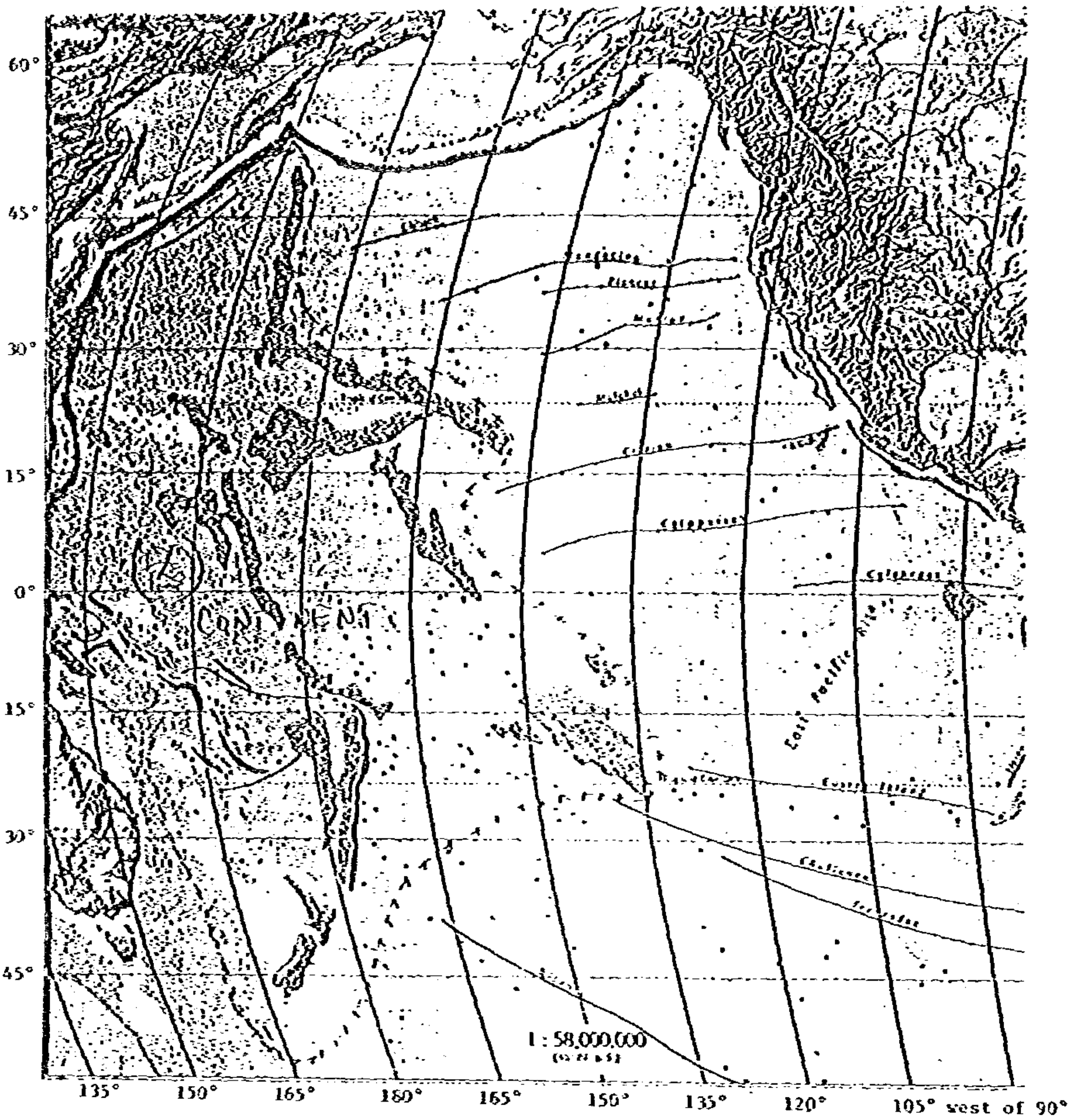

Fig. 9 The (Z) continent (THE TIMES ATLAS)

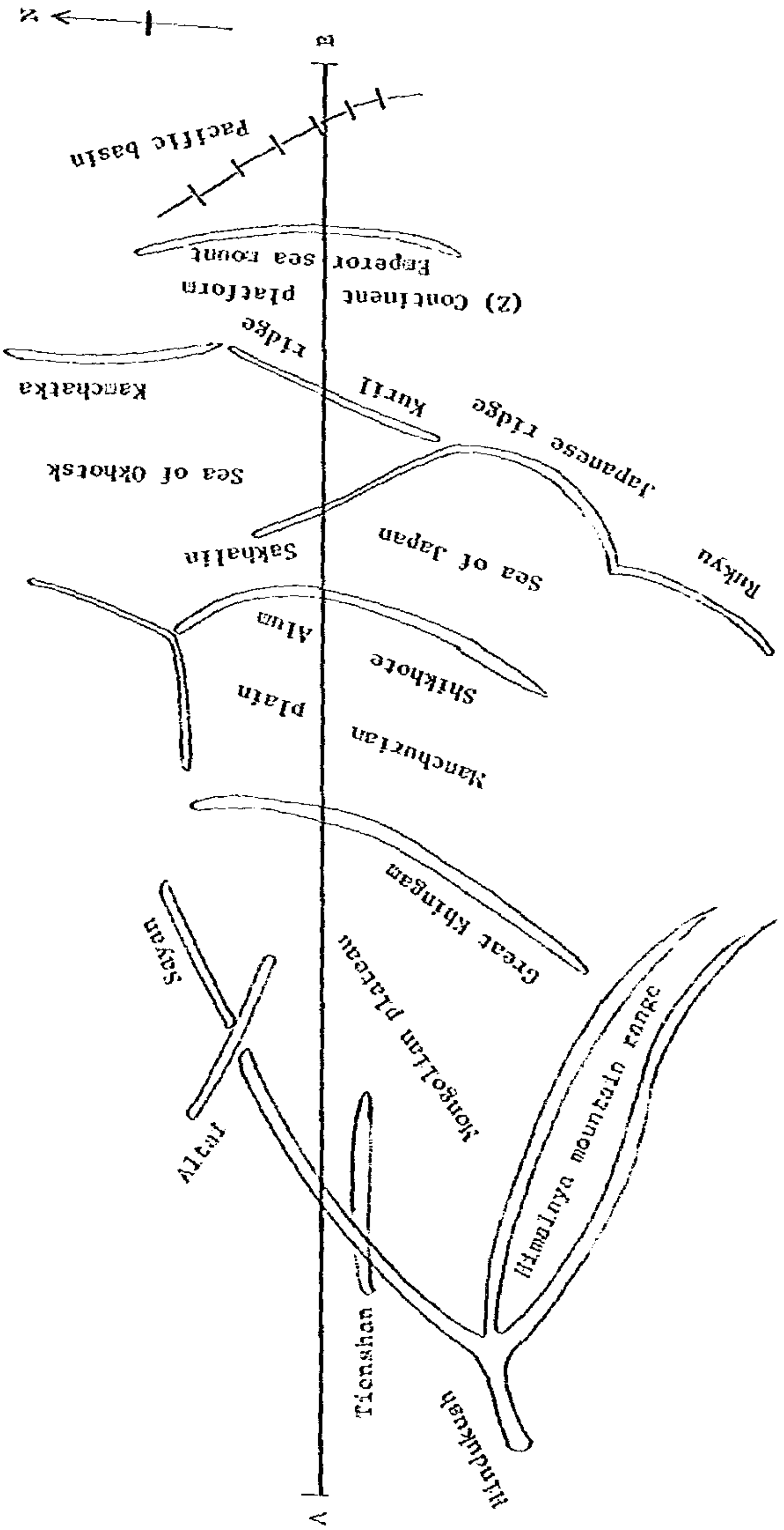

Fig. 10-a East Asian plateau system

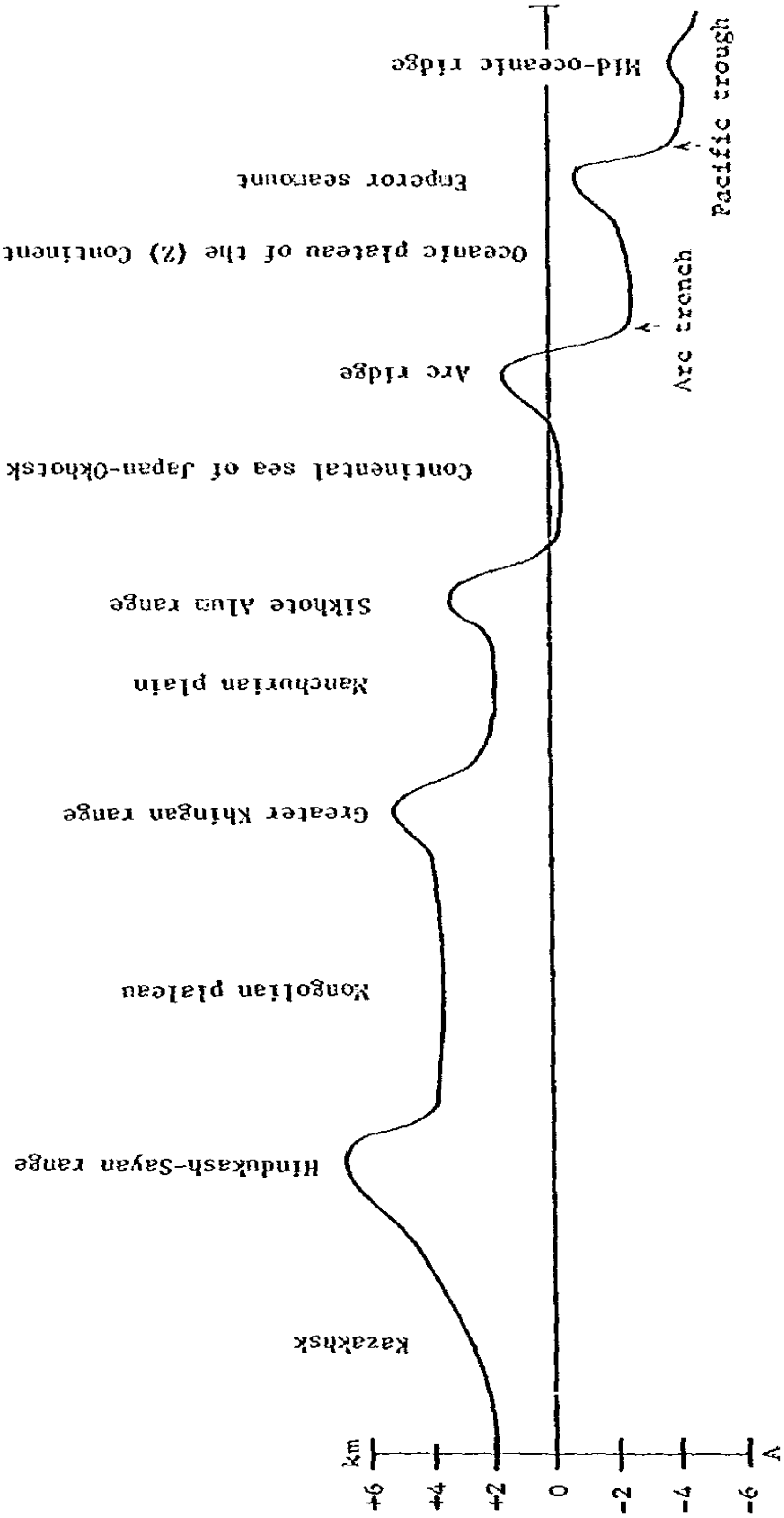

Fig. 10-b A-B cross section

have played the double role of reducing the continental crust in the (Z) Continent and also transport the dissolved sialic materials and then deposited them under the budding mountains of the folded ranges where they consolidate and provide the necessary isostatic balancing in the mantle (Fig. 10).

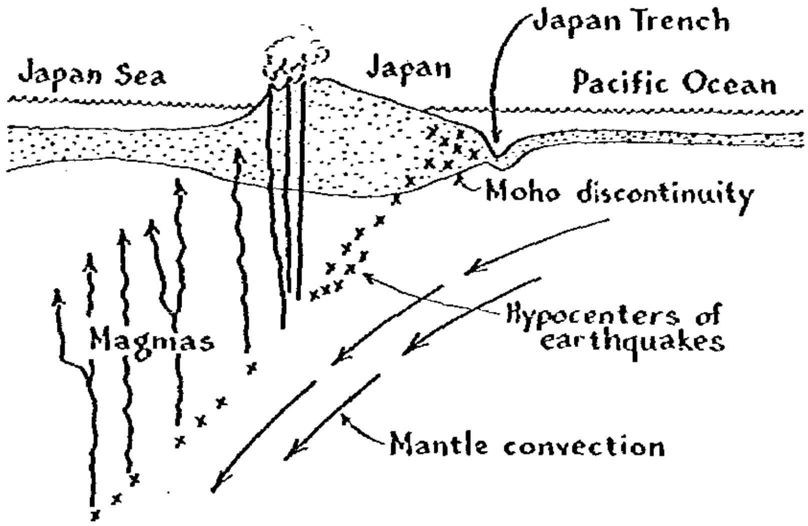

Fig. 10 Sketch showing schematically the distribution of earthquake foci beneath Japanese Islands.

3.2.1. Had American continent parted away from Euro-Africa?

Many reknowned scintists had accepted the idea that American continent had parted from Euro-African continent. Some even had gone as far as producting computer evidence to back up the pro-arguments, however, many have been convinced by the tempting arguments, some of which are mentioned below;

- the coastline of the east south America had interloking resemblance to the coastline of west Africa.
- Paleontologic data like the Glossopteris flora and Pecopter's for the two continents resembled.
- the partitioning of the two continents was achieved by a mechanism which involved separation through the crater like crust

as now found in the oceanic ridges and also through ocean floor spreading.

- Radioactive dating of the rocks on both sides of the ridge indicated increase of age from the centre of the ridge towards the continents.
- Paleomagnetic data from some rocks, indicated some changes in magnetic polarity, etc.

Certainly, some points above mentioned can be argued equally to apply to some known parts of the (Z) Continent as should be with America. Similarly it could be argued that the mid-pacific ridge could equally be the parting medium of the American continent from the (Z) Continent as is the Atlantic ridge between America and the Euro-African continent. Probably, the above arguments may sound absurd, but in light of oceanographic and physical observations, they could represent quite a true situation. If, then, America had moved or parted from Africa and at the same time it had moved or parted from the (Z) Continent; then, an equitable situation might be that it had not quite distinctly parted from any of them! However, a considerable movement might have been exercised on the American continent by either the African or the (Z) Continent or both, through ocean floor spreading.

3.2.2. South America had been moving towards Africa!

In view of some striking structural and other observable phenomenon around the Pacific and in the American continent, it is important to clear the above controversial statement with some of the following facts:

- if the equilibrium for the American continent has been achieved in relation to the (Z) Continent and Africa, then the bulging observed in the south and south east Pacific rise has been a recent phenomenon of the mid-oceanic ridge with effective consequence of wanton disruption of the equilibrium.
- the great Galapagos cross fault has been the transistional area, at which the apparently east Pacific rise has failed to re-activate the older mid-oceanic ridge to the north west through the Cliperton, Clarion, ... Chinook faults, etc.,

but a new trend of oceanic rise has been developed across the Galapagos fault through the gulf of California into the United States along the San Andreas fault.

The south east Pacific rise exerts expansional, vertical, and compressional forces towards both the (Z) Continent and the South American continent. The east ward pushing of the South American continent realised through subduction of the Pacific plate in the Andes, had caused the elongation of the Galapagos cross fault towards east, and consequently the displacement of the Mid-Atlantic ridge across the Romanche fracture zone. It seems therefore, most likely that in response to the eastward pushing of the South American continent, a great co-linear fracture had been formed and extended from the Pacific to the Atlantic oceanic basins linking the Galapagos fault through the Amazon basin, to the Romanche fault of the Mid-Atlantic ridge.

4. Mineral Distribution Pattern in relation to the (Z) continent

Distribution of the minerals in the world can be classified into three main structural categories; minerals associated with the orogenic process especially the fold mountains, platformic minerals, and minerals associated with the depressions.

4.1. Minerals associated with Platforms and Plateau's

Pre-Alpine platforms or plateau's of the south and central Africa, Brazilian plateau, west Australian plateau, Siberian plateau, etc. have for along time been associated with the invaluable mineral deposits. Such platforms and plateau's have been generally associated with intrusives and the metamorphic rocks of the basement system - generally Pre-Cambrian. Sedimentary and correspondingly younger intrusives and volcanic rocks are also possible to find in the area. A very wide range of minerals are associated with them, like chromium, nickel, iron, diamonds, gold, copper, lead, zinc, cobalt, graphite, mica, gemstones, etc.

In the (Z) Continent a similar kind of platform might have existed probably in the area covered by Philippine Sea and also the area between the Kuril trench and the Emperor seamounts. These platforms lie under great depths of the oceanic water, in which case, interfearance of the crust by the mantle convectional currents might have distorted the chemistry of rocks and mineral composition. However, it is a consolation that such minerals as should have been encountered in the crust of these platforms, can finally be recuperated from the spread on the platformic surface of the manganese nodules.

4.2. Minerals associated with the Orogenic Plateau's and Mountain Ranges

Alpine type orogeny had surpassed all previous orogenic episodes because of its effect over very large and extensive areas. Parts covered by this type of orogenesis are known to be covered by an extensive variety of rocks ranging from the intrusive rocks, extrusives, the metamorphics, and the sedimentary rocks of all generations. These rocks include the granites, gneiss, andesites, schists, quartzites, limestones, shale, etc., minerals associated with the orogenic process include iron, gold, tin, metallic sulphides, etc.

Besides Alpine type ranges across the Philippines, New Guinea, New Zealand, etc., many other like type ranges and plateau's are burried under the oceanic water of the Pacific, for example, the oceanic range of the Bonin and Mariana islands, Emperor seamounts, Melanesian plateau, Tonga-Kermadac range, Polinesian plateau, etc., indeed some plateau's are certainly pre-Alpine but, since that have been affected by the volcanic activity of the Alpine period amid the intensive influence of the convectional currents on the continental plate during the Pacific ocean floor spreading, like the Marquesas and the Hawaian islands, then, their inclusion in this group appears acceptable.

The prognosis of minerals in the lands covered by oceanic water of the (Z) Continent could be well guided from the correlation of the structures and genetic resemblances of the areas under the water to those areas of the similar origin on the dry land. Hence, Melanesian plateau's and ridges could be of better economic interest for minerals and hydrocarbons. Emperor seamount could be of great scientific interest as well as econonic. Plateau's of Polinesia, Chatham rise and the continental shelf off New Zealand could have hydrocarbon petensials - especially gas.

4.3. Minerals associated with the Depressions and Troughs

Depressions have been the catchment areas of much of the eroded materials from the mountains and plateau's. Sometimes considerable metallic ores as placer deposits have accrued in them, for example, the feruginous deposits, black sands, diamonds, gold, tin, etc., also coal, gypsum, halides, petroleum and gas have generally found natural habitats in the depressional deposits. It could be expected that orogenic activity might have lifted some of these depressional accumulations into the plateau's and ridges as found in many parts of the (Z) continent, favouring, therefore, the accumulation of the hydrocarbons. Suspected areas could include the Tuamotu archipelago, Chatham rise, Campbell plateau and the continental shelf of New Zealand, Lord Howe rise, the plateau's of the Micronesia and the continental shelf around the Indonesian and New Guinea islands, etc.

5. Conclusion

The mysteris sorrounding the Pacific region has led in the past to many fantastic theories being credited to the bizzare nature of its existence. Some early scientists had gone as far as to suggest that the moon, once considered part of the earth, was actually dislodged from it at this region. When Edeard Suess postulated his Gondwana continent and then later followed by Alfred Wagener about his Pangaea continent and even the arch-protogonists of Wagener who contributed so much in the advance on continental drift; tended to be biased in the Pacific assuming as if there was virtual emptiness in the areas covered by the oceanic water of the Pacific. It was easy, therefore, for Wagener and others to assume that America could have been parting from the Euro-African continent and speeding thousands of kilometers away into the virtual emptiness of the Pacific. It is very unfortunate that neither Suess nor Wagener had the benefit of comprehending the existance of the world wide stretch of the mid-oceanic ridges of which our modern scientists have been meticulously studying and somehow attributed them as motive power behind land movements. No wonder that the spectacular Himalayan range attracted much attention during Wagener's time, curious interest focussed on it led to observations of the anomalous Indian sub-continent which was found to have migrated from south to its present position. Apart from the re-alignment of the Himalayas due to forces originating from south supported by India, there is a curious pattern of upstepping mountain ranges and plateau formation as seen from east to west, starting from the mid oceanic ridge of the Paleo-Pacific through across the Emperor seamounts range, the Japan-Kuril ridge, Sikhote Alun range, greater Khingan range, and Hindukush-Tienshan-Altai-Sanyan range (Fig. 11). Compressional forces responsible in aligning these series of Alpine type mountain ranges appear to orient from the east to west or vice versa. Similarly, the forces responsible in the mountain building of the Rocky mountains and the coast ranges in the North American continent which also appears in steps appear to exert from west to east. In other words, there appears in the Pacific a centre of a tremendous force which impinged across the continents of both America and Asia, modeling as a consequence the great mountain ranges in vast plateau's as shown in Fig. 11-b. The great impinging force has been partly contributed by the ocean floor spreading in the Pacific and partly by the subduction of the Pacific plate and the (Z) Continent. If, however, the Mid-Atlantic spreading moved the American continent to the west, what if about the Mid-Pacific oceanic spreading moving the American continent to the east?

Certainly, there has been subduction of the (Z) Continent and the Pacific plate into the American continent and around the island arcs of the Pacific region. This phenomenon has been apparently aided by the convectional currents in the mantle but, as a compensation and reaction to the loss of crustal materials from the central Pacific to the roots of the Alpine type mountain build up around the Pacific, the Pacific plate sank further down along with the (Z) Continent. It appears therefore, that much of the materials needed to beef up mountain building, originated in the Pacific region and not necessarilly recuperated on the way out of effort of parting continents as with the case of the Rockies and Andes of America. But, to maintain the parity in the balance of forces already weakened in the Pacific, the Mid-Atlantic ridge expansion maintained that balance.

The crater like openings in the mid-oceanic ridges have sometimes acted as safety valve allowing gases and molten lava to escape. But in some areas, like in the south east Pacific, mantle materials has had no sufficient opportunity to escape and hence led to the phenomenon of mid-oceanic rise with consequent results of expansion and compressing upon the South American continent and the (Z) Continent, respectively. While the (Z) Continent has been submerging into the island arcs of the east Asia, the South American continent has been pushed across towards the African continent. Co-linear fault linking the Galapagos fracture in the Pacific with the Romanche fracture in the Atlantic across the most probable inland fault along the Amazon river basin is an obvious event of this effort. The push of the South American continent towards Africa, and the possible balancing resistance from the Atlantic mid-oceanic ridge, could result in the craving up of favourable structures which could cause immigration and/or squeezing of the hydrocarbons from the materials and sediments and emplacement of such hydrocarbons into the favourable catchment areas which could have been made quite numerous in the south Atlantic basin. The short western continental shelf of the American continent situated very near to the mountain ranges could be very favourable for placer deposits of the heavy minerals.

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9. Suppression of Seismic Noise

Suebsak Solgosoon*

Summary: The seismic method is one of the most important geophysical technique. The predominant of the seismic method over other geophysical methods is due to various factors, the most important are high accuracy, high resolution and great penetration of which the method is capable. The reliability of seismic prospecting is strongly dependent upon the quality of the records. In some areas where excellent reflection (or refraction) are obtained without any special measures being taken, at the other areas in which the most modern equipment, extremely complex field techniques must be used to yield available data.

1. Introduction

The seismic exploration method is basically the same type of measurement as earthquake seismology. However, the energy sources are controlled and movable, and distances between the source and receiving points are relatively small. The seismic waves are generated by explosives and/or other energy sources and arrays of geophones are used to detect the resulting motion of the earth. The data are recorded as the time required for the wave to travel from the sources to a series of geophones which are laid along a straight line directed towards the source. The data usually are recorded on magnetic tape so that computer processing can be used to enhance the signals with respect to the noise, extract the significant information and display the date in such a form that a geological features can be determined.

The term "signal" is denote any event on the seismic record from which we wish to obtain information. Everything else is "noise". Noise has always been the most troublesome problem in seismic prospecting because reflections are obscured by the noise. So that techniques for field procedure such as new arrangements of source and receiving elements have been introduced to improve data quality by suppression of seismic noise.

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* Department of Mineral Resources, Ministry of Industrial Affairs, Thailand.

2. Seismic Noise

Seismic noise may be either coherent or incoherent. Coherent noise can be followed across at least a few traces, incoherent noise is dissimilar on all traces. Coherent noise is subdivided into energy which travels essentially horizontally and energy which reachs the spread more or less vertically. Coherent noise includes surface waves, reflections or reflected refractions from near surface structures such as fault planes or buried stream channels, refractions carried by high-velocity stringers, noise caused by vehicular traffic, tractors, multiples, etc. Incoherent noise which is spatially random and also repeatable is due to scattering from near-surface irregularities and inhomogeneities such as boulders, small scale faulting etc. Non-repeatable random noise may be due to wind shaking a geophone, stones ejected by the shot and falling back to the earth near a geophone and so on.

The principle types of noise associated with land shooting are surface and near surface waves, scattered or incoherent noise, and multiple reflections.

1. Surface and near-surface wave are coherent noise, which are low-velocity, low-frequency with an amplitude level that is high compared to reflection signals. This seismic noise would often override useful reflection informations. These events were refered to as ground roll. Because the frequencies of the noise waves were usually much lower than those for reflection, low-cut filters were introduced into the amplifier circuits to eliminate interference from this source. Somewhat later, groups of series connected geophones were laid out over distances corresponding to one or more wavelengths of the ground roll. Such an arrangement would result in suppression of the horizontally traveling ground roll and enhancement of vertically traveling reflections.

2. Scattered and other incoherent noise. Incoherent noise refered as random noise. This is usually associated with scattering from near-surface irregularities. Incoherent noise is particularly common when the shot point overlies or is close to gravel, boulders or vuggy limestone, all of which can cause scattering of waves. Addition of signals containing incoherent noise should result in some cancellation of the noise, and the more signals are added the more complete the cancellation to be expected. To obtain the greatest suppression of incoherent noise one would therefore use as many shots and as many receivers (geophones per trace) as possible.

3. Multiple reflections. A common and particularly troublesome type of interference is that from multiple reflections, which can look so much like

primary reflections. Multiple reflections can be of many kinds, some of which are shown in Fig. 1. Elimination of the surface multiples is best accomplished by proper application of common depth point shooting. Often there is a distinct frequency change between the primary and multiple reflections because of differences in the materials through the respective waves travels as

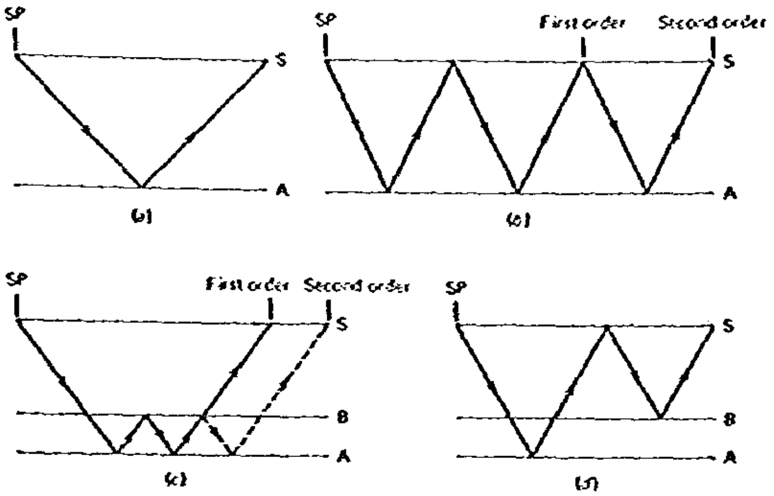

Fig. 1 Several types of multiple reflections; (a) primary; (b) surface multiple; (c) interbed multiple; (d) combination multiple. S is earth'surface. A and B are reflecting interface. (AMOCO Production Co.)

well as differences in path lengths. In such cases it may by possible to discriminate between the two by mean of frequency filtering alone.

3. Attenuation of Noise

Two primary approachs are used for reducing seismic noise to enhance desired reflections. One is to set up a recording arrangement that will cancel the unwanted waves before they are recorded in the field. The other is to process the data after they are recorded.

Techniques for cancellation noise in the field will be described as follow.

Shot and geophone arrays.

The purpose of the grouping, which groups of geophones spread out over tens to hundreds of feet were connected in series or in series-parallel arrangements and the combined outputs of the geophones were fed into single amplifier channel corresponding to the group as a whole, was for cancellation of ground roll and other horizontally traveling noise. At the same time it become customary to drill shotholes in patterns over area where it appeared desirable to reinforce the noise attenuation obtainable with geophone groups alone. The theory of noise attenuation by patterns is the same whether applied to the shot or the geophone end of the wave trajectory. The basic idea is to the design both groupings so that waves traveling vertically or nearly vertically are reinforced while those traveling in the horizontal direction are reduced. Fig. 2 shows a geophone group which covers a horizontal distance equal to a wavelength of the surface wave to be canceled. With this arrangement at any given time the horizontal wave will cause upward motion in two detectors of each group and downward motion in the other two. If all four are connected in series, the net signal from this source will be very nearly zero because of cancellation. Reflected waves, on the other hand, are very nearly vertical when they reach the surface, and all four detectors of each group will respond to them by moving in the same direction at the same time. The outputs for the reflection signals should therefore be additive. Proper grouping of geophones should thus reinforce reflected events and cancel horizontally traveling noise.

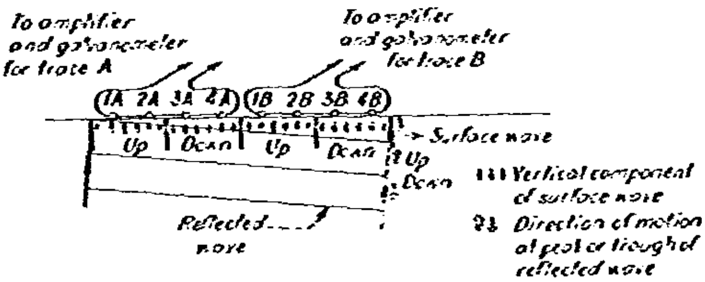

Fig. 2 Eliminating effects of ground roll by use of multiple geophones in series.

The optimum number of elements in shot or geophone pattern and the best spacing of the units within the pattern are determined by applying the same principles at those used in designing radio antennas. The theory is reviewed by Lombardi* and Parr and Mayne**, the basic concept being illustrated by

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* Lombardi, L.V. ; Notes on the Use of Multiple Geophone, Geophysics, 1955.

** Parr, J.O. and Mayne, W.H. ; A New Method of Pattern Shooting, Geophysics, 1955.

Fig. 3. Here there is an array of five uniformly spaced geophones, the separation between adjacent phones being D. We can calculate the response of the phones to waves of various wavelengths most expeditiously at the instant a peak of the traveling wave coincides with the center phone of the group. If the wavelength λ equals the spacing D (λ/D = 1), the singals picked by the phones are in phase and the output when all phones are connected together is 5 times the peak value for the center phone. If λ/D = 2, the first, third, and fifth phones record maximum positive (upward) motion, while the second and the fourth phones record the maximum negative (downward) motion. The sum is thus the peak output for a single phone or one-fifth the output for λ = D.

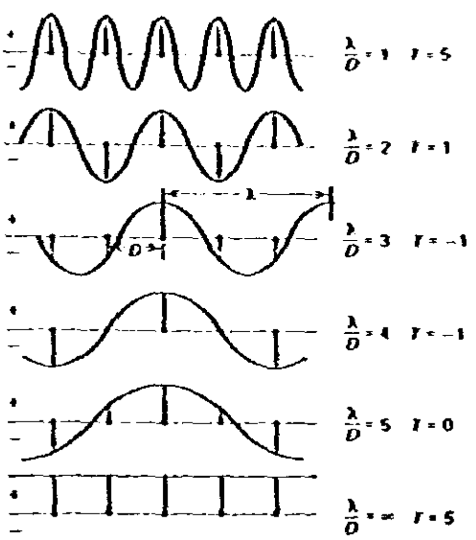


Fig. 3 Cancellation of waves of different wavelengths using five geophones separated by distance D. Numbers in right hand column represent relative amplitudes of outputs for the array. (Milton B. Dobrin, 1976).

Similarly it is evident that both for λ/D = 3 and λ/D = 4 the downward motion exceeds the upward motion by one unit. The sign is not of significance in evaluating attenuation characteristics, and we can consider the response for these to be effectively equivalent to that for λ/D = 2. When λ/D = 5, the positive and negative contributions are equal and cancel one another, leaving zero response. As the wavelength gets very large compared with D, it approaches the limit of λ/D = ∞ at which value the peak output for five units is observed again, just as with λ/D = 1.

Fig. 4 based on the model just considered, shown how the respective outputs from groups of five and eight phones vary as λ/D changes. For the five unit group, one sees that there are three values of λ/D in addition to λ/D = 5 at which there is complete cancellation. There are three λ/D values at which transmission is a maximum. The corresponding attenuation curve for an array with eight units shows seven positions along the λ/D axis at which cancellation is complete and six positions for maximum transmission. From these two examples we can make several generalizations. The number of zeros (positions where the geophones have no output) on the curve is 1 less than the number of phones, and the number of peaks or lobes between the zeros is 2 less than the number of phones. The greater the number of phones the lower one can draw the envelope (line tangent to the peaks) of the attenuation curve, indicating less transmission of horizontally traveling waves. Also,

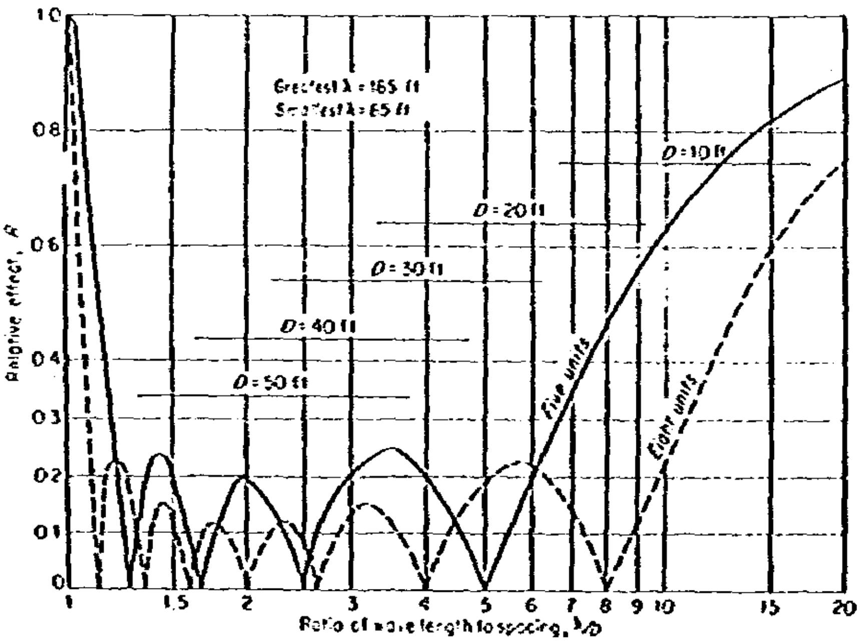


Fig. 4 Noise cancellation curves for five and eight geophones in group. Reltive response referred to amplitude of a wave recorded from a single geophone.

the great number of phones the wider the zone along the λ/D axis within which significant reduction of horizontal noise takes place. This means that the range of noise wavelengths that can be effectively reduced increases with the number of phones per group.

The equation for the fractional transmission T by an array of N geophones a distance D apart for horizontally traveling waves having a wavelength is

$$T = \frac{1}{N} \frac{\sin 2\pi(N\lambda/D)}{\sin 2\pi\ (\lambda/D)}$$

Where T is the ratio of the signal observed with the N phones a distance D apart to that which would be recorded if they were all in a huddle (at zero distance apart).

Optimum phone spacing.

To determine the optimum geophone spacing for a given number of phones per trace in an area where the characteristics of the noise are not know, it is advisable to carry out special measurements in the field. These tests are designed to establish the nature of the noise and to determine the range of wavelengths encompassed. A series of recordes is made with geophones (generally single) spaced 2 to 10 m apart, the spread being moved (or if the geophone spread is held fixed, the source being moved) so that there is continuous geophone coverage from the shot point itself out to distances as great as several thousand feet. Fig. 5 illustrates a typical noise test section recorded during a test of this kind.

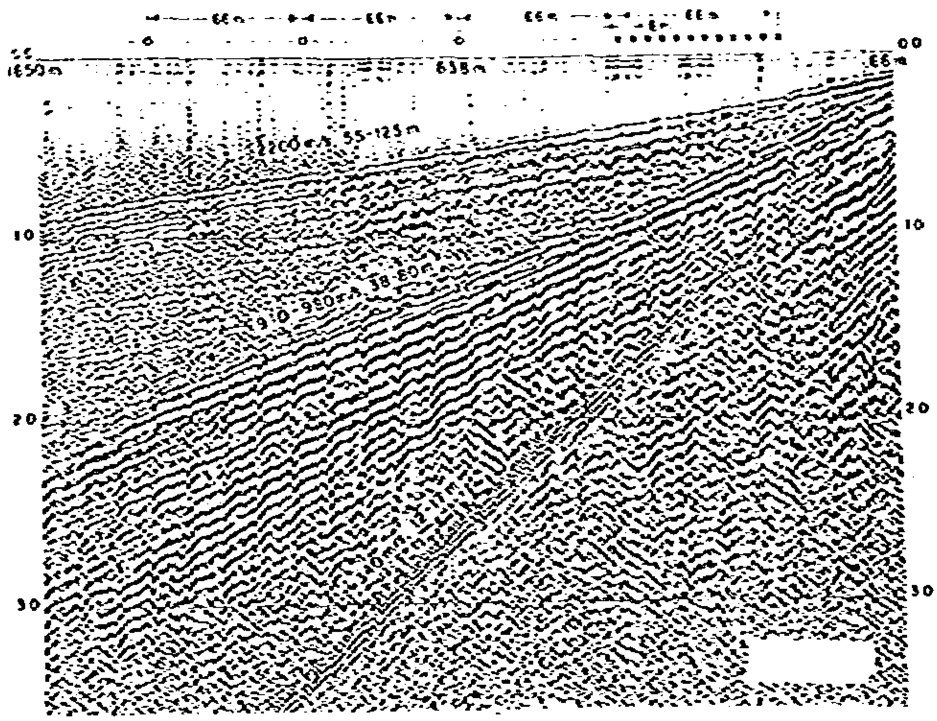


Fig. 5 Traveling waves recorded over spread about 1600m long from surface source. Velocities of waves range from 2200m/s to 340m/s, 940-980m/s are probably Rayleigh waves. (Petty-Ray Geophysical Division, Geosource Inc.)

All events on the section having a lineup at a low enough velocity to be associated with horizontally traveling surface and near sourface waves are readily identifiable on such secitons, and their velocities are determined simply by dividing the distance between the nearest and furthest phone receiving the event by the differential time required to traverse this distance. The wavelength is the velocity multiplied by the period of the traveling wave. A range of wavelengths is determined for all noise events of this type, and a spacing is selected that will optimize the noise attenuation.

Above the curve in Fig. 4 are drawn a series of bars indicating the range of λ/D values corresponding to noise events from an area where tests of the type described show the noise wavelengths to lie between 65 and 185 ft. The respective bars correspond to trial values of D ranging from 10 to 50 ft. Taking the envelope of the respective attenuation curves for five and eight units, we see that the 50 ft spacing gives optimum cancellation for the five-phone group while the 40 ft spacing appears best for the eight-phone group.

Areal arrays.

Noise often travels in directions that are not coincident with the direction of the radial line extending outward from the shot. This happens when the noise which initially travels in a direction different from that of the geophone spread is reflected back to the line of phones by some feature such as a vertical escarpment or river bank or even a hidden lateral irregularity below the earth's surface. Where this occurs, it is necessary to have geophonees in areal, i.e., two dimentional, rather than linear patterns. A properly designed areal pattern should yield adequate attenuation regardless of the direction in which the noise approaches. Areal patterns may be rectangular (for example, 24 phones may be in four rows with 6 phones in each row) or along concentric circles, depending on the nature of the noise and on the space available for the array. In determining the attenuation for an areal array one must specify the direction of the wave travel. The attenuation curves (transmission versus λ/D) for a star pattern consisting of 13 geophones will be different for different directions of propagation, as shown in Fig. 6. To use conventional attenuation curves designed for linear arrays with areal patterns the position of each phone would have to be projected on a line in the direction of wave travel, as shown in the figure. Where the noise is incoherent and traveling events cannot be followed between geophones only a few feet apart, cancellation techniques of the type described will not be effective. Statistically incoherent noise can be reduced by a factor proportional to $\sqrt{n}$, where n is the number of detectors in the group irrespective of spacing. Where m shots are used along with the n phones per trace, the improvement in signal-to-noise ratio is proportional to $\sqrt{mn}$.

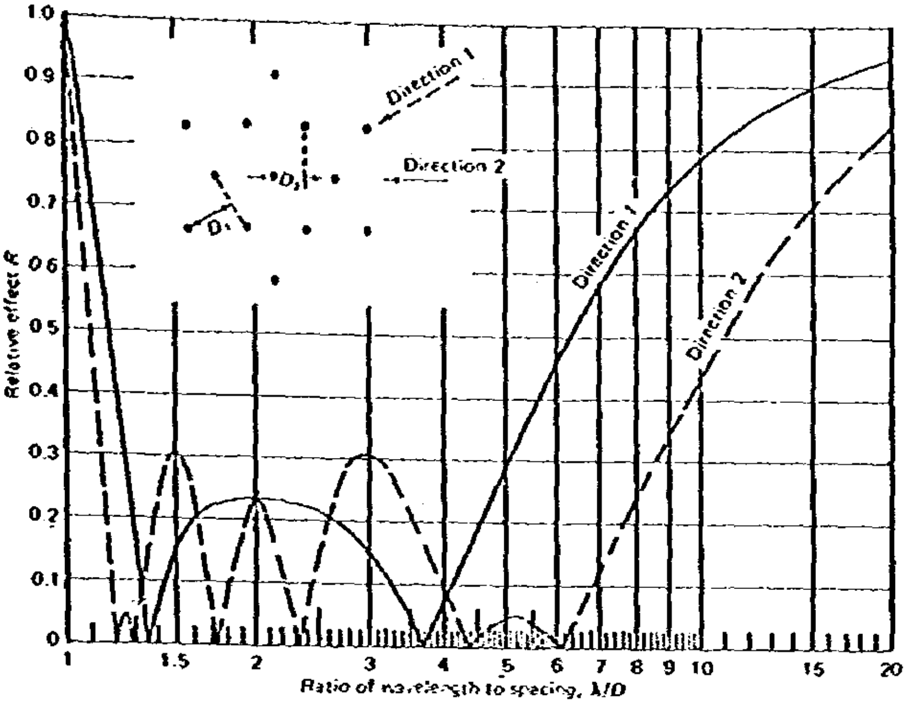


Fig. 6 Cancellation curves for an areal pattern of geophones consisting of 13 units. (Parr and Mayne)

Common depth point shooting (CDP)

The use of simple arrays of shots or geophones for canceling is practical only where the noise has wavelengths that are not appreciably greater than the lengths of the arrays themselves. The common depth point technique is designed to cancel noise of large apparent wavelength, regardless of its origin. As with conventional cancellation, outputs of phone groups distributed over a distance comparable to a wavelength are summed. The loss of definition which averaging over such an extensive baseline would otherwise cause is averted by a special arrangement of shots and geophones that combines only those signals reflected from the same region of the subsurface. The method of doing this has been described by Mayne*, the inventor of the technique. Basically, signals associated with a given reflection point but recorded at a number of dif-

*Mayne,W.H.; Common Reflection Point Horizontal Data Stacking Techniques, 1962.

ferent shot and geophone positions are composited either with special field processors or in a playback center after appropriate time corrections are applied to compensate for the increasing length of ray path as the shot-geophone distances are increased. Fig. 7 illustrates the recording arrangement when six signals are composited.

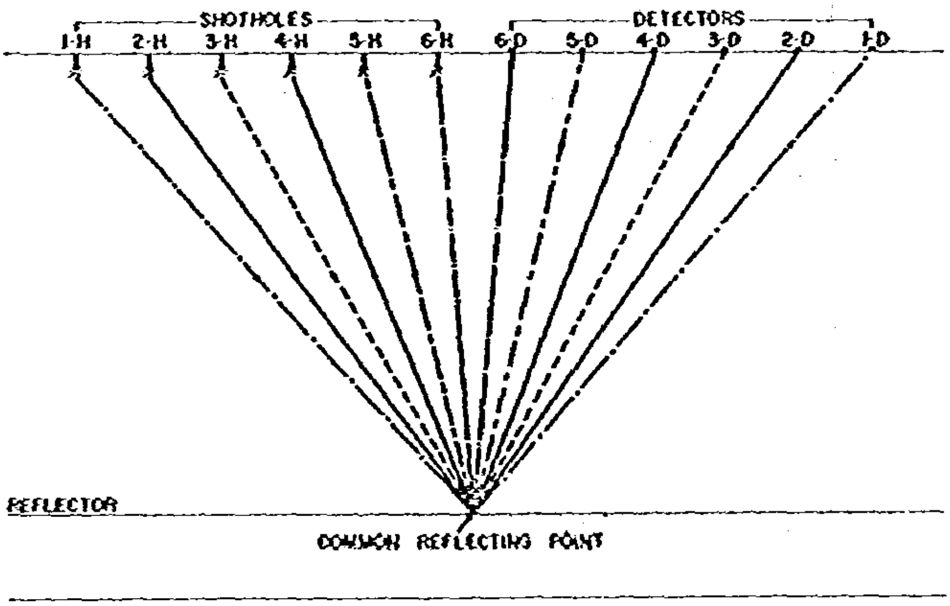


Fig. 7 Ray paths for reflections from a single point in sixfold common depth point shooting.

In an actual field setup, such common depth shooting (or multiple coverage) involves a greater number of shot points per unit distance along the line than conventional split-spread shooting does. With 24 recording stations threefold coverage will be obtained if the shots are separated by four geophone group intervals, fourfold if by three intervals, and sixfold if by two intervals. If the shooting is twelvefold there is a shot for every geophone group center. Fig. 8 shows the successive shot positions for a set of single end shooting spreads giving sixfold multiple coverage. Consider the reflecting point halfway between geophone positions 10 and 11. Reflection takes place at this position when the shot is at shot position 1 and the phone at geophone position 21, also when the shot is at position 2 and the geophone at 17. Such a reflection also occurs with shots and geophones at the four other combinations of positions shown on the left side of the figure.

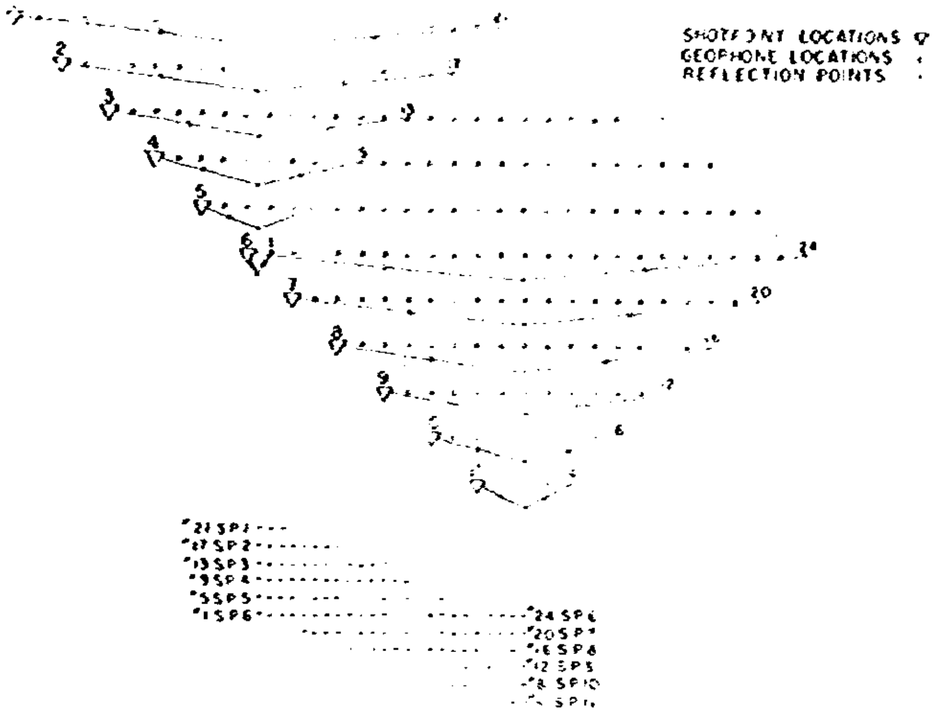


Fig. 8 Shot and geophone combinations giving sixfold multiplicity for two subsurface reflecting points. Pattern at bottom shows reflecting points for successive spreads.

To composite, or stack, the data for this reflecting point, the playback is so programmed that after all signals are corrected for normal moveout, the information on channel 21 of the tape from shot point 1 is added to that from channel 17 of the tape made from shot point 2, with similar contributions from the respective tapes corresponding to the four shot points 3 through 6. At the bottom of the figure the dots show reflection points which correspond to all recorded wave paths. It is seen that there are six such paths for each subsurface position. Adding the proper signals for coincident subsurface reflection positions as indicated on the diagram and plotting the output traces thus obtained on a record section is referred to as stacking. Shooting of this type is carried out continuously along a line, the phones at the rear being picked up in groups of four or six and moved to the front of the spread as the shooting progresses in a kind of leap-frog maneuver. This is referred to as roll-along.

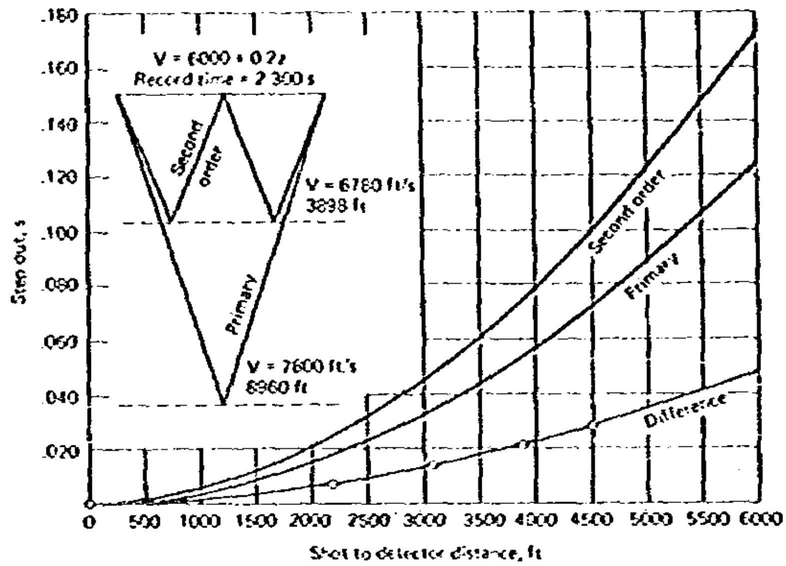


Fig. 9 Cancellation of multiple reflections by common depth point processing for five shot-geophone distances. (Mayne.)

Fig. 9 illustrates how multiple reflections are attenuated by common depth point stacking. The primary reflection and the multiple shown in the diagram at the upper left arrive at the geophone at the same time. The average velocity for the primary must be higher than that from the multiple when the velocity increases with depth, thus the multiple travels through formations having an average speed slower than the average along the path taken by the primary. The moveout items for the multiple and primary are plotted against horizontal receiving distance. The multiple shows a greater moveout time than the primary event. If a moveout correction is made using the velocity for the primary and the traces thus corrected are then added together, all primary reflections should have phase coincidence and the signal after summation should have accentuated amplitudes for such events. The multiples will be out of phase, and addition of such signals for equally distributed distances will tend to result in cancellation. In this example, the total range of differences in time between the two corrected events over a 6000 feet distance is more than 40 ms, which is greater than the periods of most seismic reflection events.
It is evident from the diagram that the deeper the primary event to be brought out over a multiple that arrives at the same time the smaller the moveout differential over a given spread length. Yet the deeper a reflection the greater the likelihood that there will be interference from multiples. The only way to

increase the time differential from moveout is to lengthen the spread. For this reason, spreads are much longer with common depth point shooting than they were with conventional single coverage.

4. Energy Sources for Seismic Prospecting

In the area where interference from noise is severe, some techniques for producing seismic waves should be taken. Several new energy sources have come into use as alternatives to dynamite, and new arrangements of source have been introduced to improve data quality by minimizing noise. Although a number of nonexplosive energy sources have come into use for seismic exploration, the source employed for more than 60 percent of all work on land is still dynamite exploded in shotholes.

Dynamite

The explosion of dynamite in a shothole is the source of seismic waves. Shots are often fired in a group as linear or areal patterns for noise reduction. The same considerations that govern the geometry of geophone patterns apply in determining the geometry of shothole patterns as well. The design of such patterns were discussed in the point of shot and geophone arrays.

Buried primacord

The greatest possible enhancement of downward-traveling energy over horizontally-traveling energy (noise) can be obtained with a continuous source horizontally elongated. Such downward directivity can be achieved by burying a proper length of primacord (an explosive extruded into a ropelike form), detonating it at one end (or at its center), and letting the explosive disturbance propagate along it at a speed much greater than the speed of seismic propagation in the near-surface material within which it is buried.

Weight dropper

A rectangular steel plate weighting about 3-ton is dropped from a height of about 3 m for producing waves. Weights often are dropped every few metres so that the results of 50 or more drops are composited into a single field record. The time between release of the weight and impact on the ground is not constant enough to permit more than one source to be used simultaneously. Often two or three units are used in tandem, one dropping its wieght while the others lift their weights into the armed position and move ahead to the next drop point.

The Dinoseis

The Dinoseis method involves the explosion of gas (mixture of propane and oxygen) within an expandable chamber. The explosion chamber is mounted under a truck and is lowered to the ground when ready for use. The explosion of the gas mixture by means of spark plug creates a pressure which acts on a moveable plat forming the bottom of the chamber, thus transmitting the pressure pulse into the ground. In normal operation, a number of Dinoseis units, generally three or four, are used at the same time, and detonation for all units will be simultaneous. After each detonation the group of trucks is moved 20 ft or more, detonating chambers are lowered to the ground, and the cycle is repeated.

Patterns of shooting and receiving are similar to weight dropping as shown in Fig. 10.

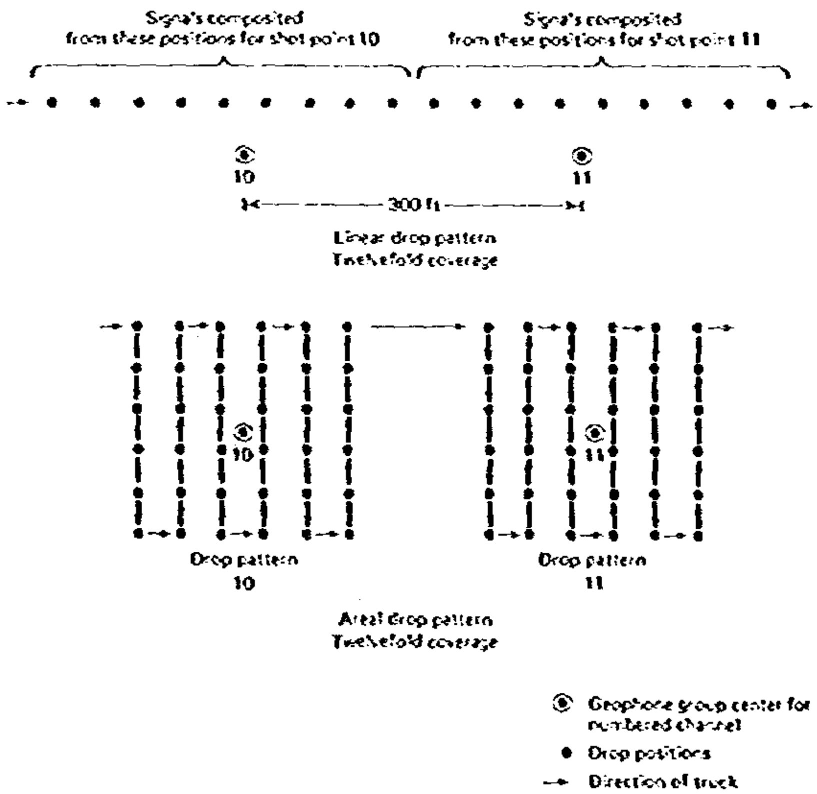


Fig. 10 Typical linear and areal patterns for weight dropping method and the Dinoseis method in seismic reflection operation. Linear pattern involves nine impacts per shot point, areal pattern 36 impacts per shot point.

Vibroseis

A vibroseis source generates the waves into the earth that is oscillatory rather than impulsive and persists for many seconds (more than 7 seconds), the frequency changing slowly over the duration of the signal. The returned signals recorded in the field cannot be interpreted directly. The recorded data must be processed by cross correlation of the signals received by the geophones with the oscillatory source signal itself. The technique involves a comparison of the two signals with progressively increasing delay times. Reflections and other seismic events related to the source signal give a greater degree of correlation with the generated waveform than random noise. The source consists of a 2 ton mass with a hydraulic vibrator controlled by wave signal sent by the recording truck. Vibroseis operation involve the use of several trucks traveling along parallel trajectories or in tandem. They stop for vibratory sweeps at intervals determined by the total number of sweeps needed per shot point, and all units sweeping simultaneously. The individual wave cycles generated by the vibrator travel into the earth like pulses from conventional sources and are reflected in the same way. The reflection signals returned to the surface are all superimposed, and the signal received by the geophones must be processed in such a way that the complex pattern of energy so recorded is converted into reflection traces of the type obtained from impulsive sources.

The vibroseis is used with 24, 48, or more geophone group, and sweep patterns may be placed to coincide with every second, third, or fourth patch of phones, depending on the multiplicity (sixfold, twelvehold, etc.) of subsequent common depth point compositing. A common field arrangement for a linear array is shown in Fig. 11.

Because the signal put into the ground persists for a long time, the reflection signals actually recorded in the field are entirely incoherent to the eye and special processing is necessary to convert the data into usable form. A reflection record obtained from a vibroseis source consists of superimposed signals from each of the reflecting surfaces, as illustrated in Fig. 12. Each reflection has approximately the same waveform as the source signal, but the wave train corresponding to each reflector is delayed by the time required for it to travel from the source to the reflecting interface and back. The combination of all the individual reflections is spread out that it would not be expected to give an interpretable record.

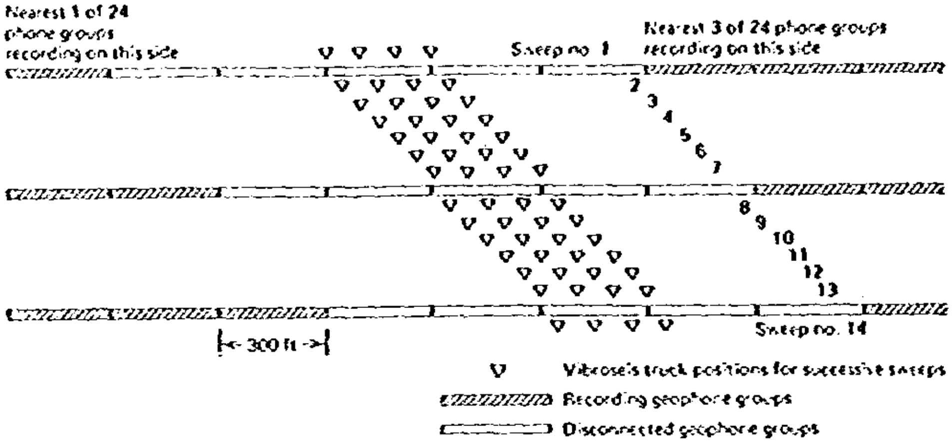


Fig. 11 Progression of Vibroseis sweep positions along geophone line in four truck operation.

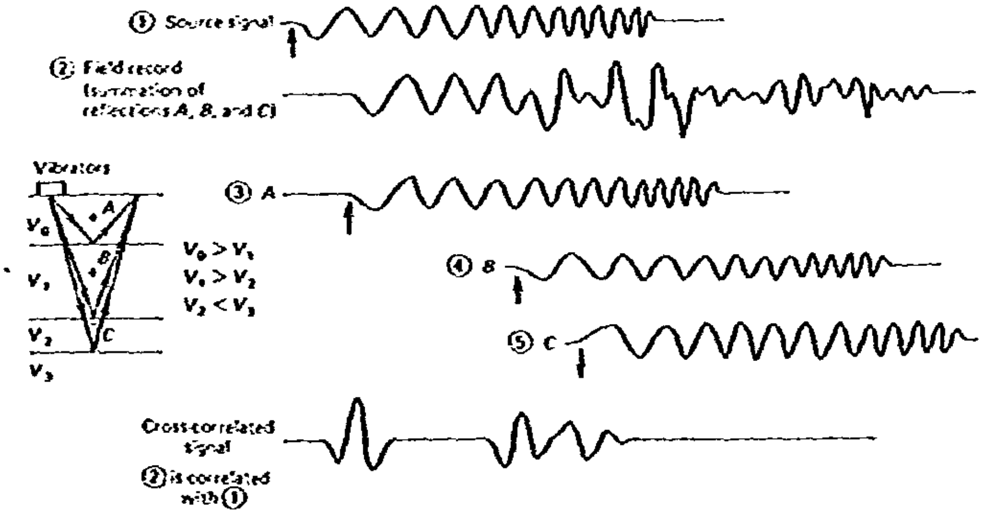


Fig. 12 Recording and analysis of a Vibroseis source signal reflected from three interfaces. (Continental Oil Co.)

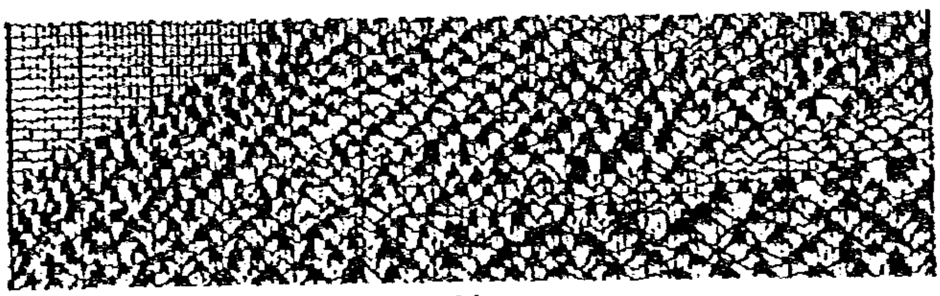
Qualitatively, it might be instructive to look on the cross-correlation process as a test of the fit of the sources signal (1 in Fig. 12) and the record signal (2 in Fig. 12) containing the reflections at successive relative displacements of the two signals along the time scale. The initial fit is tried with the beginnings of the two signals coincident, and then the fits are determined with the respective zero positions progressively shifted by constant increments such as 2 ms.

The degree of fit is determined at each juxtaposition by multiplication of the two signals over their entire length at closely sampled ordinate positions and addition of the products. The greater the sum the greater the cross-correlation is zero.

At a time shift equivalent to the two-way travel time for a reflection, the returned signal displays a partial coincidence with the source signal (only partial because other reflections and noise will be superimposed). When such a coincidence occurs, the cross-correlation value (degree of fit) will be a maximum. Elsewhere the relation between the two signals is random and the corss-correlation value is low. If the cross-correlation so determined is plotted against the time shifts, the reflections will show up as high-amplitude events that look exactly like reflections on conventional recordings from impulsive sources, the portions of each trace in between being more or less quiescent depending on the noise level.

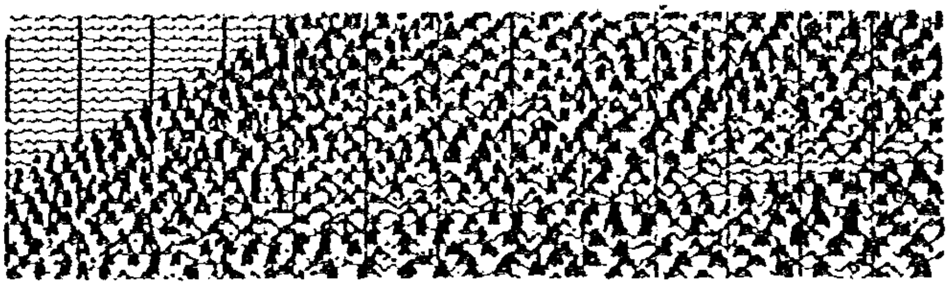
Energy from a Vibroseis unit can be introduced into the earth over the entire range of seismic frequencies although the efficiency of transmission by the earth may vary with the frequency. And a signal from it, being spread out over many seconds, will have a much lower amplitude level at the source than an impulse in which all the energy is injected into the earth within a few milliseconds. This feature makes it possible to use Vibroseis in populated areas where explosions would not be acceptable.

6. Example of Seismic Records



(a)

Fig. 13 Ground roll from single impact on ground
(a) without filtering and



(b)

(b) with low-cut frequency filter. (Patty-Ray Geophysical Division GeoSource Inc.)

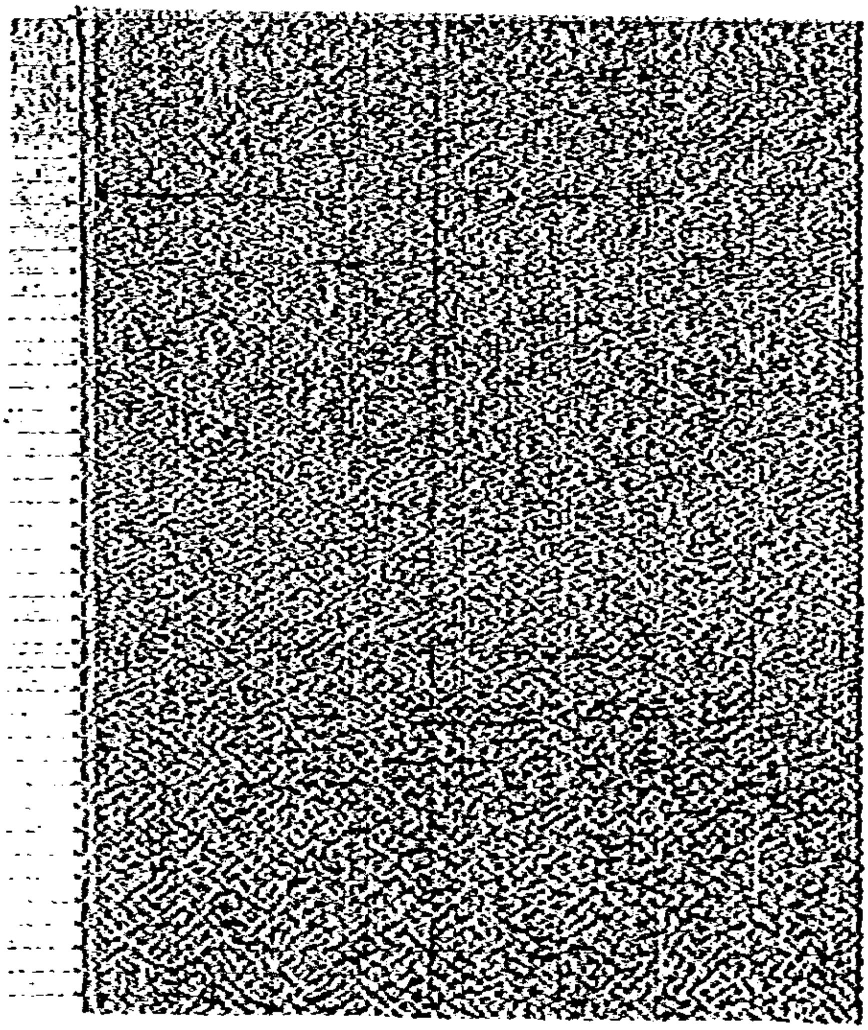


Fig. 14 A poor reflection record section, in which nearly all desired information between 1 and 3 s is obscured by incoherent noise. (Sun Oil Co.)

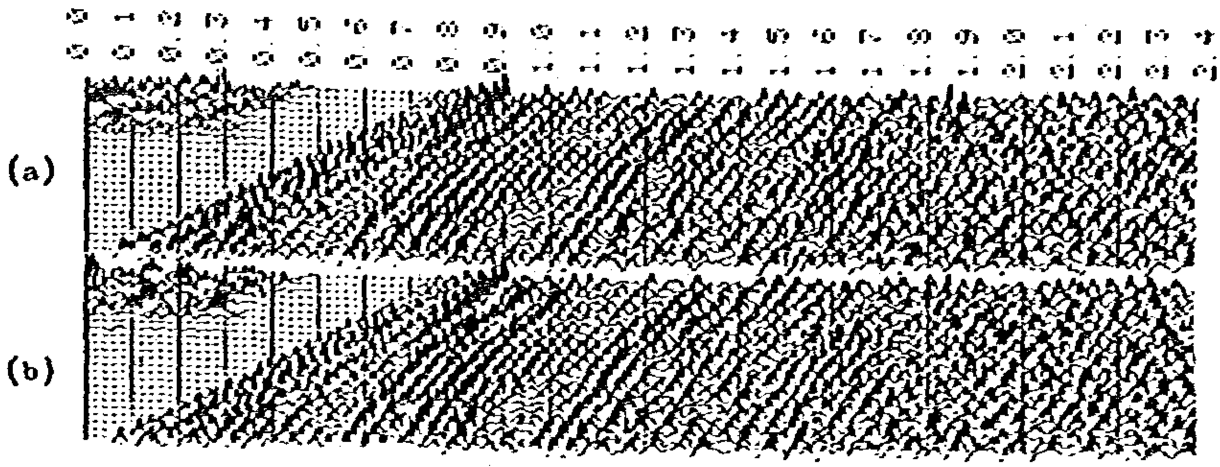


Fig. 15 Filter test, using 2 rows of 24 geophones and 5 shotholes.
(a) low filter - out, high filter - 124 Hz,
(b) low filter - 8, high filter - 124 Hz.

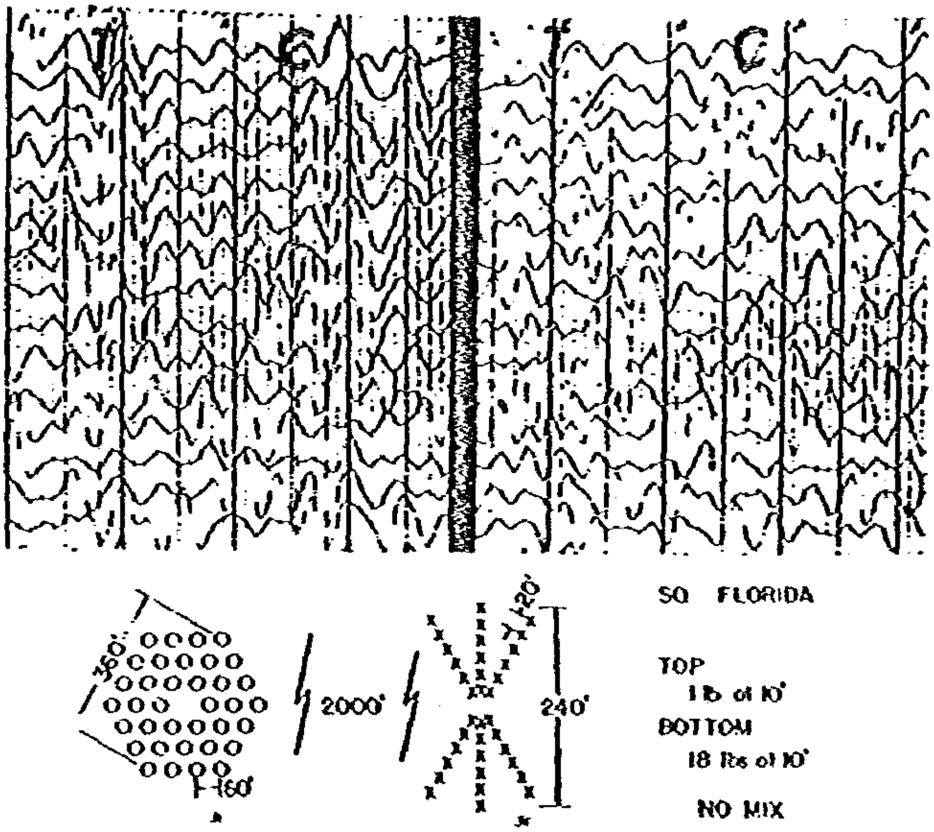


Fig. 16 Comparison of record obtained using single hold and 36 phones per trace (right) with record obtained along the same spread with pattern of 36 holes and 36 phones per traces per trace (left). The respective shot and geophone patterns are shown in the lower part of the figure. (McKay, A.E.; Review of Pattern Shooting, Geophysics)

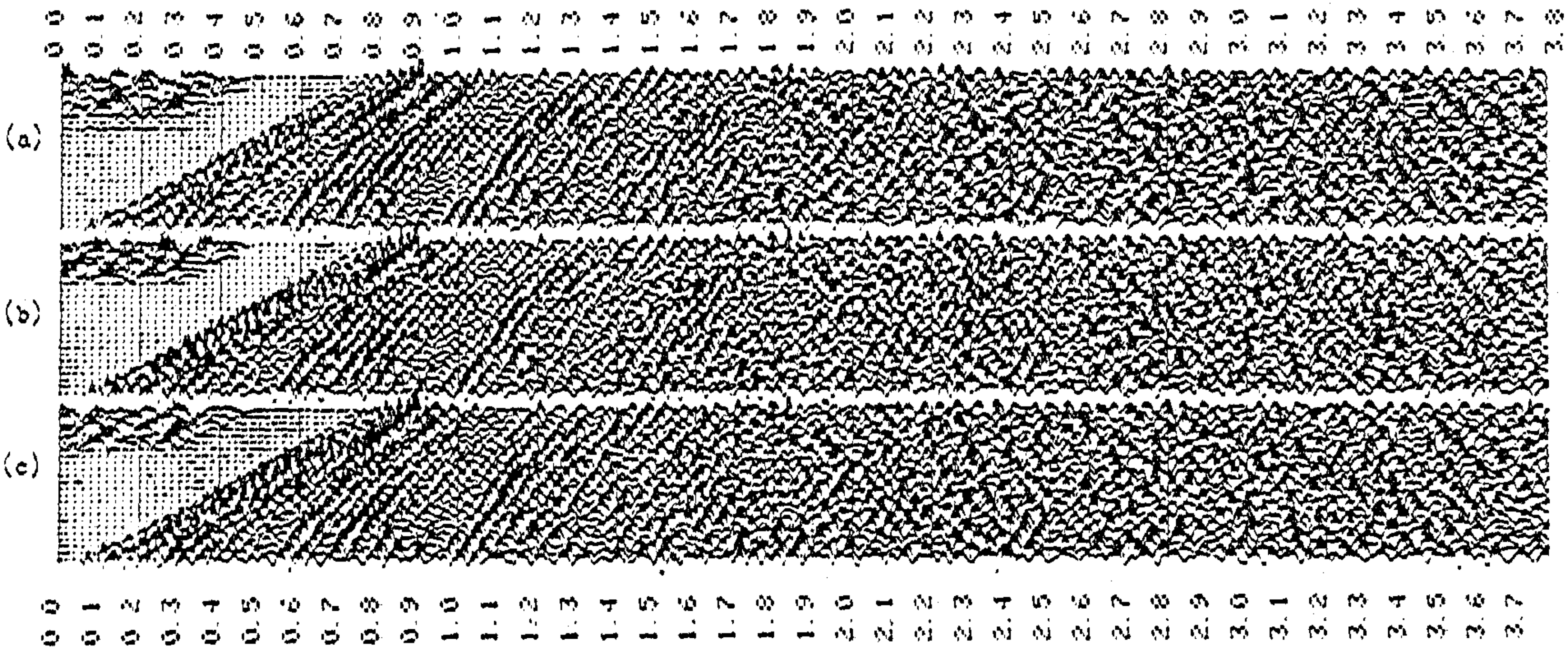


Fig. 17 Shot depth test
Filter : 8 - 12 Hz
Geophone array : 24 grouping (2 m/24)
Shot pattern ; 12.5 m/5 shotholes
Charge : 15 Kg.
(a) 32 meter
(b) 26 meter
(c) 20 meter

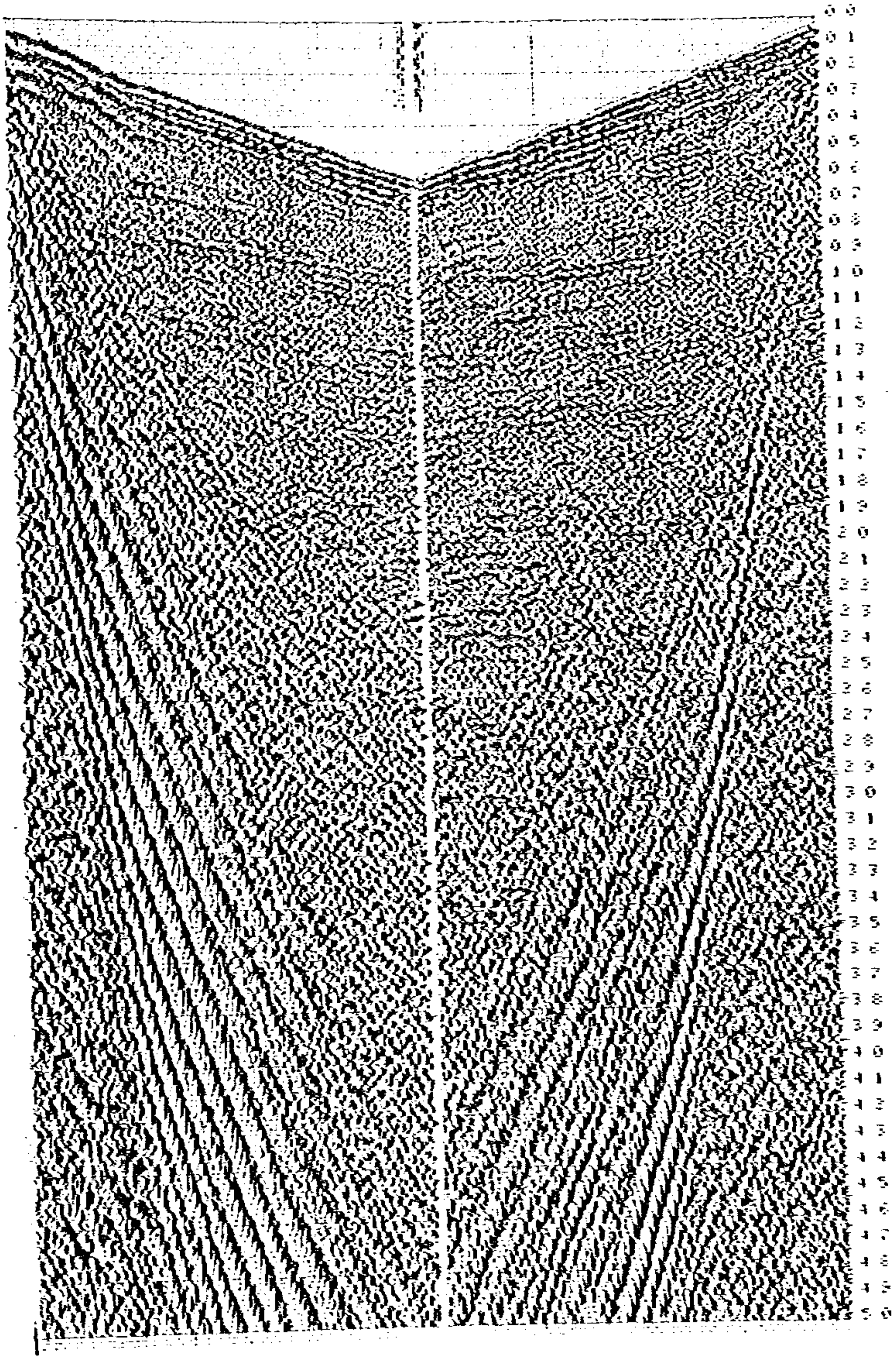


Fig. 18 Noise test
Geophone ; Single, Geophone interval ; 10 meter, Filter ; out-124 Hz
Shothole depth ; 20 meter, Charge ; 3 Kg.

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