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Digital data processing of marine seismic records from the South West Indian Ocean

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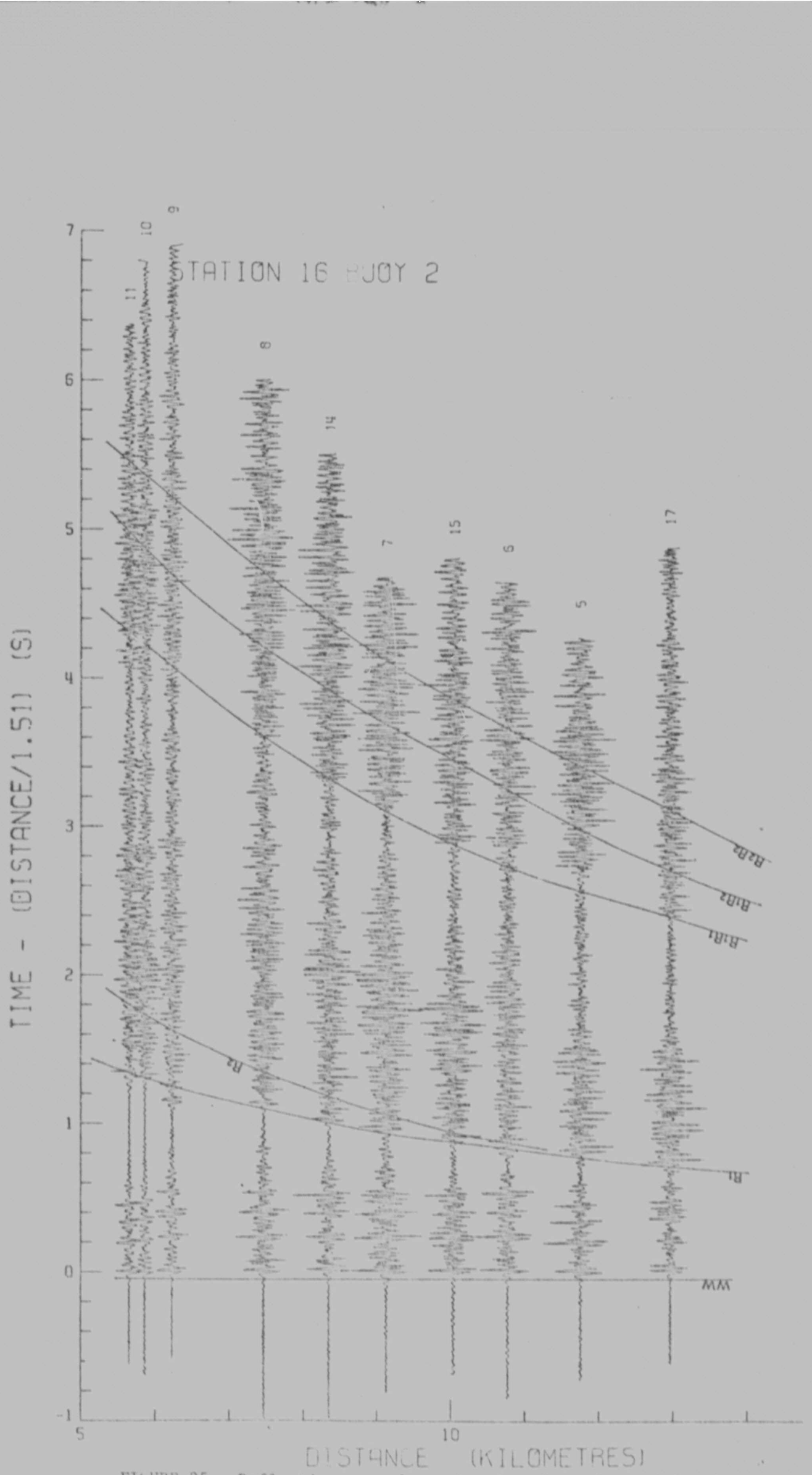


FIGURE 25. Reflection record section from buoy 2, profile 16.

Table 9

Root mean square deviation for travel times of model structures and observations for profile 16.

Buoy No	Arrival	No of Observations	Linear Velocity Gradient (sec^{-1}) 0.80	0.85	0.90	0.95	1.00
			R.M.S. Error X 10^{-2} sec				
2	R_2	8	3.20	2.40	2.20	2.80	3.70
2	R_1R_2	11	3.10	3.10	3.20	3.50	3.90
2	R_2R_2	11	2.50	2.00	1.90	2.30	3.10
3	R_2	8	3.10	3.60	4.30	5.10	6.00
3	R_1R_2	11	4.70	4.30	4.10	4.20	4.50
3	R_2R_2	11	6.60	5.20	4.00	3.50	3.90
		Mean	3.53	3.43	3.28	3.57	4.18

Table 10

Water and sediment structure for profile 16

Buoy 2		Buoy 3		Mean	
Velocity (km/sec)	Thickness (km)	Velocity (km/sec)	Thickness (km)	Velocity (km/sec)	Thickness (km)
1.51	2.60	1.51	2.58	1.51	2.59
1.51-2.12	0.67	1.51-2.14	0.69	1.96	0.69

Apparent Velocities and intercept times

for profile 16

Layer No	Buoy 1		Buoy 3	
	Velocity (km/sec)	Intercept Time (sec)	Velocity (km/sec)	Intercept Time (sec)
2	2.27	2.92	2.27	2.94
3	5.84	4.24	5.47	3.99

V. Seismic Studies on the Mozambique Ridge

A. Profile 16

Station 16 was located on the Mozambique ridge in about 2.6 km of water. Three buoys were launched, the buoys being spaced about 10 km apart. Buoy 1 experienced the maximum amount of drift being of the order of 9 km in a direction perpendicular to the line of the shots.

Generally the records obtained from this station were of poor quality as a result of noise from imperfect hydrophone suspensions. Strong sub-bottom reflections were however clear from the records of buoys 2 and 3 but were of poor quality for buoy 1. The reason for this may have been that the reflection layer exhibited rough topography or that it became more accoustically transparent. The sub-bottom reflections were generally stronger than the bottom reflection, this being particularly clear as the distance from the buoys increased (figure (25)). The root mean square deviations and the number of observations for 5 models used for determining the velocity gradient in the unconsolidated sediment is shown in table (9). As in the case of the Transkei basin, a linear velocity gradient of 0.90 sec^{-1} fits the data best, giving a unconsolidated sediment thickness of 0.7 km, with the velocity increasing from 1.5 to 2.1 km/sec. The water and sediment structure, table (10), shows that buoys 2 and 3 have similar sections of sediment. Using the intercept time of 2.94 secs obtained from the refractions from layer 2 and the mean thickness of the unconsolidated sediments an average velocity 1.96 km/sec is obtained for layer 1. This average velocity is used during the computation of the thicknesses of the underlying layers.

The deeper refractor is taken to be the top of the semiconsolidated sediment. This layer is however poorly determined by the refraction line $G_2=X/2.27 + 2.94$ (figure (26)). It also means that this refraction line

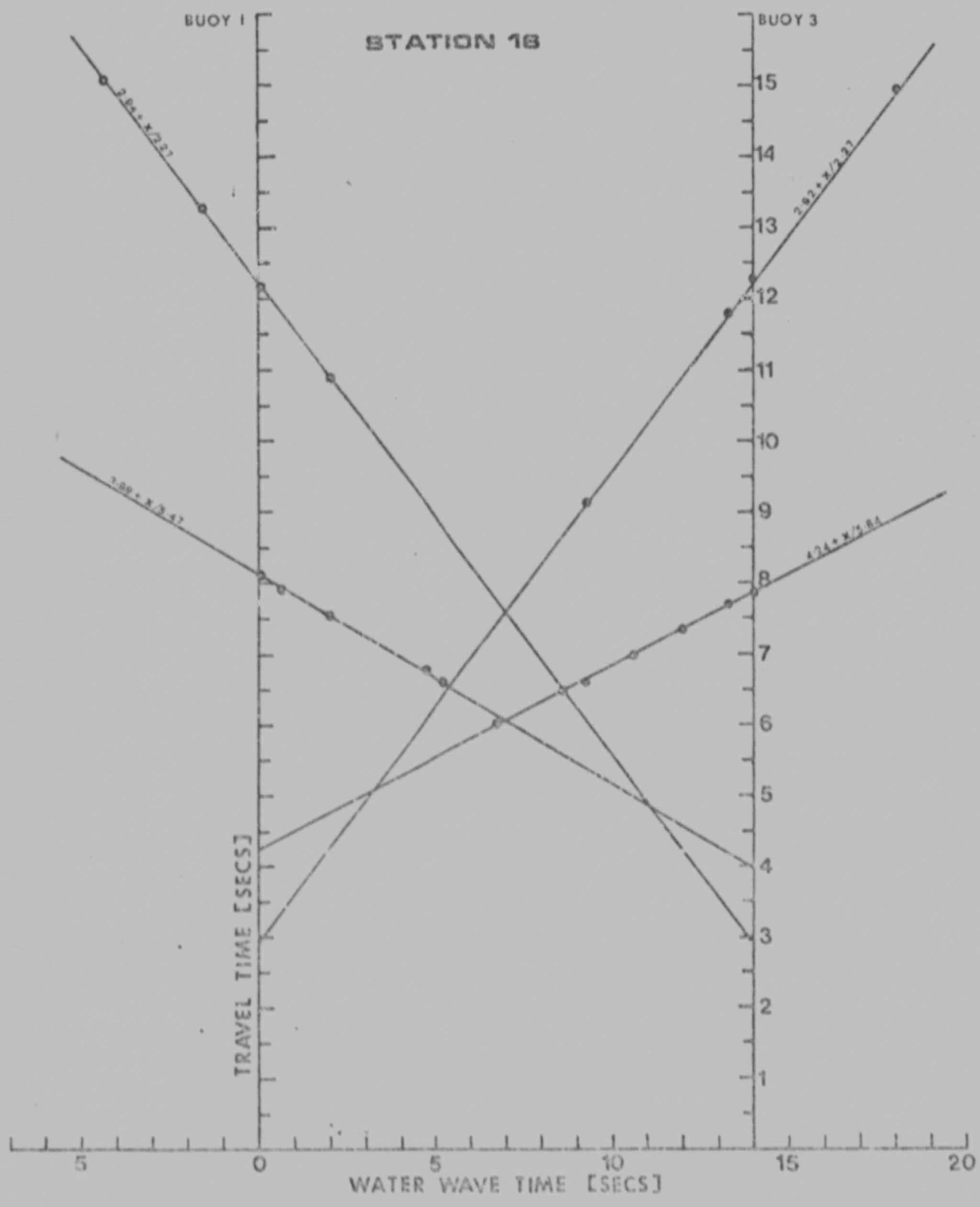


FIGURE 26. Travel-time plot for profile 16.

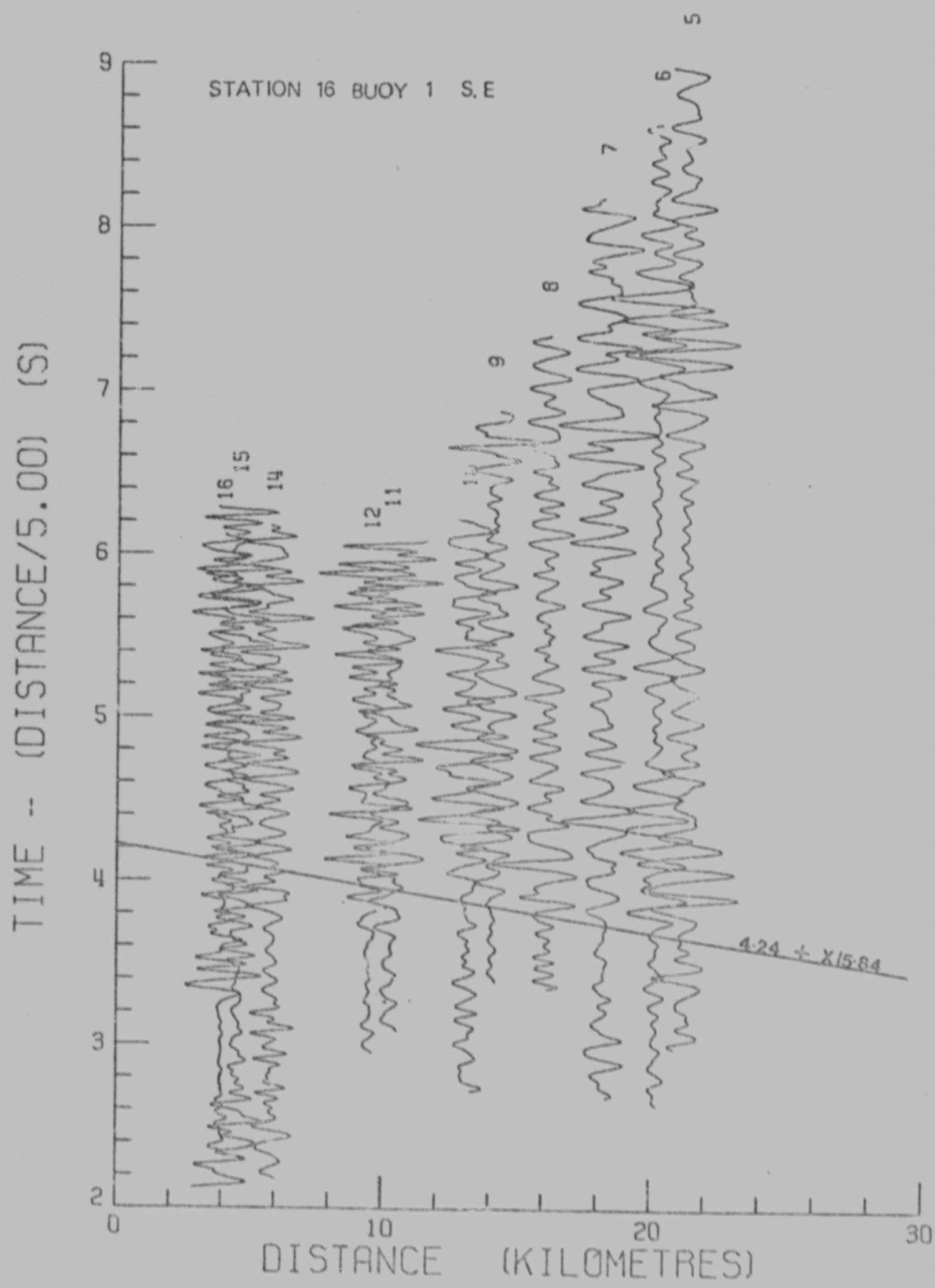


FIGURE 27. Refraction record section from buoy 1, profile 16.

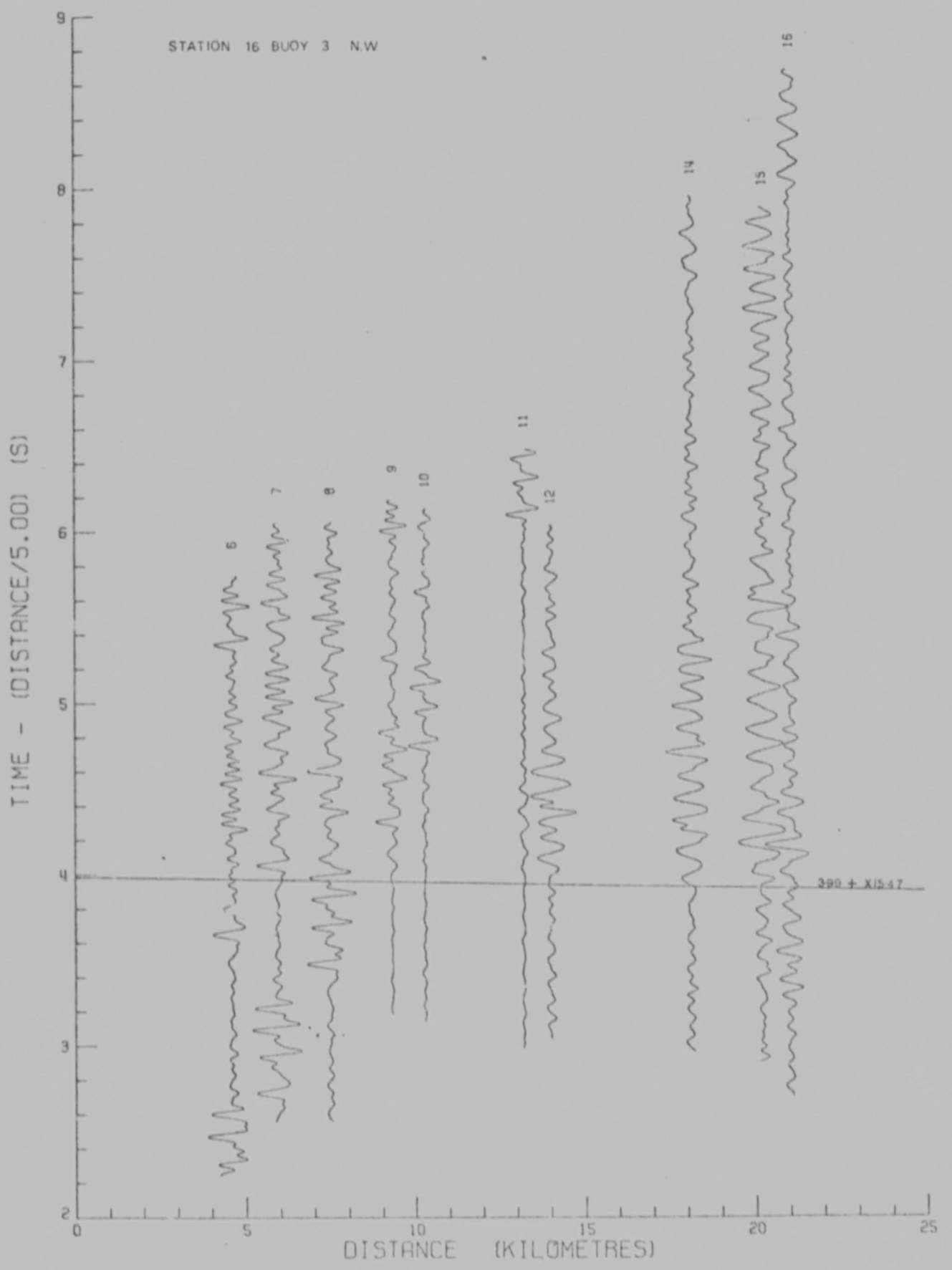


FIGURE 28. Refraction record section from buoy 3, profile 16.

Table 11

True velocities and thicknesses for profile 16 and profile 14 of Hales and Nation.

Profile 16

Velocity (km/sec)	Thickness (km)
1.51	2.59
1.51-2.13	0.69
2.27	0.35
5.65	-

Profile 14 (model A)

Velocity (km/sec)	Thickness (km)
1.51	2.40
2.0*	0.33
5.34	3.33
5.80	4.84
6.99	11.26
8.19	-

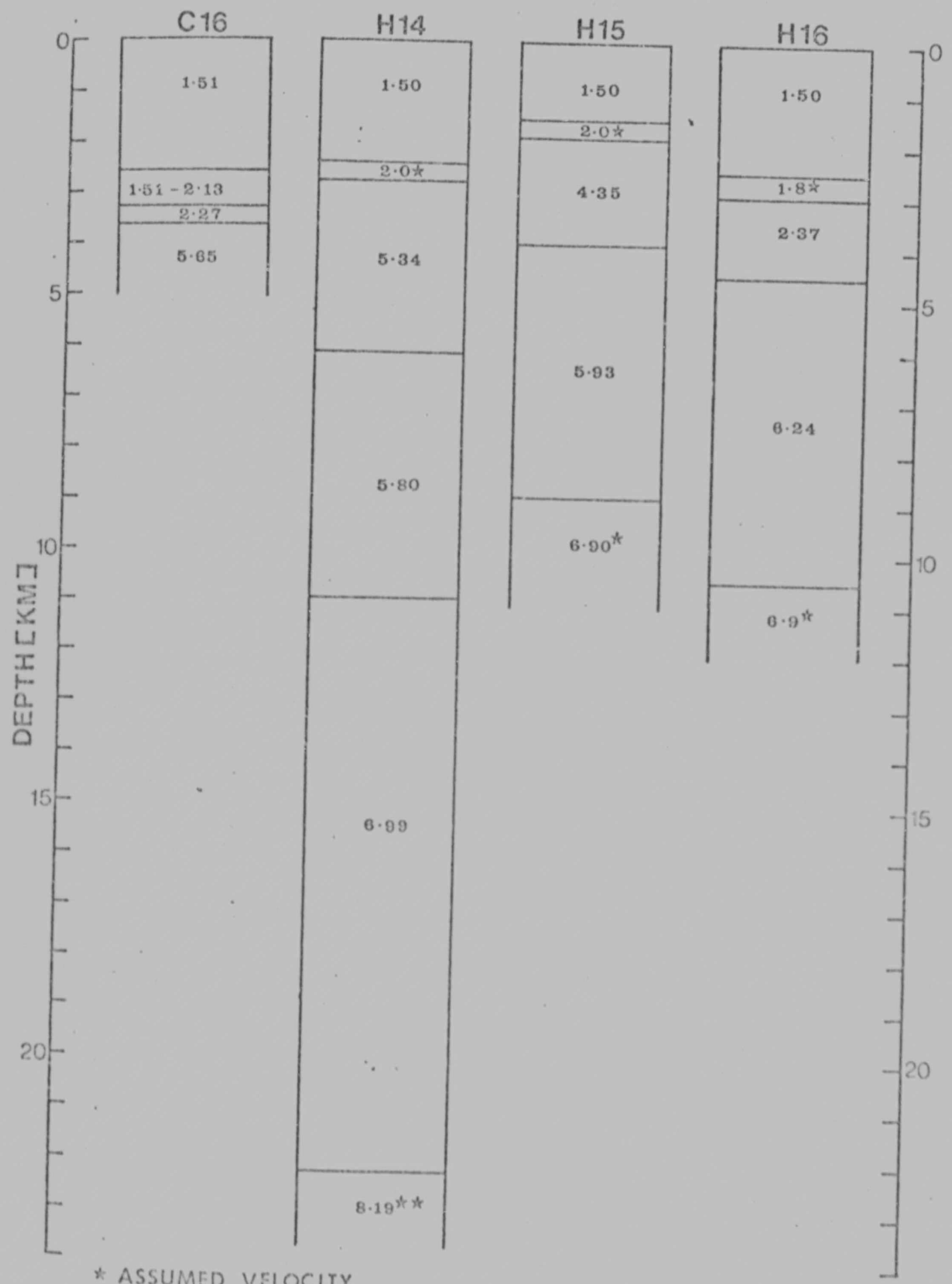
*Assumed Velocity.

should be tangential to the sub-bottom reflection curve. This requirement is approximately satisfied. No good first arrivals were observed for this reflector and the four second arrivals for each of the two buoys were from shots in excess of 15 km from the respective buoys.

The arrival with apparent velocities 5.5 and 5.8 km/sec (table (10)) for layer 3 appear as good first arrivals and seven first arrivals were observed for buoy 1 (figure (27)) in the case of the 5.8 km/sec phase. Five refracted arrivals were recorded for buoy 3 and these are shown in figure (28). It is interesting to note that the start of the arrivals for buoy 3 are not as sharp as those for buoy 1. The standard deviations on the apparent velocities are small and the dipping layer solution indicates that the dip 0.8° may be real. Table (11) lists the true velocities and thicknesses for this profile and profile 14 of Hales and Nation (1973). The velocity of 5.65 km/sec represents the average of 5.84 km/sec and 5.47 km/sec. No arrivals from layers between the 2.27 and 5.65 km/sec could be seen. In this respect profile 16 offers an important confirmation of the result published by Hales and Nation. The profile was not long enough to determine velocities from layers deeper than the 5.65 km/sec material.

B. The Preferred Interpretation of the Mozambique Ridge

The seismic velocity structure (figure (29)) of the upper portion of the profiles from the Mozambique ridge are very similar to the upper section of several profiles off the East African coast, as reported by Francis and collaborators; profiles 4 (Francis, Davies and Hill, 1966), 12, 13, 14 and 15 (Francis and Shor, 1966). The only significant difference between the two regions is that the crustal section determined by Hales and Nation is 22 km to Moho whilst the section obtained by Francis et al is only 16 kms. It is interesting to note, however that the Mozambique ridge is located under 2.6 kms of water whilst the results



* ASSUMED VELOCITY

** VELOCITY FROM ONE SIDE OF BUOY ONLY

FIGURE 29. A summary of the results of seismic profiles on the Mozambique ridge. Profiles H(14-16) from Hales and Nation.

obtained in the East African work were from deep sea basins, under 4 plus kms of water. Hales and Nation report that the ridge is in isostatic equilibrium when compared with the adjacent Transkei Basin. Thus the Mozambique ridge has a velocity structure very similar to that obtained from the deep ocean basins off the East coast of Africa, with the two crustal sections "thickness-compensated" to yield isostatic equilibrium. In the Joides drill site 249 (figure (1)) basalt was obtained at a depth of 0.4 km. The interpretation of whether this is continental or oceanic basalt awaits the results of detailed laboratory work on the cores. Also the magnetic results (Bergh, private communication) indicate that the basement is magnetic.

C. Can the Mozambique Ridge data be interpreted as continental crust?

Velocities in the range 4.4 to 5.4 km/sec are representative of a large geological time scale for South African strata. Sandstones of the Karroo Supergroup are represented by the lower and upper limits of this range (Fatti, 1970) whilst the Ecca, Bokkeveld and Cape strata fall within the upper limit of this range (Green and Bloch, 1971). Velocities within the range 5.8 to 6.2 km/sec are representative of some of the basement granites as well as the Witwatersraud and Malmesbury strata (Gane et al, 1956; Green, unpublished).

The layer with velocity 5.65 km/sec obtained for profile 16 is intermediate between the continental Precambrian rocks and the large series of Paleozoic rocks. However the confidence limits are such that it is difficult to ascribe to this strata any preferential age with reference to the velocities alone. The fact that the material is shallow (approximately 3 kms below the surface of the ocean) could conceivably favour a Precambrian basement that has a velocity lower than that typical of granite, however it is not possible to be certain. The detail

obtained by Hales and Nation (profile 14) indicates that the determination may simply be a composite of the two independent layers with velocity 5.3 and 5.8 km/sec. All that can be concluded is that an interpretation in terms of a subsided continental fragment cannot be categorically excluded, except that the basement velocity is low.

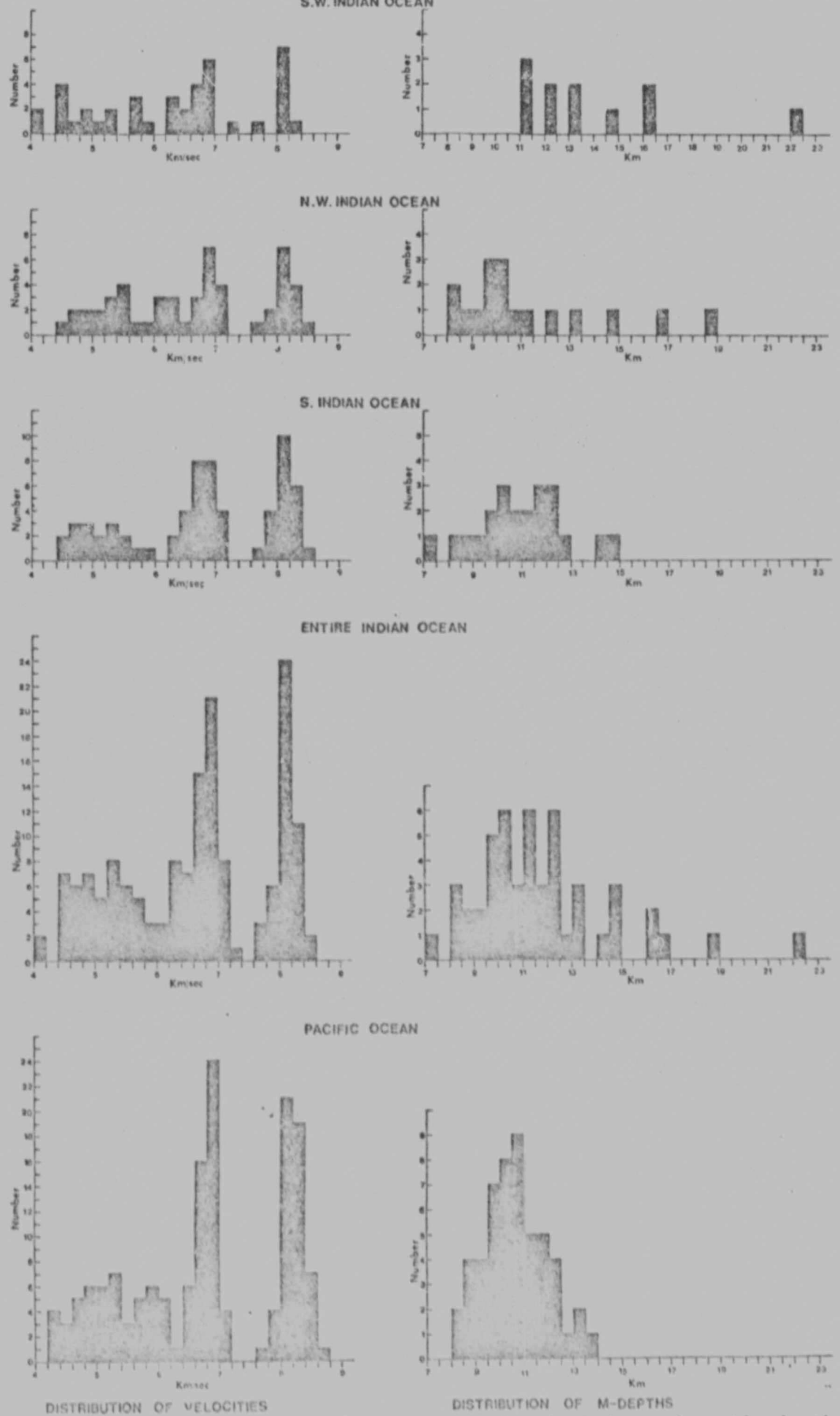


FIGURE 30. Histograms of distribution of velocities and mantle depths for the S.W. Indian Ocean, N.W. Indian Ocean, S. Indian Ocean, the entire Indian Ocean and the Pacific Ocean.

VI. General Conclusions About the Southwest Indian Ocean

Figure (30) shows histograms of the distribution of seismic velocity and mantle depth for the southwest Indian ocean, the northwest Indian Ocean (Francis and Shor, 1966; Francis et al, 1966), the southern Indian Ocean (Francis and Raitt, 1967), the whole of the Indian Ocean (the first three sets combined), and for comparison the Pacific Ocean (Raitt and Shor, 1959). In the case of the Pacific Ocean Raitt and Shor excluded refraction results from islands, trenches, ridges and seamounts whereas for the Indian Ocean histograms, the only restriction has been to neglect the results from regions where the water depth is shallower than 2 kms. Seventeen stations were used to draw the velocity distribution histogram for the southwest Indian Ocean and the locations of these are shown in figure (1). The areas included the Agulhas plateau and basin, (Ludwig et al, 1968, Barrett, private communication) the Transkei basin (Green and Hales, 1966; Hales and Nation 1973), and the Mozambique Ridge (Ludwig et al, 1968; Hales and Nation,1973).

The "transition layer", also called the second layer, has a wide scatter of velocity values. This is partly because of the inaccuracy of determination, since this layer is observed as a first arrival over only a short distance if at all. It has been shown (Christensen and Salisbury, 1972, 1973) that the density of the uppermost few meters of layer 2 basalts decreases at a rate approximately 16% per 100 m. y. Since both compressional and shear wave velocities of basalts are linearly related to density (Christensen and Salisbury, 1972), laboratory seismic velocities of layer 2 tend to decrease with age. The rates of change of Vp and Vs have been computed (Christensen, 1973) as

$$\Delta Vp / \Delta t = -1.89 \times 10^{-2} \text{ km/s. m.y.}$$

$$\Delta Vs / \Delta t = -1.35 \times 10^{-2} \text{ km/s. m.y.}$$

For layer 2 basalts 100 m.y. old Vp decreases to approximately 4.5 km/s. A very approximate age of our Layer 2 rocks (mean velocity 4.6 km/sec), from the Transkei Basin and the adjoining elevated zones (Figure 24), may be inferred from the 127 m.y. opening of the South Atlantic, deduced by Larson and Ladd (1973); our Layer 2 rocks were probably formed in the 100 m.y. -120 m.y. bracket. These velocity data are therefore consistent with the relationship given by Christensen and Salisbury.

The oceanic layer has the least scatter in the observations. Values are closely grouped around 6.9 km/sec, which suggests that this layer is of uniform composition and physical properties throughout the oceans. There is a suggestion however that the average Indian Ocean crustal velocity is higher than the worldwide average 6.69 km/sec (± 0.26 km/sec standard deviation) given by Raitt (1963).

In the southwest Indian Ocean eleven profiles recorded the mantle velocity, ranging from 8.0 to 8.4 km/sec. In all five histograms layer 4 (mantle) is clearly apparent as a peak on the velocity distribution histograms between 8.0 and 8.2 km/sec. There is a wide scatter of results for the depths to mantle in the southwest Indian Ocean, the maximum values being recorded on the Mozambique ridge (22 kms) and the Agulhas Plateau (16 kms). From the histograms it appears that the depths to mantle are higher for the Indian Ocean; however, this may be due to the restriction placed on the results for the Pacific Ocean.

The grouping of the continents of South America, India, Australia, Antarctica and Africa into the single continent of Gondwanaland is now widely accepted for most of the Palaezoic and Mesozoic Eras but there is

still disagreement on the precise way in which the continents bordering the Indian Ocean fit against one another. Sea floor spreading has not yet enabled a precise definition of the position of Australia-Antarctica to be made with respect to South America - Africa - Arabia and India. In Dietz and Sprolls (1970) reconstruction, the fit of Africa and Antarctica leaves most of the linear continental margin between Durban and the Agulhas bank bounded on the south by a gap. In the Smith and Hallam (1970) reconstruction of Gondwanaland which closel resembles that of Du Toit's (1937), Antarctica is fitted against Africa with a gap near southern Africa where the Transkei Basin is now situated; however the gaps and overlaps of the Antarctic peninsula, South America and Africa occur in regions that have been deformed in the past 200 million years. (The present shape of Antarctica is not the shape it had when it was joined to the other two continents). If the above reconstructions are correct then the Transkei basin was formed at the time of break up ie during upper Triassic to Lower Cretaceous. The formation of the Transkei Basin could be linked to the opening of the South Atlantic, i.e. the break away of South America from Africa. According to Ewing et al (1971) the Falkland plateau, east of the Falkland Islands is an extension of the South American continent. The basement has a velocity close to 6 km/sec, similar to that determined for the Argentinian Continental basement and the South African shelf. The southern limit of the South American continental block can be taken at the 3 kilometre contour. If these results are accepted, Bullard's (1965) fit of these two continents at the 3 kilometre contour extends the Falkland plateau around southern Africa right up to Durban, covering the Transkei basin and the Agulhas plateau. According to Francheteau and Le Pichon (1972) the southeastern African continental margin from South West of Cape Agulhas to near Durban represents an ancient line of shear between continental parts of the

African and South American plates. Seismic profiling data collected by the Geological Survey of South Africa show that between the Agulhas Bank and Port Elizabeth the steep scarp can be directly related to the presence of a basement ridge beneath the continental slope. Scrutton and Du Plessis (1973) suggest that the material comprising the ridge could be a splinter of pre-Cretaceous continental basement originally attached to the Falkland Plateau. Ewing et al (1969) reported that cores of Cenomanian age (90-100 m.y.) were recovered from the Agulhas plateau. This age is compatible with the spreading origin for the Transkei basin starting in early Cretaceous time.

Green (1972) reported that the 3 magnetic profiles between 25°S and 32°S across the Mozambique ridge onto the Malagasy ridge are typically oceanic in their amplitude and wavelength. He fits Madagascar against South Africa and Mozambique with the northern tip of the island south of 21°S and suggests that the Mozambique ridge was the probable spreading centre from late Triassic until late Cretaceous-early Tertiary. His magnetic profile across the Mozambique ridge showed no distinct central anomaly as was found for the extinct Philippine ridge in the West Philippine basin (Ben-Avraham, 1972). Moreover seismic refraction studies (Murauchi et al, 1959) show that the Philippine ridge is underlain by a normal oceanic crust of 5 to 6 km whereas profile 14 of Hales and Nation (1973) show that the crust of the Mozambique ridge is close to 20 km thick. There is not sufficient geophysical data to clearly define the origin of the Mozambique ridge and a more detailed survey in this area would definitely aid in the reconstruction of Gondwanaland.

A C K N O W L E D G E M E N T S

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