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Dispersion Patterns of Ground Roll (Seismic Noise) in Northern Niger Delta, Nigeria

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Abstract: All seismic waves will exhibit dispersive character in a medium which displays attenuation and the most important cause of Raleigh wave dispersion is the presence of velocity layering. Results obtained shows that the Niger Delta is not a homogeneous half-space but exhibits non-homogeneous character with unequal phase and group velocities. Hence the predominance of dispersive waves in the Niger Delta is due to its non-homogeneous character. The complex topographic nature of the Niger Delta, Nigeria give rise to scattered Raleigh waves and these can be attenuated by use of field arrays that attenuates scattered Raleigh waves from all azimuths. Frequency-wave-number transform of time-offset records can be interpreted in terms of Raleigh wave dispersion. This has been utilized in this study as dispersion curves of the ground roll in areas of study are presented and interpretation of ground roll dispersion patterns made with this.

Key words: Raleigh wave, frequency-wave-number, groundroll, velocity layering, non-homogeneous half-space

INTRODUCTION

This study covers the Oredo area of Edo State in the Northern Niger Delta, Nigeria and is part of an ongoing study on a more effective characterization of ground roll in that area.

Results of this study will be very useful to seismologists, geophysicists, geologists, researchers and the academia who would like to know the ground roll properties and dispersion patterns in the Northern Niger Delta, Nigeria with a view to designing attenuation strategies for it.

Ground roll is a collection of surface waves generated by a seismic source (Anstey, 1993; Chukwueke and Ghosh, 2004; Hudson and Knopoff, 1967; Telford *et al*., 1976). The vertical component of ground roll is composed of Raleigh waves (Fig. 1). These Raleigh waves have their most natural classification in terms of dispersion patterns. Dispersion pattern is defined as the relationship between phase velocity, frequency and wave-number (Mooney and Kaasa, 2005; Sengbush, 1983). Raleigh waves can be dispersive or non-dispersive. In the dispersive Raleigh waves, different frequency components propagate at different velocities. All seismic waves will exhibit dispersive character in a medium, which displays attenuation (Futherman, 2001; Chidi, 1988; Fitch, 1976; Short and Stauble, 1967). It has been proved that the most important cause of Raleigh wave dispersion is the presence of velocity layering. In contrast, non-dispersive Raleigh waves exhibit a sharp onset, a short duration and a uniform wavelet for all non-dispersive Raleigh waves propagate at the same velocity and the output wavelet is identical to the input wavelet with a time delay (White and Sengbush, 1956).

In the study area ground roll override useful reflection information on seismic records obtained in oil exploration because of the unusually high amplitude. They also make it difficult for seismic interpreters to identify useful reflectors (hydrocarbon reservoirs) (Fig. 2a and b). Additionally they also have the highest amplitude of any noise type and this explains why the choice of any noise type and this explains why the choice of their frequency and wave-number band-widths must be determined before conducting reflection survey. To attenuate the predominant wavelengths of ground roll in the study area, we exploited the spatial filtering action of source an receiver arrays after establishing the characteristics of the ground roll in the area

The objective in this study is to document information on dispersion pattern of ground roll in Oredo area of North Niger Delta and secondly make a deduction as to whether this part of Niger Delta is a homogenous half space or a non-homogeneous half-space. This information will be useful to processors and interpreters of seismic data and students of geology and geophysics and other related disciplines who wish to know how this information can be related to geologic studies. The study is based on the recent findings of Mooney and Kaasa, 2005, that the southern Niger Delta, Nigeria is a homogenous half space. This study also intend to show that in dispersive medium, different frequency components travel at different velocities.

Geologic setting: The Niger delta is a complex environment. It does not have a uniform weathering layer and thickness. The weathered layer is a Low Velocity Layer (LVL) and precursor of ground roll. It is therefore important to have knowledge of the environment so as to

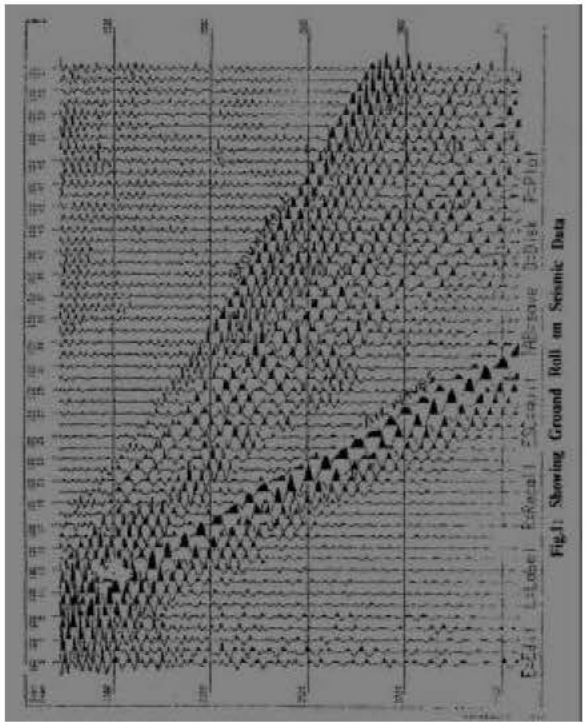

Fig. 1: Ground roll on seismic data

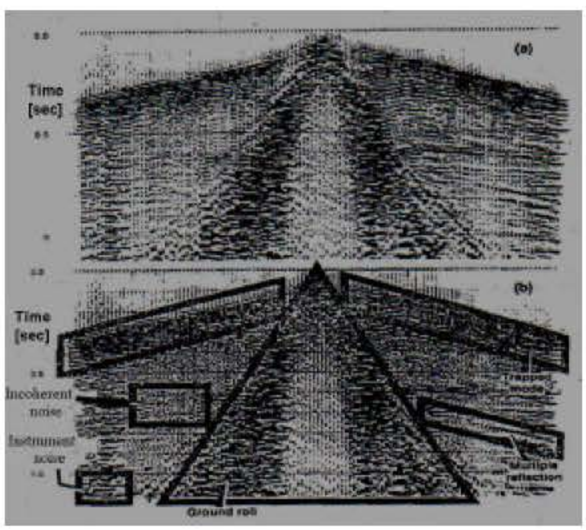

Fig. 2: a) Example of a noisy shot profile; b) Noise trains annotated

know how to appreciate the ground roll dispersion patterns in this part of Northern Niger Delta. To gain insight into this, it is necessary to know how sediments of the Niger delta accumulate and the geomorphic features involved, sediment types characteristics and of course period of deposition. The geomorphic region of the Niger Delta has been defined as extensive, composite and multifaceted (Jolly and Misfud, 2000; Morse and

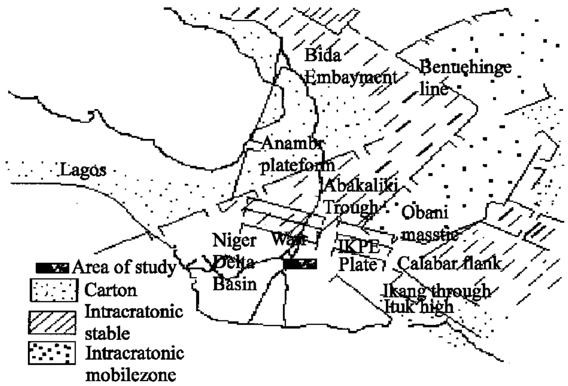

Fig. 3: Map of niger delta-Nigeria, showing area of study

Hildebrandt, 1989). Three geomorphic zones are of interest in this study. Part of the study area falls within the mangrove swamp geomorphic zone, which backs the barrier Island (Fig. 3). The sediments differ from those of the flood plain in that they are finer. Hence available evidence, sediments of the Niger Delta were transported by Niger and Benue Rivers and subsequently redistributed by long-shore currents (Short and Stauble, 1967; Futherman, 2001; Parasins, 1966).

MATERIALS AND METHODS

Data for this study was acquired during field work in the study area with a seismic crew of Nigeria National Petroleum Corporation (NNPC), at Oredo field in Nigeria. It was during this period that the seismic records were generated through seismic shooting of lines using dynamite as energy source and geophones as the receivers. However, facilities for processing were obtained Seismograph Services Ltd. the study of dispersion patterns of ground roll requires a knowledge of the group and phase velocities that will determine whether the ground roll is dispersive or non dispersive. These parameters were calculated from generated seismic data. Other necessary parameters calculated are the ground roll wavelengths, frequencies periods and wave-numbers (Anstey, 1970).

Speed with which the energy peak of a band limited wave packet travels from the source to the receiver. We calculated the group velocity using the relation:

$$\mu = \frac{X}{t} \tag{1}$$

Where x is distance measured from the record while t is the time for the wave to travel from source to receiver. In our study X = Trance number x Station Interval + 87.5 (2)

$$U = \frac{\text{Trace Number x 25 m+87.5 m}}{t} \tag{3}$$

Where 25 m = station interval while
87.5 m = station interval while 87.5 m = distance from shot to the first life station (in our study area).

Table 1 shows the values of group velocities (u) for the study area and the associated periods, frequencies, wavelengths and wave-numbers.

Phase velocity (V): Similarly group velocity for ground roll in Oredo area was calculated from generated seismic data this is commonly called moveout velocity. It is the velocity at which a fixed phase of a frequency component of a wave packet propagates. The phase velocity determines the apparent wavelength (λ) in the design of arrays.

$$\lambda = \frac{V}{f} \tag{4}$$

Where λ is apparent wavelength, V is phase velocity and F is frequency.

Phase velocity is bounded by V_{min} and V_{max}. Hence it has an immediate relevance in the design of source and receiver arrays. The arrays must attenuate a range of wavelength associated with a frequency bandwidth bounded by F_{min} and F_{max}. Phase velocity is given by the relation.

$$V = \frac{dx}{dt} \tag{5}$$

$$V = \frac{x_2 - x_1}{t_2 - l_1} \tag{6}$$

Where X_2-X_1 are two points on seismic record and T_2-T_1 are the arrival times. From Eq. 2, X = Trace No x station interval +87.5. Table 2 shows the values of phase velocities for the study area and the associated periods, frequencies, wavelengths and wave-numbers.

Dispersion curves: The curves are plotted on a 3 cycle log-log paper. In these curves, velocities are plotted against frequency. A close look at Fig. 4 shows that the curves are cup shaped or have parabolic shapes. There is a uniform decrease of the curve to a lowest limit before it rises again. This lowest point is probably the limit of the

Table 1: Group velocity for oredo field

Station No.	Shots	Freq.	T (sec)	X (m)	K
201	Max 1947	14	70	136	0.007
	Min 1729	11	90	156	0.006
202	Max 1820	12	80	146	0.007
	Min 1470	9	110	172	0.006
203	Max 1672	10	105	174	0.006
	Min 1470	8	120	176	0.006
204	Max 1800	13	80	144	0.007
	Min 1570	9	110	173	0.006
205	Max 1700	11	92	156	0.007
	Min 1500	9	108	162	0.006
206	Max 1900	13	75	143	0.04
	Min 1700	11	92	156	0.05
207	Max 429	17	60	26	0.04
	Min 281	13	80	22	0.05
208	Max 434	16	63	28	0.04
	Min 234	12	84	20	0.05
209	Max 500	20	50	25	0.04
	Min 350	14	70	25	0.05

Table 2: Phase velocity for oredo area

Station No.	Shots	Freq. (Hz)	T (Sec.)	X (m)	K
201	Max 675	14	70	43	0.02
	Min 553	11	90	50	0.02
202	Max 655	12	80	52	0.02
	Min 433	9	110	48	0.02
203	Max 650	10	104	68	0.01
	Min 525	8	120	63	0.02
204	Max 625	13	80	50	0.02
	Min 525	9	110	58	0.02
205	Max 844	17	60	51	0.02
	Min 554	13	50	50	0.02
206	Max 729	16	63	46	0.02
	Min 437	12	34	37	0.03
207	Max 756	20	50	38	0.03
	Min 450	14	70	63	0.03

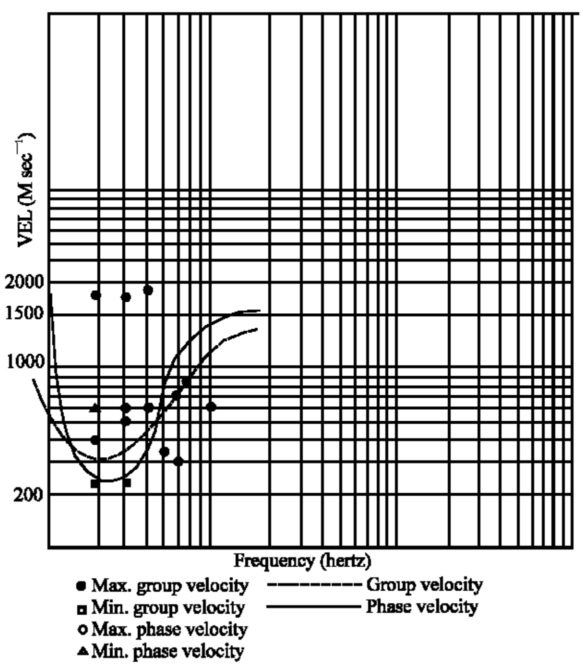

Fig. 4: Dispersion curves of oredo prospect depicting group and phase velocities

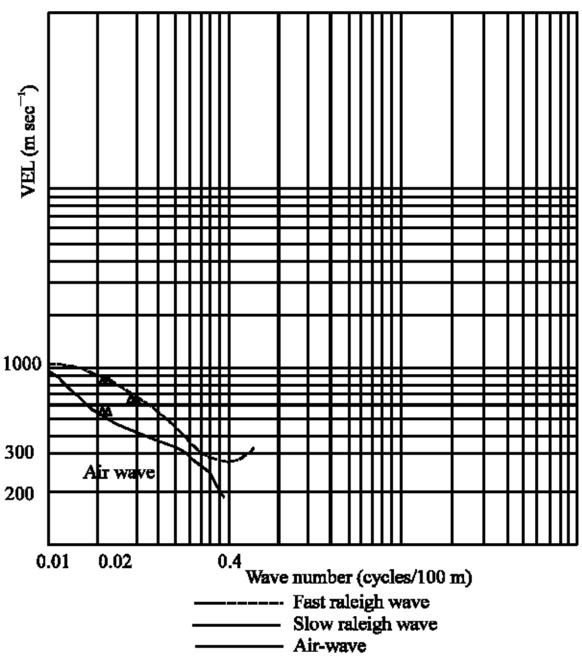

Fig. 5: Curves of phase velocity against wave number for oredo prospect and effect of air-wave

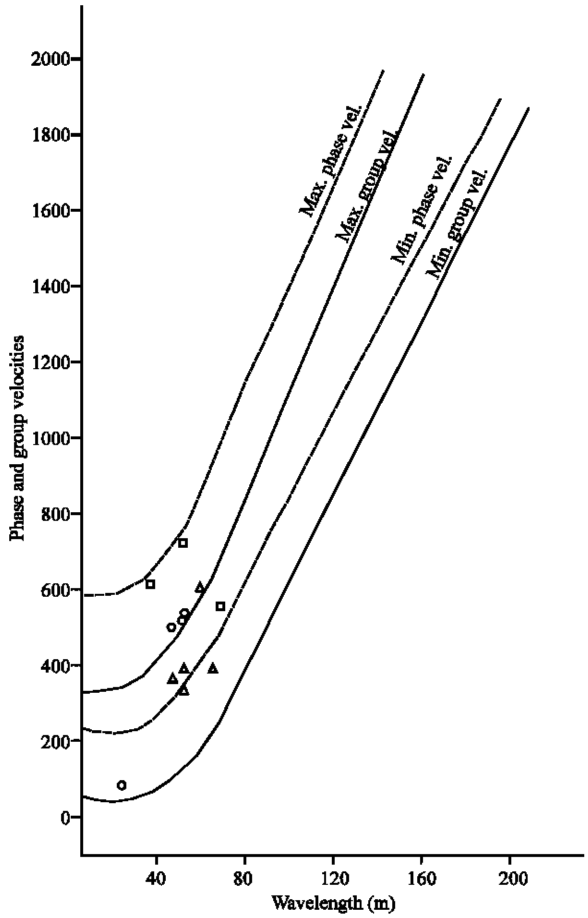

Fig. 6: Shows plot of phase and group velocities against wavelength for Oredo prospect

overhead layer-a Low Velocity Layer (LVL). The phase velocity plots lower than the group velocity, which is a reflection of the dispersive environment.

These dispersion curves are different from those plotted by Grant and West. This is because Grant and West curves were for uniform single layer while the ones plotted here are for non-homogeneous layered dispersive medium. Figure 5 shows plot of phase velocity against wave number. In the study area, it is observed that the last Raleigh waves plot below. This is a reflection of the phase velocities of the waves. Furthermore airwaves were observed and they plotted horizontally showing that they originate from the base of the vibrator or sources.

Figure 6 shows plot of phase and group velocities against wavelength. These plots made on ordinary graph show that the maximum phases and group velocities plot higher than the minimum phase and group velocities. At the same time, phase velocities plot higher than group velocities suggesting that the environment is dispersive. The plots look linear but not absolutely. This is because there is an observed decrease first to a minimum level which might probably be the limit of the weathered layer.

RESULTS AND DISCUSSION

Results so far obtained shows that Oredo of Northern Niger Delta exhibits dispersive waves, which infer non-homogenous character. The cause of the Raleigh wave dispersion is mainly the presence of velocity layering. That of the layered medium is typical of the Niger Delta. With regard to non-dispersive Raleigh waves, there is a relationship between (Fig. 7). Compressional waves (V_p) and shear waves (V_s) and Raleigh waves (VR) in homogenous elastic half-space. (Al-Husseini *et al.*, 1981). This relationship can be expressed mathematically as:

$$\left(\frac{V_R}{V_S}\right)^6 - 8\left(\frac{V_R}{V_S}\right)^4 + \left(24 - 16\frac{V_S}{V_P^2}\right) - \left(16 + 1 - \frac{V^2}{V_S^2}\right) \quad (7)$$

Equation 7 shows that Raleigh wave velocity is a function of shear wave velocity (Vs) and ratio of V_S/V_P.

However Raleigh wave velocity is a function of poisson's ratio (δ).

$$\delta = {}_{1/2}\frac{1(VS/VP)^2}{1+(V_S/V_P)^2} \quad (8)$$

Poisson's ratio that we calculated for the study areas average 0.45. This value is indeed ideal for the swampy Niger Delta with its shallow water table and high moisture content ranging form 60-75 and sometimes close to 100%. It has been observed that P to S wave velocity ratio and

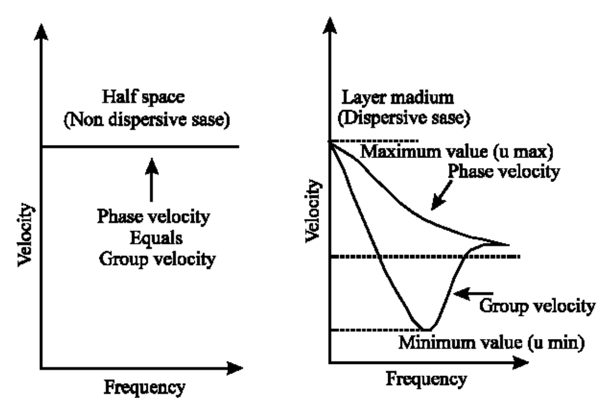

Fig. 7: Curves illustrating the dependence of Rayleigh wave phase and group velocities on frequency for propagation in a half-space [left] and in a layered medium (right). (Al-Husseini *et al.*, 1981)

hence piosson's ratio increases strongly below water table (White and Sengbush, 1956). However, in arid region, there is low piosson's ratio.

Similarly densities calculated for the study area also confirm that the media is layered and made of unconsolidated clastic rocks. Compressional wave velocity for loose sand is about 1800 m sec^{-1} and shear wave velocity about 500 m sec^{-1} (Dobrin, 1986). However, Raleigh wave velocity for sand range from 200-800 m sec^{-1} while for hard pressured bed-rock it range from 1900-4000 m sec^{-1} depending on the level of consolidation (Parasins, 1966). These values agree with calculated values of V_P and V_S in the study area which confirm that the area is made up of unconsolidated clastic layered rocks.

Air waves were observed in the study area with velocity range of 250-375 m sec^{-1} and frequency range of 8-10 Hz. These air waves tend to be broad band and non-dispersive and this is in contrast to the air-coupled Raleigh waves with velocity of more than 100 m sec^{-1} and frequency of 30 Hz. Plot of phase velocity and wave-number for air waves show that they trend horizontally. This explains their origin from the base of the sources as atmospheric acoustic wave. The airwave move the geophones as they reach them by transferring energy across the earth/atmosphere interface. For tropical areas like the Niger Delta, the air wave is pronounced similar to the finding by AΠ-Husseini *et al.* (1981) in Saudi Arabia. This supports the findings that air wave depends upon atmosphere temperature (T) such that:

$$\text{Air Wave Velocity-1051.0} + 1.1T \quad (9)$$

The incidence of air wave is pronounced in the Niger delta is because of its non-homogenous tropical environment.

Scattered Raleigh waves were observed in the study area. Results from the monitor records in the study area show that Raleigh waves are scattered in some parts of the area (Fig. 8). This scattering has been attributed to the shallow topographic features beyond the receivers. The horizontal dimension of the surface morphology will affect the amplitude spectra of scattered Raleigh waves resulting from P-wave conversions or direct Raleigh wave reflections. In data processing stage scattered Raleigh waves suffer only a weak attenuation. This explains why it is necessary to attenuate the scattered Raleigh waves directly in the field using sources and receiver arrays with omni-directional attenuation characteristic field array that attenuate Raleigh waves from all azimuths. Any remnant ones can then be removed during processing

The calculated phase and group velocities for the Oredo area of Northern Niger delta shows that it is not a homogenous half space. This is because a homogeneous

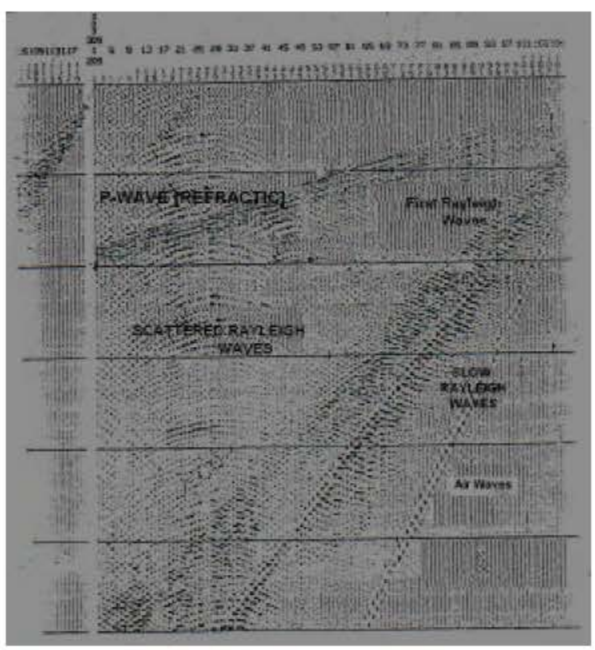

Fig. 8: Presence of scattered rayleigh waves

half-space gives only non-dispersive Raleigh waves due to the fact that the thickness of the surface layer is large compared to the longest wavelength of the Raleigh wave and thus all wavelengths propagate at the same velocity. The Niger Delta is a layered medium and exhibits dispersive pattern of Raleigh waves and the Oredo area conforms with this conclusion. The group velocity is bounded by maximum and minimum values (U_{max} and U_{min}) and this depends on frequency. Additionally, the Raleigh wave energy arrive at an offset X for a time bounded by F_{min} and F_{max}.

Thus

$$\frac{V_{max} > \lambda > V_{min}}{F_{min}\ F_{max}} \tag{10}$$

For the Oredo area of Northern Niger Delta, the calculated phase and group velocities are related by the equation.

$$V = U\left(I \frac{F}{V} \bullet \frac{d_v}{df} \right.$$

From this relation, it can be observed that if the phase velocity is independent of frequency, then group velocity is equal to phase velocity (U = V) and as such the medium approximates to a homogenous half space. This study however shows that in dispersive medium, different frequency components travel at different velocities. Moreover, these properties of dispersive Raleigh waves are very important and influence array design for wavelength spectrum and cut off velocities and frequency for better resolution of seismic data.

CONCLUSIONS

The Oredo area of Northern Niger Delta is not a homogenous half space but exhibits non-homogeneous character with unequal group and phase velocities as against the findings of Mooney and Kaasa (2005) in southern Niger Delta, Nigeria.

The presence of dispersive Raleigh waves in the Niger Delta is due to its non-homogenous character and velocity layering.

The Oredo area of Northern Niger Delta has some scattered Raleigh waves. This is attributed to shallow topographic feature beyond the signal receiver, P-wave conversions and Raleigh wave reflection. Hence use of field arrays that attenuate Raleigh waves from all azimuths will be effective for their attention.

The application of field arrays, muting, stacking, use of deep hole shorts and velocity filters (F-K filters) in the study proved to be very effective in increasing the signal to noise ratio. This is highly recommended.

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