Tectonic Implications of the Teleseismic P-Wave Travel Residuals at the Ile-Ife Nigeria Seismic Station

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Abstract

The Teleseismic P-wave travel time residuals were observed at the Obafemi Awolowo University (OAU), Seismic station, Ile – Ife, Nigeria. The station is a new University based seismic station Using the Jeffreys-Bullen (JB) tables, 6 events recorded at distances between 50^0 and 90^0 over the period of September 2008 to February 2009 were used. These events occurred in the Asian and South American continents and were received at the station in Nigeria. The study aimed at assessing the quality of data obtained at this station, based on the nature of the equipment being used, and the fact that it has been in operation for only $2^1/_2$ years. These earthquake events were chosen based on certain criteria which include, the events should be large and also that the first arrival (P-waves) should be sufficiently sharp and distinct. In order to reduce source and station effects to a negligible level, only events in the distance range greater than 50° were used, where such effects can be assumed negligible. The earthquakes used were distributed in such a way that more than one different tectonic region were traversed by the ray paths. The arrival time of all the events were picked manually and subsequently their P-wave time residual were computed using the Jeffrey-Bullen's seismological tables.

The result of the residuals, which was obtained from calculation showed that the travel time residual varies from -1.01s to +1.6s for the above regions, also the result show that the residual values are negligible and have no significant effect on the earthquake events picked (i.e. too small to be taking into account). This result lead to the conclusion that the residual obtained are not significant. Thus the implication of this residuals derived from this work is that the quality of the data being acquired at the Obafemi Awolowo University (OAU), Ife Seismological station is quite satisfactory.

Introduction

The relevance of accurate timing of individual arrival times remains crucial for many tomographic applications have been shown by several authors in the past. Most of the previous studies on data quality are concerned with teleseismic data rather than local earthquakes (for example, Diehl et al. 2009). To achieve a data set of high quality, Husen et al. (2009) showed that, arrival times need to be picked with high accuracy, including a proper assessment of the uncertainty of timing and phase identification, and a high level of consistency.

Agarwal et al. (1976) demonstrated that insight into crustal and upper-mantle structure can be obtained using teleseismic P-wave traveltime residuals.
Similarly, Oniku et al. (2006) derived the P-wave teleseismic residual for the Ahmadu Bello University, Zaria, Nigeria. From their study, they were able to establish the anomalies pattern of the travel time pattern, the upper mantle structure and the tectonic regime beneath their station. Myers et. al (2015) validated 116 seismic events and 20,977 associated *Pn* and *P* arrivals using travel-time prediction and event location accuracy for the global-scale, 3D, *P*-wave velocity model. Possible crustal and lithospheric and crustal thinning was obtained for the Deccan area of India using normalized P-residual. These residuals showed dominant negative values.

Since our station is a very young seismic station, it is thus expedient to carry out Teleseismic P-Wave Travel Residuals assessment in other to ascertain the quality data of the station because the data that are being acquired would eventually be used for various seismological studies in the future. The aim of this study is, to establish for the first time, the relative travel time residuals for this station. We adopted the well-established approach.

In this study, the teleseismic P-wave travel time residuals for events that occurred at distances between 50^0 and 90^0 recorded over the period of September 2008 to February 2009 were used to assess the quality of the data being acquired at the Obafemi Awolowo University (OAU), Ile-Ife Nigeria Seismic monitoring station.

Geology of the Area

The seismological observatory station is situated on the basement complex terrain of the southwestern Nigeria. The Nigerian basement complex lies to the east of the West African and Congo craton. The Nigeria Basement complex extends westwards and is continuous with the Dahomeyan of the Dahomey, while to the east south is covered by the Mesozoic (recent sediments of Dahomey and Niger Coastal Basins). The basement complex have been extensively studied by Oyawoye (1964), Rahaman (1976, 1988), Odeyemi (1976) and others. Based on both the petrographical and petrological Rahaman (1976, 1988) classifies the rock into five major groups; as follows:

1. The migmatite-gneiss-quartzite complex.
2. Slightly migmatized to Non-migmatized metasedimentary, and metaigneous rocks.
3. Charnokitic, Gabbroic and Dioritic rocks [Pan African, 600 ± 150 ma].
4. Older granites [Pan African, 600 ± 150ma].
5. Metamorphosed to unmetamorphosed Alkaline Volcanic and Hyperbasal rocks [Pan African, 600 ± 150ma]; Unmetamorphosed dolerite dykes, syenite dykes.

But according to Odeyemi (1988), was able to recognize four rock types. These are:

1. The migmatite-gneiss complex.
2. The metasediments which includes: schist, calc-gneiss, Meta conglomerate and quartzite.
3. The Older Granites
4. The Unmetamorphosed Syenite and Dolerite dykes.

Obafemi Awolowo University is located at the North western outskirt of Ile-Ife in Osun State, Nigeria. The seismological station is on latitude 7.52062°N and longitude 4.52115°E with altitude 954.40ft (Fig. 1). The university is underlain by Precambrian basement complex rocks, which were estimated to be within 600-850 million years old (Rahaman, 1988). Four major rock types underline Obafemi Awolowo Universit. These include schist undifferentiated, pegmatite, granite gneiss, gneiss and migmatite undfifferentiated, and banded gneiss (Fig. 1).

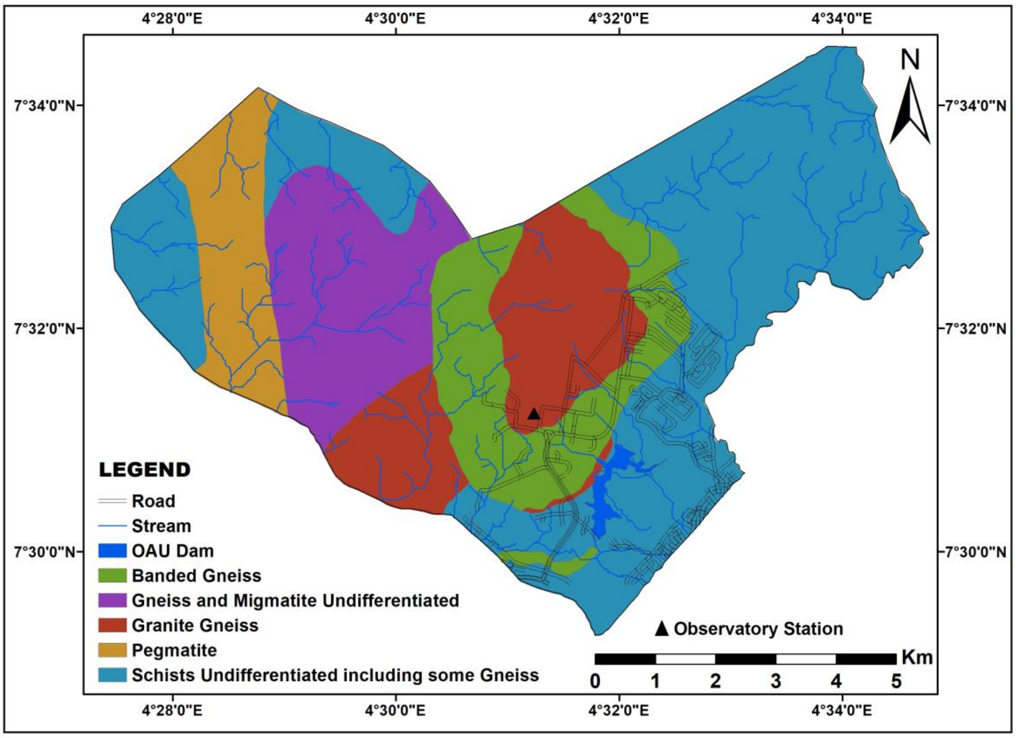


Figure 1: Geological Map of Obafemi Awolowo University

Methodology

CMG-EDU system, which was installed in the Seismological Research Laboratory (SRL) of Obafemi Awolowo University (OAU), Ile-Ife, Nigeria, is based on Guralp System CMG-6 broadband seismometer technology and was used for acquiring the teleseismic data used in this study. The Guralp CMG-EDU seismometer is an ultra-lightweight and waterproof digital seismometer that has an incorporation of a triaxial broadband sensor and a compact digitizer with 21-bits resolution which samples at the rate of 4-1 samples/s. The broadband feedback sensor has an outputs voltage that is proportional to velocity in the 30s-100Hz frequency range with a standard output sensitivity of 2 × 1000 V/m/s. The seismometer's sensor was installed in a 2m-deep vault that has a leveling range of ±3° from the horizontal. This was done in order to reduce the noise interference generated by human activities in the recording data. Recorded teleseismic data in this station are viewed and filtered using Scream 4.4 software. In order to determine the quality of data recorded in the station, the teleseismic data used were carefully selected based on the following factors:

i. Events prior to 2007 could not be used since the station started operation in 2007 and the data for this period was not considered reliable. Therefore, only events from 2008 to 2009 were therefore used.

ii. In order to minimize the effects of local structure at the source and station regions, only events at epicenter distances greater than 50^0 were used

iii. High magnitude events were used in order to have significant first arrival amplitude.

Six (6) teleseismic data were found to satisfy these requirements and they are listed in Table 1. The teleseismic data used are events from earthquakes that have occurred globally and are being recoded in diverse observatory stations.

Table 1 Show the data gotten from the high pass filter and low pass filter of the six (6) events observed at the seismic station; Order of the filter is 4th Order; Sample per second uses is 40.

S/N	DATE YMD	ORIGIN TIME ($t\alpha$)	REGION	HIGH PASS FILTER (Hz) and (sec)	LOW PASS FILTER (Hz) and (sec)
1	20081019	18633	Tonga	0.01948264 and 51.32775	0.9709768 and 1.029891
2	20081028	83398	Pakistan	0.01948264 and 51.32775	0.8296906 and 1.205269
3	20081116	61352	Minahasa, Sulawesi, Indonesia	0.01948264 and 51.32775	0.7250694 and 1.379178
4	20081122	57699	Southeast Of the Loyalty Island	0.01948264 and 51.32775	0.5579027 and 1.792427
5	20081122	57659	Southern Sumatra, Indonesia	0.01948264 and 51.32775	0.5579027 and 1.792427
6	20090215	36291	Near the cost of Northern Peru	0.01962908 and 50.94482	0.4390292 and 2.277753

**The last three from the table indicate the observed time, theoretical time (from Jerrey-Bullen's seismological table), and absolute travel time residual.*

In the case of earthquakes that have occurred at global distances, at least three or more geographically diverse observing stations (using a common clock) recording P-wave arrivals permits the computation of a unique time and location on the planet for the event. Typically, dozens or even hundreds of P-wave arrivals are used to calculate hypocenters. The misfit generated by a hypocenter calculation is known as "the residual". Residuals of 0.5 second or less are typical for distant events, residuals of 0.1-0.2 s typical for local events, meaning most reported P arrivals fit the computed hypocenter that well. The absolute travel time residual (R) is then defined as:

$$R = T_0 - T_c \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(i)}$$

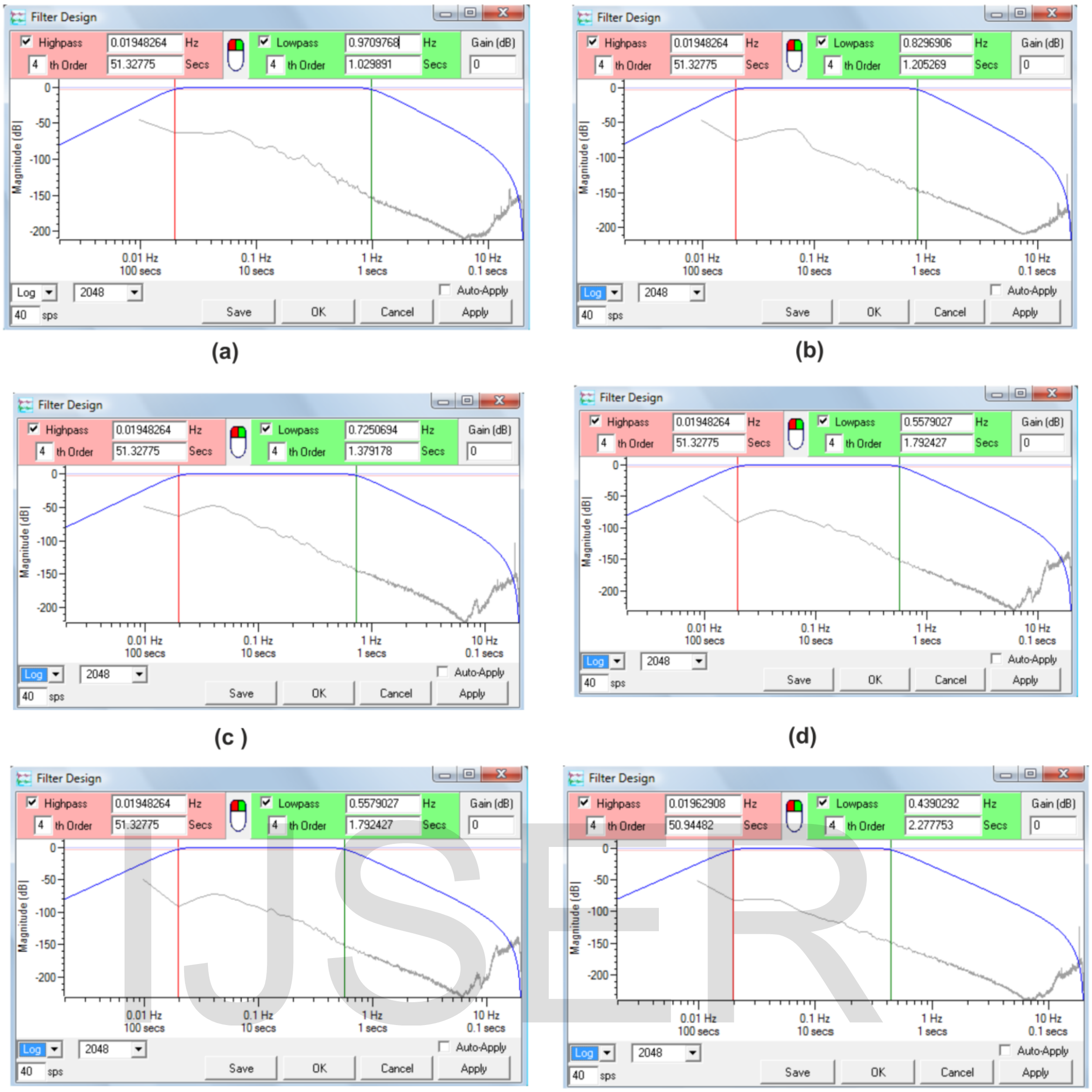
$$T_0 = t_c - t_o \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\text{(ii)}$$

$Where\ T_0\ is\ the\ observed\ travel\ time, while\ T_c\ is\ the\ theoretical\ travel\ time,$
$t_c\ is\ the\ event\ origin\ time\ time\ reported\ by\ USGS, while\ t_0\ is\ the\ arrival\ time.$

If errors in the travel time tables are small and considered negligible, the major source of error in the travel time residuals is the accuracy of the observed travel times. Origin times of events are normally listed to the nearest tenth of a second, and event arrival times at standard stations can be determined to the same order of accuracy or better. However, the instrument presently in use at SRL, OAU station has a recording/drum speed of 1mm/sec., and reading precision in therefore not better than 0.5s. The calibration standard for the instrument clock is the British Broadcasting Corporation (BBC) time pips. Considering the propagation time delay between London and Ife, error in calibration is less than 15ms and not more than twice this value for the longest path if the time signal originates from a relay transmitter. Maximum error in timing calibration when the fact that calibration is done manually is taking into consideration is therefore not expected to exceed 0.1s. The maximum standard error in the travel times is thus 0.52s

Error due to background noise is another effect that may arise. This is an important aspect of the signal-to-noise properties at a particular site. A variety of near-site conditions which affect the ambient noise include cultural activities, weather and wind patterns, local seismicity, and proximity to oceans or seas. According to Al-Amiri *et al.* (1999), the teleseismic and regional signal reception levels are affected more by regional structures than the site characteristics. In order to have higher signal to noise ratio, a high pass and low pass filtering (band pass filtering) was applied to the six (6) seismic events obtained. This was achieved using scream 4.4 software. The result obtained from the filtering and the parameters used are shown in Table 1 and Figure 2.

For this study, the focal parameters used were obtained from the preliminary earthquake report on earthquake archives published by the United States Geological Survey (USGS) National Earthquake Information Centre. The reported epicenter distances and focal depths of the events were incorporated into in the the J-B tables to obtain the theoretical travel-times T_c. This was done by tracing out the epicenter distances to meet the corresponding focal depths.



(a)

☑ Highpass 0.01948264 Hz; 4 th Order 51.32775 Secs; ☑ Lowpass 0.9709768 Hz; 4 th Order 1.029891 Secs; Gain (dB) 0; Log; 2048; 40 sps; ☐ Auto-Apply

(b)

☑ Highpass 0.01948264 Hz; 4 th Order 51.32775 Secs; ☑ Lowpass 0.8296906 Hz; 4 th Order 1.205269 Secs; Gain (dB) 0; Log; 2048; 40 sps; ☐ Auto-Apply

(c)

☑ Highpass 0.01948264 Hz; 4 th Order 51.32775 Secs; ☑ Lowpass 0.7250694 Hz; 4 th Order 1.379178 Secs; Gain (dB) 0; Log; 2048; 40 sps; ☐ Auto-Apply

(d)

☑ Highpass 0.01948264 Hz; 4 th Order 51.32775 Secs; ☑ Lowpass 0.5579027 Hz; 4 th Order 1.792427 Secs; Gain (dB) 0; Log; 2048; 40 sps; ☐ Auto-Apply

(e)

☑ Highpass 0.01948264 Hz; 4 th Order 51.32775 Secs; ☑ Lowpass 0.5579027 Hz; 4 th Order 1.792427 Secs; Gain (dB) 0; Log; 2048; 40 sps; ☐ Auto-Apply

(f)

☑ Highpass 0.01962908 Hz; 4 th Order 50.94482 Secs; ☑ Lowpass 0.4390292 Hz; 4 th Order 2.277753 Secs; Gain (dB) 0; Log; 2048; 40 sps; ☐ Auto-Apply

Figure 2 shows the filtered result of : (a) Tonga Event; (b) Pakistan Event; (c) Minahasa, Sulawesi Indonesia Event; (d) Southeast of the Loyalty Island Event; (e) Southern Sumatra, Indonesia Event; (f) Near the coast of Northern Peru Event

However, the filtered seismogram obtained from the teleseismic data recorded in SRL, OAU, Nigeria, were interpreted manually to determine the angular epicenter distance of the events using the standard travel time curve of Jeffreys-Bullen. The time difference between the arrival time of P and S wave were used to determine the epicenter distance. The first arrival times (Table 2), corresponding to P-waves, picked form the seismograms and together with the origin times of the events by the USGS archives were integrated into equation (ii) to obtain the observed travel times T_o. The obtained parameters T_c and T_0 are inserted into equation (i) to obtain the absolute travel time residual(R). The obtained absolute travel time residual (R) for the Six (6) Teleseismic data used are shown in Table 3. After this processes, interpretation was done.

Table 2: Show the arrival time of each events occurring at the various regions

S/N	DATE YMD	REGION	ARRIVAL TIME (tα) HMS
1	20081019	Tonga	19240
2	20081028	Pakistan	84023
3	20081116	Minahasa, Sulawesi, Indonesia	61930
4	20081122	Southeast of the Loyalty Island	58310
5	20081122	Southern Sumatra, Indonesia	58310
6	20090215	Near the coast of Northern Peru	36820

Table 4.2 Show the computation of travel time residual of six (6) events that were found to satisfy these requirements, using the Jeffrey Bullen Seismological Tables, 1970

S/N	**DATE YMD**	**ORIGIN TIME(tα) HMS**	**ARRIVAL TIME(tα) HMS**	**LATITUDE (°)**	**LONGITUDE (°)**	**REGION**	**DEPTH (KM)**	**MAGNITUDE**	**FOCAL DEPTH h**	**ANGULAR EPICENTER DISTANCE Δ(°)**	**OBSERVED TIME (T_o) T_o=tα-t_o (sec)**	**THEORETICAL TIME (Tc) Tc=T(Δ,h) (sec)**	**ABSOLUTE TRAVEL TIME RESIDUAL R=T_o-Tc (sec)**
1	20081019	18633	19240	21.864°S	173.814°W	Tonga	29	6.9	0.002	61	606.6	606.7	-0.1
2	20081028	83398	84023	30.656°N	67.361°E	Pakistan	15	6.4	0	65	625.2	624.3	0.9
3	20081116	61352	61930	1.290°N	122.100°E	Minahasa, Sulawesi, Indonesia	30	7.3	0.002	60	601.8	602.7	-0.9
4	20081122	57699	58310	22.503°S	171.166°E	Southeast of the Loyalty Island	59.4	6.4	0.004	62	610.8	610	0.8
5	20081122	57659	58310	4.411°S	101.218°E	Southern Sumatra, Indonesia	10	6.4	0	72	675	673.4	1.6
6	20090215	36291	36820	5.835°S	80.880°W	Near the coast of Northern Peru	35.6	6.2	0.004	54	552.6	553.61	-1.01

Data Filtering, Sesimic Wave Signature and Its Geological Implications

Noise condition at seismic stations may be due to instrumental characteristics, seasonal noise (which is quietest between April and June, and noisiest between October and December), slight tilting of seismometer's sensor, slight change in peak microseism frequency and Human activities (noisiest in the morning and early afternoon, and quietest at night). These therefore prompt the need for data filtering. From the result obtained from the application of band pass filter on the recorded Teleseismic data, it was observed that the signatures obtained delineate the surface geology, basic geology, geomorphology and how far it has travelled.

Looking at the signature generated for each event, firstly the Tonga Island event shows that the event has travelled over a long distance. High pass filter was applied between 0.01948264 Hz and 51.32775 s, while the low pass filer was applied between 0.9709768 Hz and 1.029891 s (Fig. 2a). The signature explain the geology on which it has travelled, the band pass width for the high pass filter show that the event has travelled over a soft rock due to the signature observed on the wavelength while at the low pass window a series of packed signature was observed suggesting that the event has travelled across hard rock before finally dying out. The amplitude generated by the event show a magnitude of -45dB, and this decreases as distance increases. This also shows that before the event reaches the seismic station it has passed through hard rock causing spurious effect along a frequency of 10 Hz. The spurious effect may be due to the obstacles observed in the cause of its travel (Fig. 2a).

The Pakistan event shows that the event has travelled over a long distance which most of the events have too. High pass filter was applied at 0.01948264 Hz and 51.32775 s, while the low pass filer was applied at 0.8296906 Hz and 1.205269 s (Fig 2b). The signature explains the geology on which it has travelled. The band pass width for the high pass filter reveals that the event has travelled over a soft rock due to the signature observed on the wavelength and that spurious effect in the amplitude occur as a result of obstacle encounter along it travel path within the soft rock while at the low pass window a series of packed signature was observed suggesting that the event as travelled across hard rock before attenuating. The amplitude generated by the event show a magnitude of -45dB, and this decreases as distance increases. This also shows that before the event reaches the seismic station it has passed through hard rock causing spurious effect along a frequency 10 Hz. The spurious effect may be due to the obstacles observed in the cause of its travel (Fig. 2b).

Further, the seismogram of Minahasa-Sulawesi-Indonesia reveals that the event has travelled over a long distance. High pass filter was applied at 0.01948264 Hz and 51.32775 s, while the low pass filer was applied at 0.7250694 Hz and 1.379178 s (Figure 2c). The signature explains the geology on which it has travelled as explained in previous events. The amplitude generated by the event show a magnitude of -50dB to as low as -220dB then it increases back to about -100dB before dying out. This also shows that before the event reaches the seismic station it has passed through hard rock causing spurious effect along a frequency 6.5-10 Hz.

Also, the Southeast of the Loyalty Island event has travelled over a long distance. High pass filter was applied at 0.01948264 Hz and 51.32775 s, while the low pass filer was applied at 0.5579027 Hz and 1.792427 s (Figure 2d). The signature explains the geology on which it has travelled. The amplitude generated by the event show a magnitude of -50dB to as low as -220dB then it increases back to about -120dB before attenating. This also shows that before the event reaches the seismic station it has passed through hard rock causing spurious effect along a frequency 6.0 Hz (Fig. 2c). The spurious effect may be due to the obstacles observed in the cause of its travel.

The Southern Sumatra, Indonesia event has travelled over a long distance. High pass filter was applied between 0.01948264 Hz and 51.32775 s, while the low pass filer was also applied at 0.5579027 Hz and 1.792427 s (Fig. 2e). The signature explains how the event has passed through soft and hard rocks. The amplitude generated by the event show a magnitude of -50dB to as low as -220dB then it increases back to about -120dB before dying out. This also shows that before the event reaches the seismic station, it has passed through hard rock causing spurious effect along a frequency 6.0 Hz. This spurious effect may be attributed to the obstacles observed in the cause of its travel.

Near the coast of Northern Peru, the event has travelled over a long distance. High pass filter was applied between 0.01962908 Hz and 50.94482 s while the low pass filer was also applied between 0.4390292 Hz and 2.277753 s (Fig. 2f). The signature describes the geology predicting that it has travelled through series of soft and hard rock. The amplitude generated by the event show a magnitude of -55dB to as low as -235dB then it increases back to about -120dB before dying out. This also shows that before the event reaches the seismic station, it has passed through hard rock causing spurious effect along a frequency 6.0 Hz still it dies out. The spurious effect may be due to the obstacles observed in the cause of its travel.

Results and Discussion

The results of the travel time residual were obtained using the Jeffrey-Bullen tables (1970) to calculate the travel time residuals for six (6) events are shown in Table 2. Looking at the various seismograms (Fig. 3) which was used in analyzing the six (6) events, it was possible to determine that the arrival time P-wave from each seismogram, the arrival time for Tonga Island was sharp, clear and was picked at 1924 s, that of Pakistan is also clear and sharp and the arrival time was picked at 84023 s, the arrival time for the Minahasa-Sulawesi-Indonesia event was picked at 61930 s, the arrival time for Southern Sumatra-Indonesia and South of the Loyalty Island was picked at 58310 s , and finally the arrival time of Near the coast of Northern Peru was at 36820 s. These arrival times were used to calculate the observed travel time. The Jeffrey-Bullen table 1970 was used in the analyses of obtaining the absolute travel time for the six events.

These results, as shown in Table 3, reveals that the residuals vary between -1.01 to +1.6 s , and two observations can be made from these values. Firstly, the values of the residuals are relatively low (less than 1.2s for the most part) which is an indication that the data set is of reasonably good quality. It can therefore be assumed that there were no gross errors in the measurements and the identification of the P-phase onset and the time standard used were both good. Secondly, the suggestion to the variation in the residuals is as a result of the various heterogeneous subsurface crust and mantles which the travel time has passed through before reaching the station.

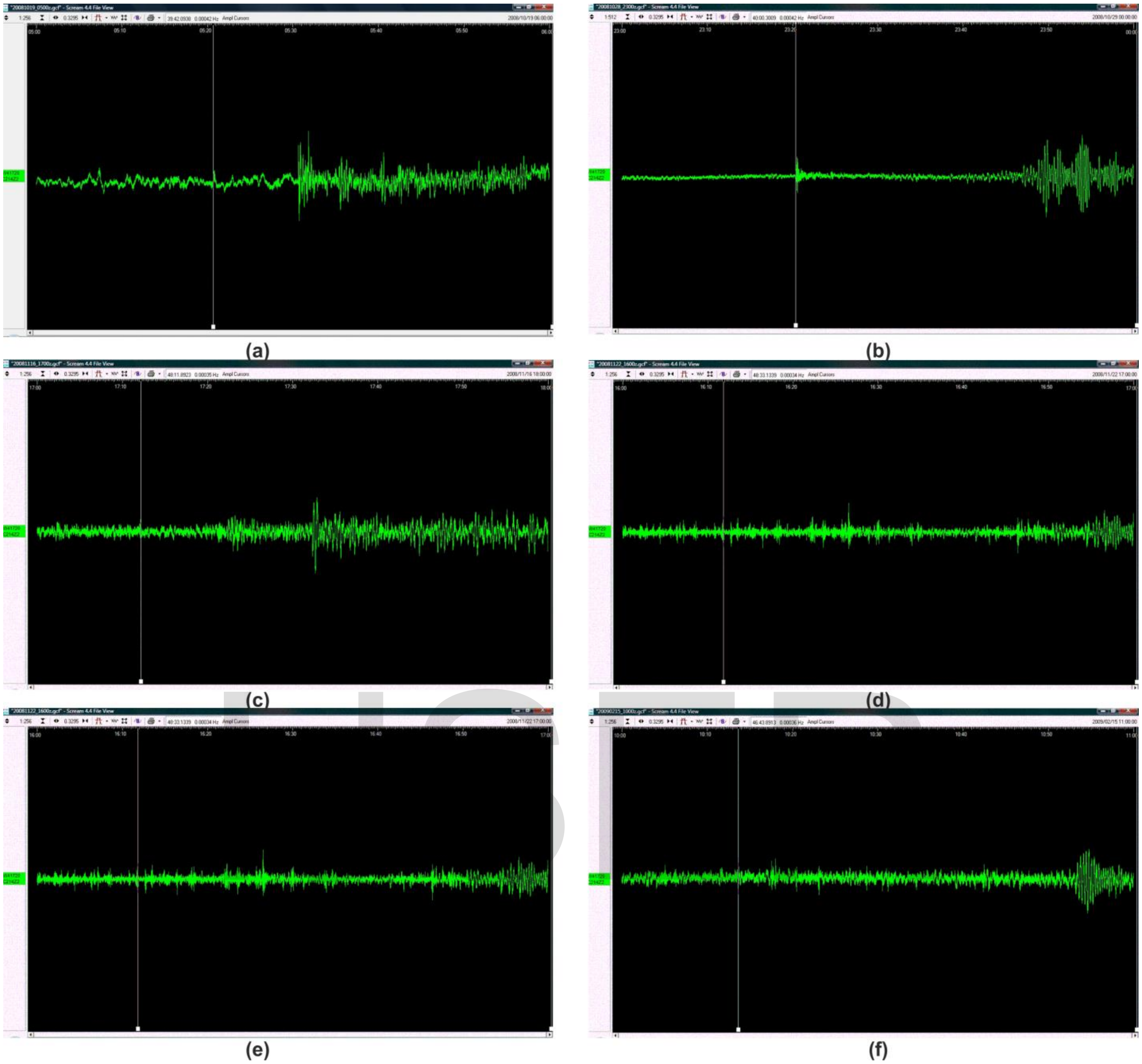


Figure 3 Showing the Seismograms of: (a) Tonga Event; (b) Pakistan Event; (c) Minahasa, Sulawesi Indonesia Event; (d) Southeast of the Loyalty Island Event; (e) Southern Sumatra, Indonesia Event; (f) Near the coast of Northern Peru Event

As a matter of fact, a closer examination of the results show that the amplitude of the residuals can be distinctly related according to their source region (as shown in Table 2) and hence their propagation paths. All these events originating from Tonga, Minahasa-Sulawesi Indonesia, and near the coast of northern Peru have negative residuals which are -0.1s, -0.9s and -1.01s, while the events from Pakistan, southeast of the Loyalty Island and southern Sumatra Indonesia have positive residuals which are 0.9s, 0.8s and 1.6s (Table 3). However, the events which have positive anomalies are quite lager than those from Tonga, Indonesia, and northern Peru, because of the relatively low values of the residual for each event, it could be concluded that the scatters in the data within each region are due to the normal statistical variation of the travel times in these regions. If the assumption is valid that the contributions to the variation in residuals form the sources and station is negligible compared to that, that forms the propagation paths in the distance range greater than 50^0, then the distinct differences in the residuals for these regions must be an indication of the varying tectonic character of the different propagation paths.

Looking at the various tectonic systems and how it affects the travel time residual obtained from these regions, basic information on the region from which this event occur has to be explained in order to understand what was going on at those places. The Arabian Plate is a continental tectonic plate covering the Arabian Peninsula and extending northward to Turkey and Pakistan. The plate borders are: to the east we have the Indo-Australian plate; to the south we have the African Plate and west; divergent boundary with the African Plate forming the northern part of the Great Rift Valley; and the Red Sea rift zone, north with the Eurasian Plate (Encyclopedia–Arabian). A fracture exists in the vicinity of the Red Sea; the Red Sea and the Gulf of Aden is active diverging boundaries along which the Arabian Peninsula is being separated from northeastern Africa. In East Africa, spreading processes have already torn Saudi Arabia away from the rest of the African continent, forming the Red Sea. The actively splitting African Plate and the Arabian Plate meet in what is called a triple junction, where the Red Sea meets the Gulf of Aden. A new spreading center may be developing under Africa along the East African Rift Zone. When the continental crust stretches beyond its limits, tension cracks begin to appear on the Earth's surface. Magma rises and squeezes through the widening cracks, sometimes to erupt and form volcanoes. The rising magma, whether or not it erupts, puts more pressure on the crust to produce additional fractures and, ultimately, the rift zone (Kious and Tilling, 1996).

East Africa may be the site of the Earth's next major ocean. Plate interactions in the region provide scientists an opportunity to study firsthand how the Atlantic may have begun to form about 200 million years ago. It is believe that, if spreading continues, the three plates that meet at the edge of the present-day African continent will separate completely; allowing the Indian Ocean to flood the area and making the easternmost corner of Africa (the Horn of Africa) a large island (Kious and Tilling, 1996). The Indo-Australian Plate is a major tectonic plate that includes the continent of Australia and surrounding ocean, and extends northwest to include the Indian subcontinent and adjacent waters. The two protoplasts or sub-plates are generally referred to as the Indian Plate and the Australian Plate. The Pacific Plate subducting under the Australian Plate forms the Tonga Trenches, and the parallel Tonga island arcs (From Wikipedia, 2009).

Some volcanoes crown island areas lying near the continents, and others form chains of islands in the deep ocean basins. Volcanoes tend to cluster along narrow mountainous belts where folding and fracturing of the rocks provide channel ways to the surface for the escape of the magma. Significantly, major earthquakes also occur along these belts, indicating that volcanism and seismic activity are often closely related, responding to the same dynamic Earth forces (Tilling, 1985). Island-Arc Volcanic: In a typical "island-arc" environment, volcanoes lie along the crest of an arcuate, crustal ridge bounded on its convex side by a deep oceanic trench. The granite or granite like layer of the continental crust extends beneath the ridge to the vicinity of the trench. Basaltic magmas, generated in the mantle beneath the ridge, rise along fractures through the granitic layer. These magmas commonly will be modified or changed in composition during passage through the granitic layer and erupt on the surface to form volcanoes built largely of non-basaltic rocks (Tilling, 1985).

Trench positions changes with time, as one plate subducts, the overlying plate may be moving toward it. The Peru-Chile trench is moving over the Nazca plate in this manner as South America moves westward. This is the reason trenches move. There is another reason that trenches move: it is now widely believe that a subduction plate does not sink in a direction parallel to the length of the plate, but fall through the mantle at an angle that is steeper than the dip of the down going plate. This sleep sinking pull the subduction plate progressively away from the overlying plate, and causes the hinge line of bending and the oceanic trench to migrate seaward onto the subducting plate. An example of a continental-oceanic subduction zone is the area along the western coast of South America (Peru-Chile Trenches) where the oceanic Nazca Plate is being subducted beneath the continental South American Plate. The Peru Chile Trench is relatively shallow; between these regions the Nazca Ridge constricts and deforms the trench (Fisher, 1958). The active zone of crustal earthquake is located on the eastern or landward of the Andes in Peru. Shallow earthquake occur frequently in the near coastal wedge of relatively low seismicity between the Benioff zone and the interior zone of shallow earthquake, this may be characteristic of other regions of subduction. The most active shallow zone located landward of the subduction zone are those of the Peru-Chile system.

In the early 1960's, the related concepts of "sea-floor spreading" and "plate tectonics" emerged as powerful new hypotheses that geologists used to interpret the features and movements of the Earth's surface layer. According to the plate tectonics theory, the Earth's surface consists of about a dozen rigid slabs or plates, each averaging at least 50 miles thick. These plates move relative to one another at average speeds of a few inches per year -- about as fast as human fingernails grow. Scientists recognize three common types of boundaries between these moving plates:

Divergent or spreading -- adjacent plates pull apart, such as at the Mid-Atlantic Ridge, which separates the North and South American Plates from the Eurasian and African Plates. This pulling apart causes "sea-floor spreading" as new material is added to the oceanic plates.

Convergent -- plates moving in opposite directions meet and one is dragged down (or subducted) beneath the other. Convergent plate boundaries are also called subduction zones and are typified by the Aleutian Trench, where the Pacific Plate is being subducted under the North American Plate.

Transform fault -- one plate slides horizontally past another. The best known example is the earthquake-prone San Andreas Fault zone of California, which marks the boundary between the Pacific and North American Plates. The rates of plate movements range from about 1 to 10 centimeters per year (Noson et al, 1988).

The result shows that the maximum depth of propagation paths to epicenter distances between 54^0 and 72^0 lies deep in the upper mantle and the depth ranges between an approximately 1,185 to 1,580 km. The Jeffreys and Bullen (1970) was used to calculate the depth range in the upper mantle. In the Jeffreys-Bullen (1970) travel time study, it was found that a discontinuity in the slope of the travel-time curve between 19° and 20° shows a sharp bend between these ranges. This discontinuity at 20° would correspond to a rapid increase in velocity at a depth of about 400 km, but due to the study of the density distribution at the top of the mantle (which is a high velocity zone by Jeffreys) Jeffreys-Bullen (1970) estimated the depth of the discontinuity as 439 km, (Hales, 1971). From these, the upper mantle depth range in which these earthquakes occur beneath the subsurface could be estimated.

The explanation based on the variation in the residuals is as a result of the distance range and the zone in which it is coming from. The Tonga, Indonesia, Loyalty Island events, are of the Circum-Pacific belts with a travel path at the bottom in the upper mantle region beneath the Indian-Australia plate, and then travels through the African plate passing Kenya, Congo and Cameroon till it reaches the earthquake station in Nigeria, OAU Ife. For the Pakistan event which is also an Indian-Australia plate of the eastern Mediterranean belt, the travel path is beneath the Arabian Sea, while Peru event is beneath the South American plate at Central Andes along the Circum-Pacific belt. Places like Pakistan (eastern Mediterranean), southeast of Loyalty Island and Southern Sumatra Indonesia (Circum-Pacific belt) exhibit positive residual which is an active spreading centers. The temperature regime of the upper mantle in these regions must therefore be “hotter” than for normal upper mantle which would account for the delay in travel times (positive residuals). On the other hand, the process taking place in the Circum-Pacific belt, involves collision of the Pacific plate and the Indonesian-Australian plate, also the collision of the Nazca plate and the South American plate along the Central Andes. This could well lead to the presence of high velocity slabs in the upper mantle resulting in the faster travel paths (negative residuals) for this region.

For further explanation of what causes the variation in values obtained from the travel time residual of each region, certain fact have to be looked into in order to make judgments concerning what causes variation in the value of the residual time. We will take a look at the Hess (1962) hypothesis of the sea floor spreading of the deep mantle convection, mid oceanic ridges and the oceanic trenches. Hess's driving force original hypothesis was that sea floor spreading is driven by deep mantle convection. Convection is a circulation pattern driven by the rising of hot material and / or the sinking of cold material. Hot material has lower density so it rises; cold material has a higher density and sink. In the mid oceanic ridges, Hess showed that the existence of the ridge and its high heat are caused by the rise of this hot mantle rock. The basalt eruptions on the ridge crest are also related to the rising rock, for here the mantle rock is hotter than normal and begins to undergo partial melting. As hot rock continues to rise beneath the ridge crest, the circulation pattern splits and diverges near the surface. Mantle rock moves horizontally away from the ridge crest on each side of the ridge. This movement creates tension at the ridge crest, cracking open the oceanic crust to form the rift valley and its associated shallow focus earthquakes.

Also in the oceanic trenches the mantle rock moves horizontally away from the ridge crest it carries the sea floor (the basaltic oceanic crest) piggy-black along with it. As the hot rock moves sideways, it cool and becomes denser, sinking deeper beneath the ocean surface. Hess though it would be cold and dense enough to sink back into the mantle. This downward plunge of cold rock gives an account for the existence of the oceanic trenches as well as their low heat flow values. It also explain the larger negative gravity anomalies associated with trenches, for the sink of the cold rock provided a force that holds trenches out of isostatic equilibrium. As the sea floor moves downward into the mantle along subduction zone, it intercept with the stationary rock above it. This interaction between the moving sea floor rock and the stationary rock can cause the benioff zones of earthquakes associated with trenches. It can also produce andesitic volcanism, which forms volcanoes either on the edge of a continent or in an island arc.

This scenario suggested above satisfy observations which are predicted by the concept of plate tectonics. Further still, it explains why the positive residual for paths beneath the Arabian Sea is much lower than those paths beneath the Indian-Australian region. The spreading rate in the Indian-Australian region estimated at an average of 2.0cm/year (Gaina *et al.* (2007) is twice the value of 1cm/year estimated on the axis of the Arabian Sea (Mckenzie *et al.*, 1970). If the source of the heat is of the lower mantle as other evidence suggests (Morgan, 1972) and if both regions have comparable heat sources. It follows that more heat must be dissipated in the Indian-Australian region of Southern Sumatra Indonesia (Circum-Pacific belt) where the spreading rate is faster. The upper mantle in the Indian-Australian region must therefore remain colder than that in the Arabian Sea which explains the faster travel times and lower positive residuals observed for the former region. Plans are underway to test this hypothesis by investigating other spreading centers.

Conclusion

This study was embarked upon with the aim of determining the quality of the seismic data that are acquired at SRL, OAU, Ile-Ife, Nigeria. The residual time of all the arrival time for six (6) events (from Tonga, Pakistan, Minahasa-Sulawesi-Indonesia, Southeast of the Loyalty Island, Southern-Sumatra-Indonesia and near the coast of Northern Peru) that were recorded at station were picked and analyzed using the Jeffreys-Bullen (JB) tables 1970. The result obtained for the six events that cover 50° to 90° showed that the values obtained for the residual time vary between -1.01s to +1.6s, indicating that the values obtained are very low i.e. a range greater than -1.0 s to less than 1.2s. Due to the very low values obtained from the analyzed travel time residual shows that the data sets are of good quality. Furthermore, the time taken for the P-wave of an event to reach the seismic station are always in seconds; this shows that the time taking for the P-wave travel time residual of each event was very fast in reaching the seismic station on campus irrespective of the various heterogeneous crustal mantles it passes through. The study therefore concluded that the data recorded at the SRL, OAU,Ile-Ife are of sufficiently reliable quality, and they satisfactory for usage in seismological analysis.

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