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# REASSESSMENT OF A REPORTED S-DELAY UNDER TRINDADE

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Abstact. We present a correction to a paper by Okal and Anderson (1975) about multiple ScS travel-time anomalies. We have reanalyzed data for $ScS_2$ surface bounces in the South Atlantic Ocean. From these data an $ScS_2$-S residual of 23.6 seconds was found by Okal and Anderson (1975). This corresponded to an $ScS_2$ surface bounce point under Trindade island and was inferred to be due to very slow upper mantle associated with the Trindade hot spot. The analysis we present here invalidates this conclusion. The nature of the upper mantle under Trindade is an open issue.

## Introduction

It is possible to use $ScS_2$-ScS time anomalies to estimate S travel-time heterogeneities in the upper mantle below the surface bounce point of $ScS_2$. The time difference between $ScS_2$ and ScS or S is obtained by cross-correlation of the two signals. The residual is the difference from the predicted time using Jeffreys-Bullen (JB) tables (1958). This method was used by Okal and Anderson (1975) -hereafter referred to as O&A- with data from the WWSS long period network. O&A obtained travel time residuals for bounces under continents and oceans. Among their numerous data, one is of special interest both because it gives the largest delay and because it corresponds to the unique case of a surface bounce under a 'hot spot'. Indeed O&A found an 11.8 seconds one-way travel-time residual corresponding to an $ScS_2$ surface bounce point under Trindade island in the South Atlantic Ocean (see figure 1). Trindade's volcanism is as young as 1 million years ,and extremely silica undersaturated,suggesting origin from a hydrous mantle (Oversby,1971;Valencio and Mendia,1974). This led O&A to propose that the large S delays which they observed were due to reflection in a very slow upper mantle, possibly indicating a higher degree of partial melting under the hot spot. In this paper we present a detailed analysis of the data O&A used to reach this conclusion. We show that for the South Atlantic data points O&A used the SV component instead of the SH component. In fact,the stations used are on a node of the SH radiation pattern. Besides the fact that waveform distortion might occur on the SV component,we show that in this particular case the first arrival corresponds to the interference of three phases; SKS,S and ScS. Moreover we examine seismograms for stations further east and show that the phase which O&A used in their cross-correlation is not $ScS_2$. Therefore these data cannot be used to determine the nature of the upper mantle under Trindade, which remains an open question.



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## Data

We use the same data as O&A; two deep Peruvian events recorded at two South African WWSSN stations. In addition,we also use seismograms recorded at two other stations further east. The parameters of the two earthquakes and of the four stations are given in Table 1 and Table 2. The two events produce almost identical seismograms at the South African stations. This is not surprising as the two events are only a few kilometers apart and have almost the same focal mechanism as determined by Isacks and Molnar (1971) and shown in figure 2. O&A find the same residuals from both events. Our analysis applies equally to both events. Figure 3 shows the rotated seismograms recorded at WIN and SDB at times corresponding to S and $ScS_2$ arrivals. The horizontal components are within 8 degrees of being naturaly rotated. The tangential component is almost the NS seismogram (with opposite sign) and the radial component is almost the EW seismogram.

## Analysis

We observe that the SH (tangential component) arrival is very weak. This is in good agreement with the SH radiation pattern for the given focal mechanism. Therefore O&A used the SV signal in their cross-correlation. The problem is that at these epicentral distances three phases (SKS,S and ScS) arrive almost together on the radial component. For the SV component (radial) the focal mechanism predicts a strong negative first

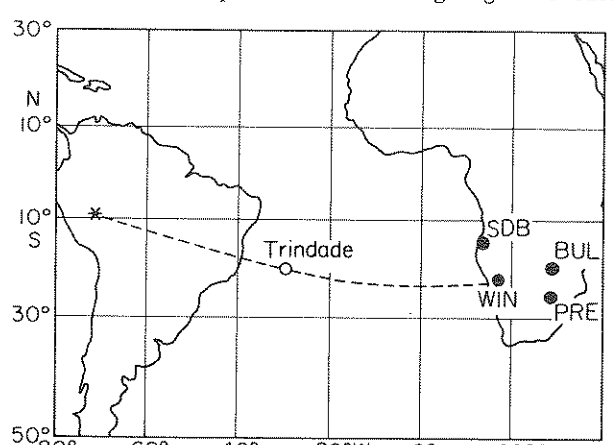


Figure 1 : Map of the South Atlantic showing the location of the Peru-Brazil events,of the four African stations used and of the Island of Trindade. Also drawn is the ray from the epicenter to station WIN.

TABLE 1 : parameters of the two Peruvian earthquakes from the ISC catalogue

| date | origin time,UT | latitude | longitude | depth,km | magnitude |
|---|---|---|---|---|---|
| Nov 3 1965 | 01h39m03.2s±0.092s | 9.04°S±0.022° | 71.32°W±0.032° | 587±4 | 5.9 |
| Feb 15 1967 | 16h11m11.8s±0.25 s | 9.05°S±0.020° | 71.34°W±0.024° | 598±3 | 6.1 |

arrival for S. At station WIN the first arrival is positive, corresponding to the arrival of SKS which has a sign opposite to S. It is then followed by the S phase which gives the major negative peak. Then the ScS phase arrives with a sign opposite to S. The presence of ScS is clearly expressed as it splits the large positive peak at SDB. Our interpretation is consistent with the JB times and the predicted amplitudes, as shown by the arrows on figure 3. Our main conclusion at this point is that the shape of the SV arrival is due to the interaction of three phases. It is therefore very different from the shape the S phase would have alone. Cross-correlation with the $ScS_2$ signal would thus lead to spurious results. The cross-correlation performed by O&A was not rejected by the quality test they applied because the first arrival and the signal they identified as $ScS_2$ are somehow similar in shape. Figure 4 shows the correlation found by O&A at stations WIN and SDB. The '$ScS_2$ - S' time thus obtained is 790.5 seconds for WIN yielding a 23.6 seconds delay when compared to JB times (corrected for ellipticity and elevation). For SDB one finds '$ScS_2$-S' = 768.0 sec which gives a -3.9 sec residual (see Okal ,1978). From these results it was deduced that a very slow upper mantle (+11.8 sec one way residual) was under the $ScS_2$ surface bounce point corresponding to the ray recorded at WIN. This bounce point turned out to be very close to Trindade island,whereas the path

TABLE 2 : parameters of the stations for the Peruvian earthquakes

| name | epicentral distance | azimuth | back azimuth |
|---|---|---|---|
| SDB | 82.84° | 104° | 263° |
| WIN | 85.15° | 112° | 262° |
| PRE | 94.58° | 117° | 258° |
| BUL | 96.13° | 111° | 258° |

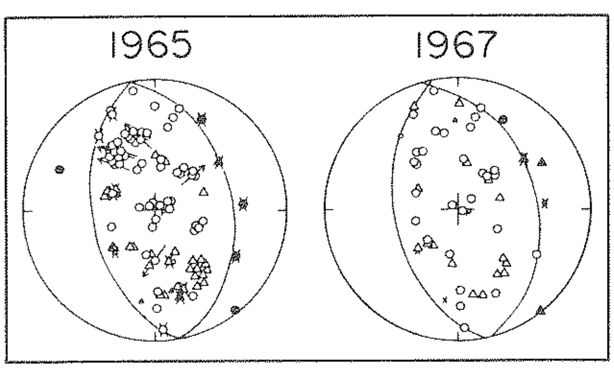


Figure 2 : Focal mechanisms for the 1965 and 1967 events as determined by Isacks and Molnar,1971.

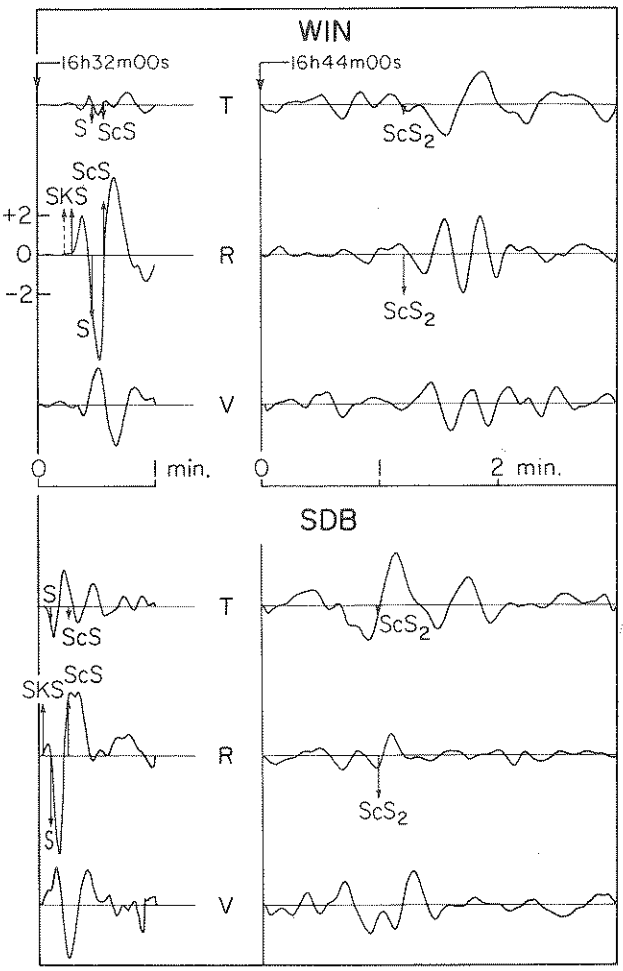


Figure 3 : Rotated seismograms for the 1967 Peru-Brazil event recorded at South African stations WIN and SDB. The amplitude and time scales are the same for all the records. The vertical scale is given in centimeters : it is the amplitude recorded on the WWSSN Long Period instrument of amplification 1500. T,R and V stand for Tangential, Radial and Vertical respectively. The sign convention is as follows : positive for a tangential displacement clockwise around the source ; positive for a radial displacement away from the source ; positive for a vertical displacement upwards. Arrows are drawn to indicate JB arrival times (corrected for ellipticity) of SKS,S,ScS and $ScS_2$ phases. The algebraic length of each arrow is proportional to the normalized amplitude deduced from the focal mechanism. For SKS, JB times have been increased by 4 seconds,following Hales and Roberts, 1970. The dashed arrows indicate the JB arrival time for SKS.

to SDB was inferred to be far enough north to avoid the apparent anomaly.

Having shown that the cross-correlation method cannot be used in this case to determine the $ScS_2$ travel-time, we could try picking directly the $ScS_2$ onset time. Unfortunately, we find that the signal which O&A identified as $ScS_2$ is actually not $ScS_2$. This is proved by figure 5, which shows the EW seismograms at stations SDB, WIN, PRE and BUL on an epicentral distance versus time plot. The wave packet that O&A identified as $ScS_2$ at SDB and WIN is present at the stations PRE and BUL further east. The $dT/d\Delta$ slope of the phase arrival is much steeper than the one $ScS_2$ would have. It is indeed close to the slope of an sSSS or SSSS phase. Our best interpretation is that the energy arriving at $ScS_2$ time at WIN consists principally of sSSS and SSSS energy and not of $ScS_2$ energy. This explains why SDB and WIN yielded very different '$ScS_2$' residuals in the interpretation proposed by O&A. The $ScS_2$ signal is very small at PRE and BUL because the reflection coefficient on the core is small for the SV component due to P conversion into the core. We should not expect it to be large at WIN or SDB either. On the other hand, at these epicentral distances, sSSS and SSSS are amplified by the upper mantle triplications (Grand and Helmberger, 1980). Figure 5 shows that the amplitude of these phases gets almost as large as that of sSS and SSS, which they resemble in shape and frequency content.

## Discussion and Conclusion

We have shown that the interference of three phases (SKS, S and ScS) in the 'S' arrival is responsible for its complex shape. Therefore the cross-correlation performed by O&A does not give the arrival time of $ScS_2$. In fact there is no visible $ScS_2$ arrival at WIN or SDB. The phase that O&A identified as $ScS_2$ is probably sSSS+SSSS instead. This should not, however, affect other results given by O&A, in particular those concerning ScS delays at KIP, Hawaii : KIP delays were station delays, obtained by correlation with other stations whose station corrections were known, and mostly from events with vertical dip-slip focal mechanism, favoring downward S radiation, and therefore ScS and its multiples. The cross-correlation method applied to multiple-ScS timing should be restricted to SH records and to distances smaller than 70 degrees, as indicated by Sipkin and Jordan (1976). However, as shown by Okal (1978), the O&A data set is not systematically biased by the replacement of ScS by S at large distances. This is due to the predominant number of SH records used. As a consequence, the present discussion does not invalidate the principal conclusions of the O&A paper. However, it clearly indicates that the believed anomaly under Trindade was erroneous : the present data set cannot be used to help resolve the nature of the upper mantle under this oceanic hot spot, which remains an open issue.

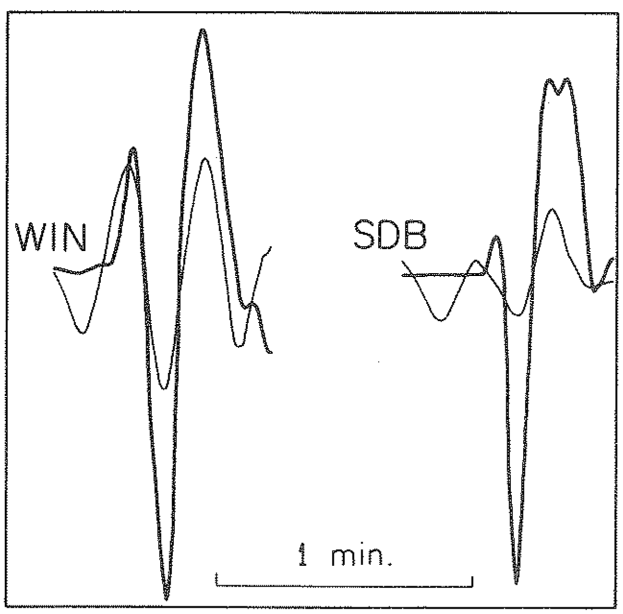


Figure 4 : Superposition of the 'S' (thick line) and '$ScS_2$' (thin line) signals on the radial components at WIN and SDB using the time interval obtained from cross-correlation by Okal, 1978.

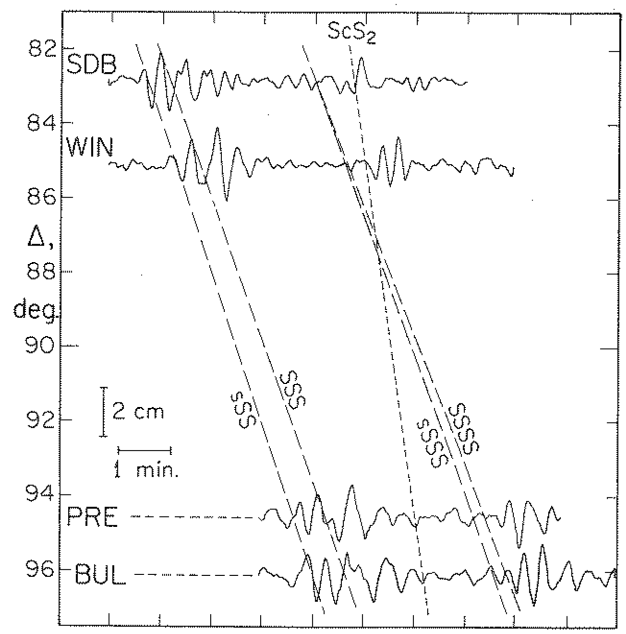


Figure 5 : EW seismograms for the 1965 event. All the instruments are 1500 gain Long Period WWSSN seismograms. The amplitude is given in centimeters. The origin time in the figure is 28 minutes after the earthquake. Arrival times calculated from JB tables are indicated for sSS, SSS, sSSS, SSSS and $ScS_2$.

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