TWO-STATION PHASE VELOCITY DETERMINATION FOR STRUCTURE IN NORTH AFRICA

Shannon Hazler*, Michael Pasyanos, William R. Walter, and Anne Sheehan*

Lawrence Livermore National Laboratory
Geophysics and Global Security Division, Livermore, CA

University of Colorado at Boulder*

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ABSTRACT

The seismic structure of North Africa is poorly understood due to the relative paucity of stations and seismicity when compared to other continental regions of the world. A better understanding of the velocity structure in this area will allow improved models of travel times and regional phase amplitudes. Such models will improve location and identification capability in this region, leading to more effective monitoring of the Comprehensive Nuclear-Test-Ban Treaty. Using regional-to-teleseismic Rayleigh and Love waves that traverse the area we can obtain information about the region's seismic structure by examining phase velocity as a function of period. We utilize earthquakes from the tectonically active regions bounding North Africa (Mediterranean, Red Sea, East African Rift, and Mid-Atlantic Ridge) recorded at broadband seismic stations distributed throughout the region. A two-station method is utilized to determine phase velocity information along the interstation segment of the ray path. The two-station method provides particular advantage in this region as it dramatically increases the number of events available to provide pure North African sampling. Bandpass filters are applied to the seismograms so that peaks and troughs may be correlated. The phase is unwrapped and a difference curve computed. The difference curve is then converted to a phase velocity dispersion curve. Phase velocity curves are constructed in the range of 10 to 120 seconds. Rayleigh and Love waves in this period range are most sesitive to the shear velocity structure of the lithosphere and can be used in combination with additional independent seismic observations (e.g. Pn tomography, surface wave group velocity tomography, receiver functions, etc.) to construct reliable velocity models. We compare velocities computed in this study to those generated from well known models for similar tectonic regions throughout the world in order to better define the tectonic setting of North Africa. Results from this study help constrain the regional tectonics of the area and will also be used to better define the seismic characteristics required to verify the CTBT.

Key Words: Surface waves, phase velocity, structure, Africa

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OBJECTIVE

North Africa has been only sparsely sampled both geologically and seismically; yet knowledge of regions such as this is critical for CTBT monitoring purposes. In an effort to fill in the gaps present in our knowledge of the seismic structure of Northern Africa, a study of the shear wave velocity structure beneath this region has been undertaken (Hazler, 1998; Pasyanos et al., 1999). Previous work in this vein has focused on single station group velocity measurements. We have implemented a study of phase velocities in North Africa and the Middle East to augment the knowledge accrued from the ongoing group velocity study at Lawrence Livermore Laboratory. The goals of this phase velocity study are to improve both 1-D models shear velocity versus depth for particular paths as well as the 3-D shear velocity structure of the region. The increased understanding of the regional tectonic setting and shear velocity structure provided by these surface wave studies will better define the seismic characteristics needed to properly monitor the Comprehensive Nuclear-Test-Ban Treaty (CTBT). In particular, increased knowledge of seismic shear wave structure will lead to improved detection, location, and identification capabilities in the region.

RESEARCH ACCOMPLISHED

Paths Chosen

A search was made for pairs of seismic stations whose back azimuths to a given earthquake differed by three degrees or less. Broadband three-component stations from the IRIS/GSN, MEDNET, and GEOSCOPE networks were included in the search. Seismograms from earthquakes between the years 1977-1999 of magnitude 4.5 and greater with great circle paths crossing North Africa or the Middle East were included in the search. A total of 60,559 possible two station pairs were retrieved. Figure 1a depicts the coverage which these paths would provide. A subset of these paths have been examined at this date. The paths presented here are depicted in figure 1b.

Measurement Technique

To make a phase velocity measurement, the raw data are demeaned and detrended, and the instrument response is removed from all seismograms. For each pair of Rayleigh wave records, a Fourier transform is performed, the phase information is unwrapped, and a phase difference curve is computed; the phase difference curve is then converted to a phase velocity curve using the following equation: $\psi_1(\omega) - \psi_2(\omega) = \omega(t_1 - t_2) - \omega(c(\omega))^{-1}(x_1 - x_2) + 2\pi M$, where $c(\omega)$ represents phase velocity, x_1 and x_2 refer to the positions of the stations, t_1 and t_2 refer to the start times of the two records, $\psi_1(\omega)$ and $\psi_2(\omega)$ represent the phase information in each record, and M is an integer describing the number of cycles the surface wave has undergone in its travels. A suite of potential phase velocity curves is computed for several possible values of M and the appropriate dispersion curve is chosen from this suite. For ease of display, phase velocity curves along the same path were averaged and are pictured here with the region bounded by one standard deviation from the average (Figure 3, 4, and 5).

Error Sources

The two factors which have most contributed to the errors inherent in this study are scattering and inaccurate source information. Scattering occurs when an incoming seismic ray encounters a geologic feature, most often crustal, which changes the ray's path so that it deviates from the path predicted by the ray tracing method employed in a given study. The errors associated with this scattering effect are due to the observer's choice of an assumed path which deviates from the true path of the seismic wave. Errors can also result from inaccurate source information particularly origin time and source location. By examining phase velocity curves which demonstrate reversed propagation direction, one can gain insight into the influence of these error sources on the dispersion curve. Seven of the nine two-station pairs examined in this study contain reversed paths. These reversed paths are visually indistinguishable from phase velocity curves representing forward propagation. The repeatability of measurements along a single path can also provide some understanding of the degree to which these error impact phase velocity measurements. An example of the phase velocity curves measured along a single path, TAM to DBIC, is presented in figure 3.

Discussion

Figure 2 depicts generalized geologic divisions in North Africa. The path from TAM to DBIC samples a large amount of shield material, the West African Craton, and lithified sedimentary material [Bertrand-Sarfati et al, 1991; Cahen and Snelling, 1984; Rocci et al, 1991]. Unlithified sediments are minimal along this path. The phase velocities in figure 3 reflect this geologic setting. The curves obtained along this path display uniformly high velocities which conform to a high velocity shield body. High phase velocities can also be found in figure 4a which depicts the results from the KEG to ATD path. The high velocities at short periods probably reflect travel off the assumed path through the fast oceanic material in the Red Sea. At longer periods, high velocities can be linked to the crystalline material of the Nubian Shield (Goodwin, 1996). Figure 4b depicts results for the KEG to TAM path. This path crosses the East African Craton which is largely covered by the sediments of the Sahara (Condie, 1982). The thickness of these sediments is reflected in the slow phase velocities at short periods. At longer periods, the curves demonstrate the fast velocities common to cratons.

In figure 4c, we move away from cratons and shields and into a regime dominated by old orogenic belts. The path from TAM to BGCA demonstrates slower phase velocities at longer periods than the paths which sample shield material. Low velocities are also displayed at short periods reflecting the unlithified fluvial deposits as well as Saharan sediments (Petters, 1991). Figure 4d shows results from the ATD to BGCA path. This path samples the Central African Belt, the Mozambique Belt, as well as the northern-most extent of the East African Rift (Goodwin, 1996). Again, we see velocities slower than those presented in shield dominated paths. These curves display faster short period results which are indicative of the small amount of unlithified sediment sampled along this path.

Figure 5a depicts the results for the path from ATD to ABKT. This path samples the thick sedimentary basins of Saudi Arabia as well as an active orogenic belt. Both of these features result in strikingly low velocities at short periods. At longer periods, velocities are comparable to those found along the previously discussed shield poor continental paths. Figure 5b examines results from the TAM to PAB path. This path samples a moderate amount of unlithified sediments and minimal amount of shield material. The curves produced along this path return to the pattern established by the other shield poor continental paths. Figure 5c shows results from the DBIC to BGCA path. This path samples shield material, unlithified fluvial sediments, and an old orogenic belt (Cahen and Snelling, 1984). This geologic hodgepodge results in phase velocity curves which appear to be closer to the results from shield poor continental paths than results from paths dominated by shield material.

Figure 5d depicts the results from the path linking ATD and KMBO. This paths samples the edge of the East African Rift. Specifically, the path samples faulted material belonging to the Mozambique Orogenic Belt which dates to the Proterozoic. At the uppermost crustal level, this material is interfingered with largely alkaline volcanics implaced during the rifting process beginning in the mid-Tertiary [Sandvol et al, 1998; Cahen and Snelling, 1984; Tesha et al, 1997]. These extrusive volcanics are believed to be underlain by magmatic intrusions at the middle and lower crustal level (Petters, 1991). Like most of East Africa, this region is covered by Phanerozoic sediments. At longer periods, this path displays the slowest phase velocities found in this study. These velocities are not as slow as those calculated from Priestley and Brune's (1978) model of the Basin and Range. At short periods, (30 seconds and lower) the phase velocities are comparable to those found for non-shield continental regimes.

Knox et al. (1998) demonstrate the potential power of phase velocity information in conjunction with such numerical techniques as the grid search method. Using a grid search method, Knox et al. found a significant negative shear wave velocity gradient at 100 km depth beneath the Afar triangle and linked this low velocity zone to a thermal anomaly. As our phase velocity study proceeds, it is hoped that similar methods will allow our group to develop a coherent picture of the 1-D shear velocity structure which lies beneath the paths described in this paper.

CONCLUSIONS AND RECOMMENDATIONS

In this study we find that phase velocities at short periods are strongly controlled by the presence or absence of sedimentary basins. The variation produced by different amounts of unlithified sediments along a path can be seen in the TAM-DBIC path and the KEG-TAM path. These paths both sample cratonic bodies. The TAM-DBIC path contains little sediment cover and has higher short period phase velocities; while the KEG-TAM path contains substantial amounts of unlithified sediments and has slower short period phase velocities. Our results from the ATD to KMBO path, an active tectonic path, show the slowest long period velocities in this study. This may indicate the presence of a large low velocity body; however, the geometry of this path does not provide optimal sampling of the East African Rift. Results for paths which sample shield material (TAM-DBIC, KEG-TAM, and KEG-ATD) return the highest phase velocities.

Future work on this project will include an expansion of the dataset so that measured paths may closer reflect the coverage displayed in figure 1a. As crossing path coverage improves, the dataset will be used as the backbone of an inversion for 3-D shear velocity structure. The 3-D inversion will also utilize other datasets such as group velocity data. On a smaller scale, phase velocity information will be inverted with group velocity information to produce a 1-D model of shear velocity.

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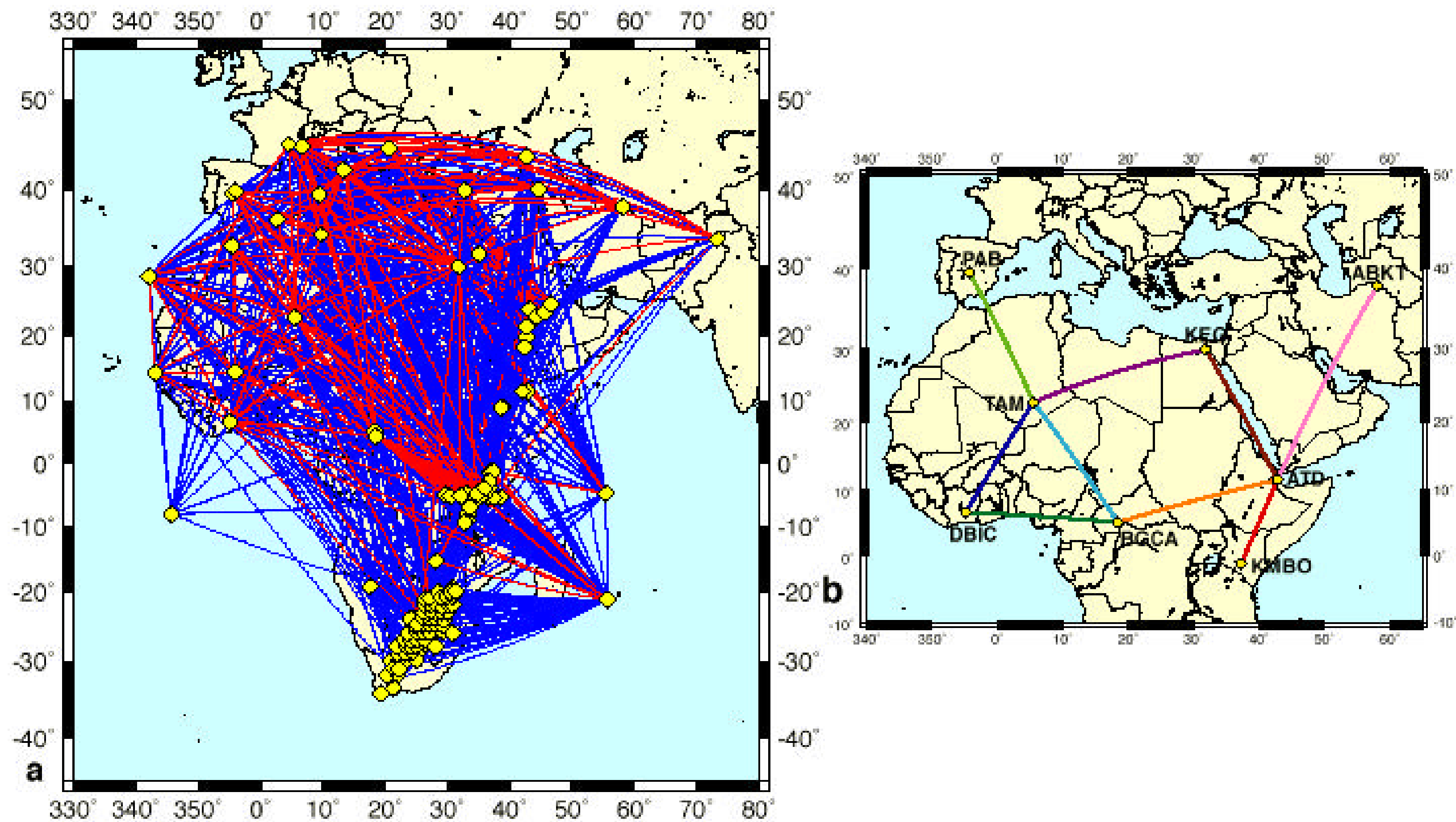

Figure 1. Panel a shows the 60,599 possible two station pairs which have been identified by searching against the CMT catalog. Paths which are returned represent two station pairs whose back azimuths to a given earthquake differ by three degrees or less. The search notes the on and off dates for each broadband seismic station in an effort to significantly reduce false returns. Panel b depicts the broadband seismic stations (diamonds) and the great circle paths which are examined in this study.

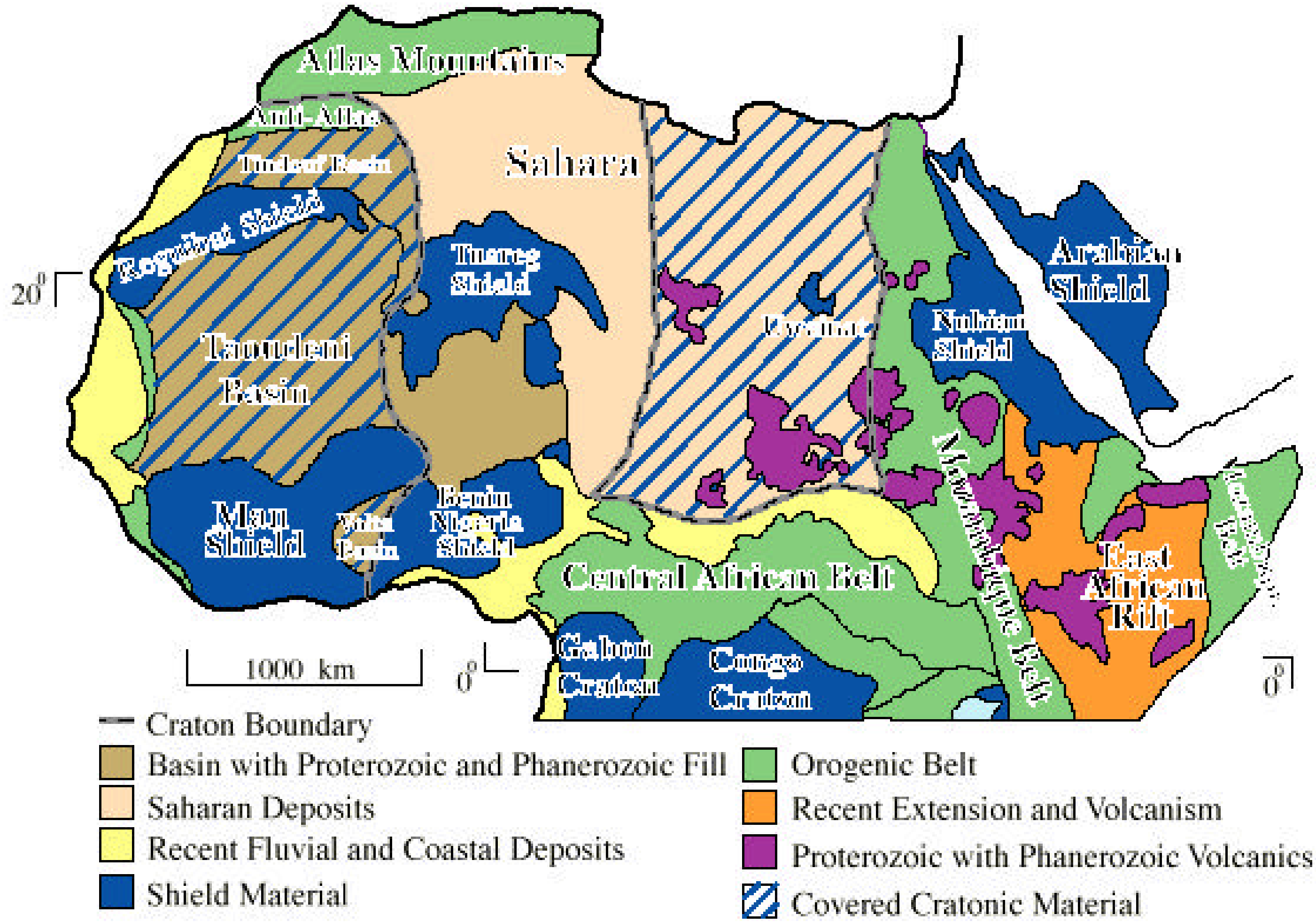

Figure 2. Generalized geologic divisions of North Africa. Major divisions include shield material, covered cratonic material, basins filled with Proterozoic and Phanerozoic sediment, Saharan deposits, recent fluvial and coastal deposits, orogenic belts, regions of recent extension, and Proterozoic regions with Phanerozic volcanics. After Goodwin (1996).

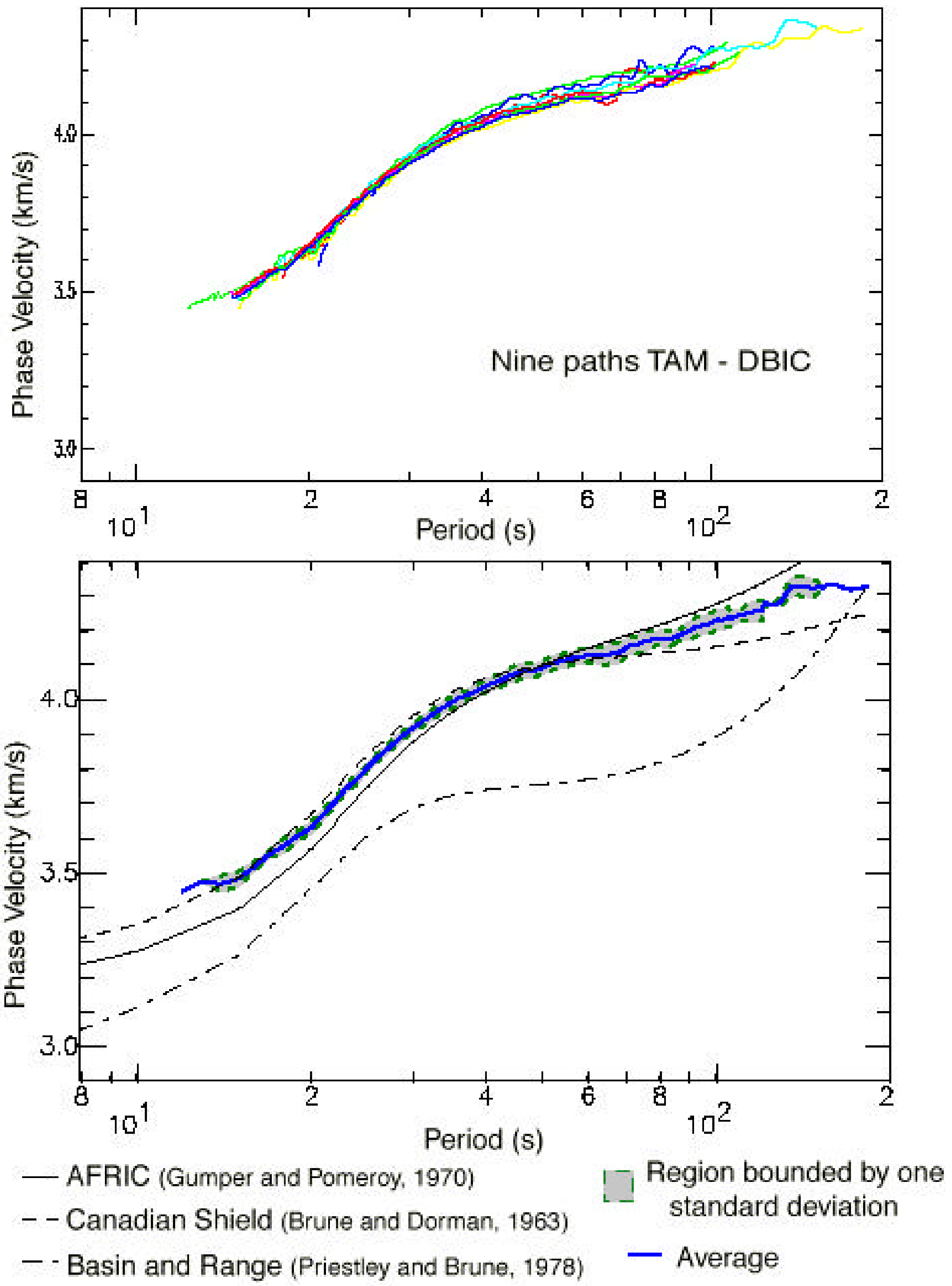

Figure 3. The upper panel shows nine phase velocity curves which were measured along the great circle path between the seismic stations, TAM and DBIC. Three of these curves represent a reversal of propagation direction. The lower panel depicts the average of these curves as well as the region bounded by one standard deviation. The averaged results found in this study are compared to phase velocity curves calculated from three reference models; AFRIC (Gumper and Pomeroy, 1970), Canadian Shield (Brune and Dorman, 1963), and Basin and Range (Priestley and Brune, 1978).

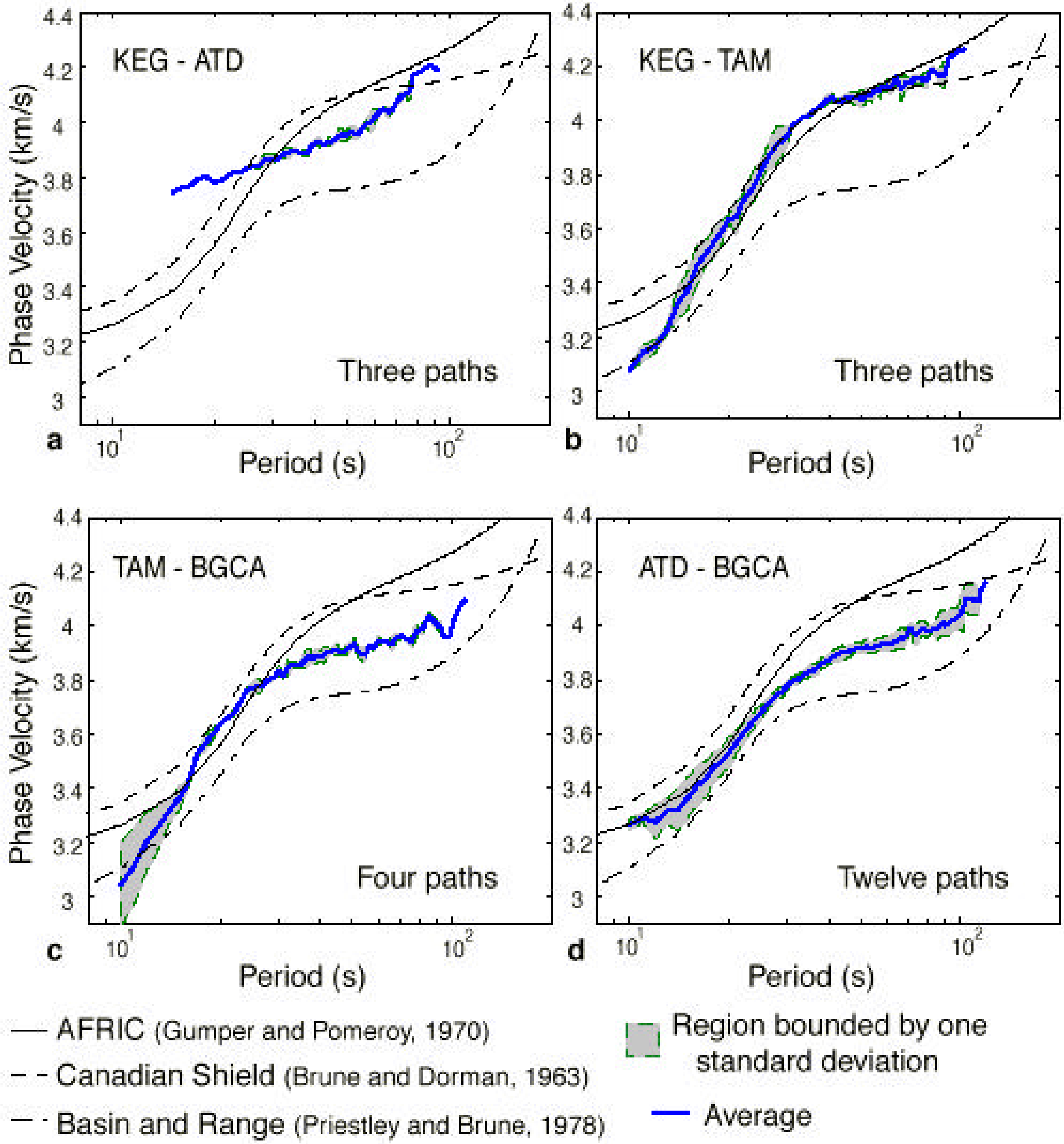

Figure 4. Panel a shows the average of the three phase velocity curves calculated between the broadband seismic stations, KEG and ATD. One of these curves represents a reversal of propagation direction. Panel b depicts the average of the three phase velocity curves calculated between the stations, KEG and TAM. One of these curves represents a reversal in propagation direction. Panel c depicts the average of the four phase velocity curves calculated between TAM and BGCA. Two of these curves represent a reversal of propagation direction. Panel d shows the average of the twelve phase velocity curves calculated between the stations, ATD and BGCA. Five of these curves represent a reversal of propagation direction. The averaged results found in this study are compared to phase velocity curves calculated from three reference models; AFRIC (Gumper and Pomeroy,1970), Canadian Shield (Brune and Dorman, 1963), and Basin and Range (Priestley and Brune,1978)

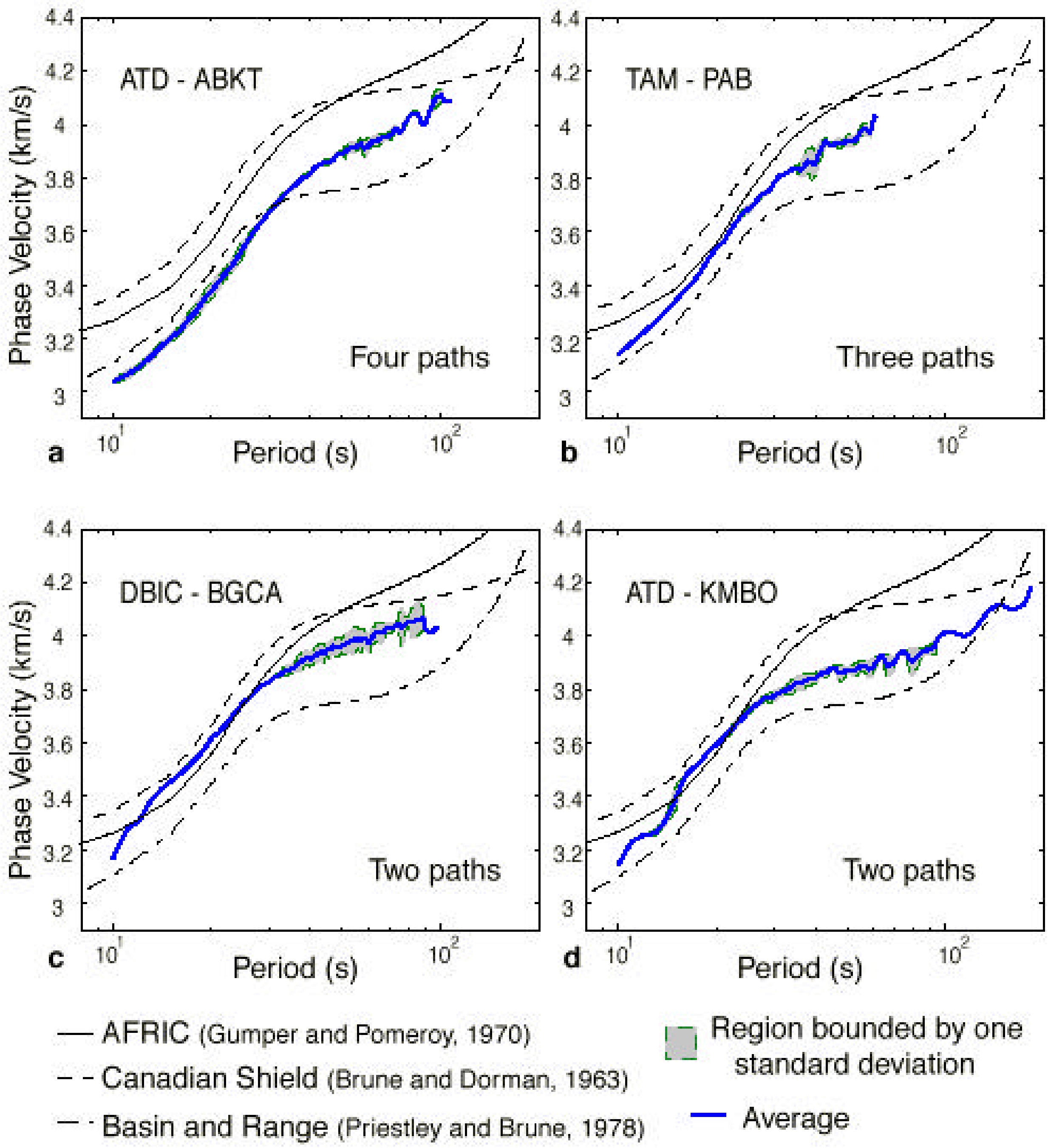

Figure 5. Panel a shows the average of the four phase velocity curves calculated between the broadband seismic stations, ATD and ABKT. Two of these curves represent a reversal of propagation direction. Panel b depicts the average of the three phase velocity curves calculated between the stations, TAM and PAB. None of these curves represent a reversal of propagation direction. Panel c depicts the average of the two phase velocity curves calculated between the stations, DBIC and BGCA. None of these curves represent a reversal of propagation direction. Panel d shows the average of the two phase velocity curves calculated between the stations, ATD and KMBO. One of these curves represents a reversal of propagation direction. The averaged results found in this study are compared to phase velocity curves calculated from three reference models; AFRIC (Gumper and Pomeroy,1970), Canadian Shield (Brune and Dorman, 1963), and Basin and Range (Priestley and Brune,1978)