New evidence for the asthenospheric origin of the Cameroon Volcanic Line from 1D shear wave velocities

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ABSTRACT

The composition of the lithosphere beneath Cameroon and the origin of the Cameroon Volcanic Line (CVL) are still debated by the Science Community. Although many studies based on regional or global observations provide good arguments for the setting of the CVL, none of them are strong enough to be considered as unique. In this work we used the joint inversion of Rayleigh wave group velocities and Rayleigh wave group velocities to provide shear wave velocity profiles of the lithosphere beneath Cameroon. Preliminary results show that lithosphere is, on average, faster beneath the Congo Craton than the Pan-African lithosphere beneath Cameroon. Due to the limited resolution of the dispersion curves, the maximum investigation depth was taken to be 200 km. The calculated velocity-depth profiles do not show any sharp discontinuity that could be interpreted as the lithosphere-asthenosphere transition. In addition there is no clear evidence of the existence of a low velocity zone beneath any geologic province within Cameroon. The smooth velocity contrasts observed on the velocity models are believed to be influenced by lateral mantle heterogeneities rather than vertical ones. The shear wave velocities for the uppermost mantle are in general greater than 4.3 km/s at all stations. This is higher than the values obtained in the Main Ethiopian Rift, and suggest that the lithosphere is not globally perturbed by thermal anomalies. This suggests that the source of volcanism along the CVL is from small scale convection in the asthenosphere and occucontrolled by lithospheric fractures that are probably driven by the cold (and fast) edge of the Congo Craton.

Key words: Cameroon Volcanic Line, Rayleigh wave group velocities, receiver functions

INTRODUCTION

The Cameroon Volcanic Line (CVL) in West Africa, formed across the Pan-African Proterozoic rocks, is an example of a geological features from which the internal evolution of the Earth can be inferred. It is a major geological feature that cuts across Cameroon from the southwest to the northeast. It is a unique volcanic lineament which has both an oceanic and a continental sector and consists of a chain of Tertiary to Recent, generally alkaline, volcanoes stretching from the Atlantic island of Pagalu to the interior of the African continent (Lee et al. 1994). The line has been recently investigated using earthquake seismology data (Tabod et al., 1992; Plomerova et al., 1993; Tokam et al., 2010; Reusch et al., 2010; 2011; Koch et al., 2012) in order to assess the tectonic evolution of the CVL.

The topography of the Moho over Cameroon has been estimated using 1D Vs models from the joint inversion of Rayleigh wave group velocities and receiver functions (Tokam et al., 2010). One of the main finding was that the presence of the CVL has not affected the overall bulk structure of the Precambrian crust. However, due to the limited resolution of the dispersion curves with periods greater than 60 s, the lithosphere was not investigated at depths greater than about 60 km.

In this study, we used a revised Rayleigh wave group velocity models of Raveloson et al. (in prep.) to refine the 1D shear velocity models using the same technique as in Tokam et al. (2010). The new 1D shear velocity models were well resolved up to depth 200 km. We determined the topography of the lithosphere, and inferred its composition and thermal state .

GEOPHYSICAL AND GEOLOGICAL SETTING

The first regional investigation of the structure of the lithosphere beneath Cameroon was been carried out using gravity data (Poudjom et al., 1995). The effective elastic thickness was estimated, which is basically the response of a plate to lateral density variations at the surface or within the plate. From their analysis, Poudjom et al. (1995) concluded that lithosphere is relatively weak beneath the CVL and other active rifts (the Benue trough and its extension in Cameroon as Garoua Rift) and strong beneath the Congo Craton.

Although this study shows the difference in mechanical behaviour of the lithosphere beneath the CVL and Congo Craton, it does not strictly map the base of the lithosphere.

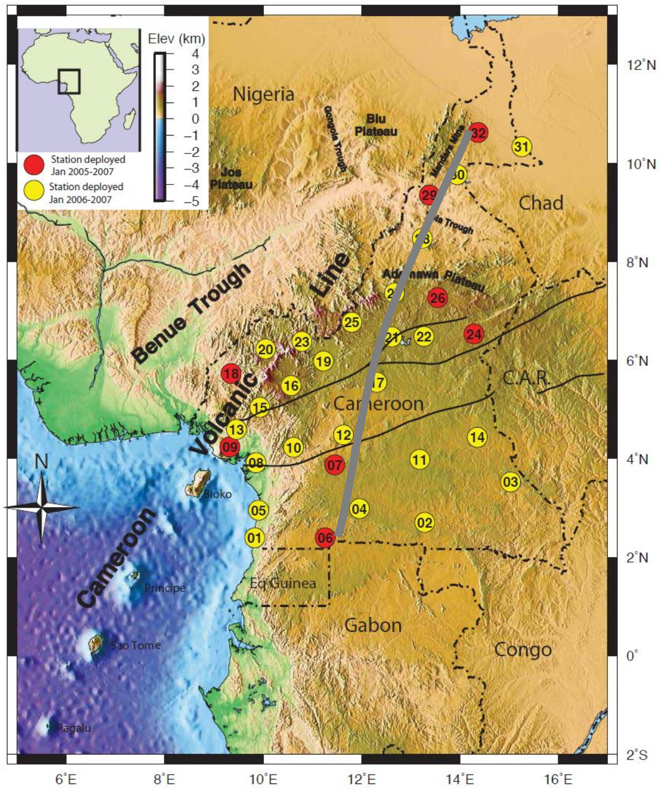


Figure 1: Location of the seismic stations used for this study. The grey thick line is the profile used for the cross section.

The first attempt to map the base of the lithosphere at local scale along the CVL was done by Plomerova et al. (1993). The authors used gravity data and teleseismic P and PKP arrivals times recorded by a network of 40 seismic stations deployed across the Adamawa plateau and Garoua Rift. Their results show a shallow lithosphere-asthenosphere boundary (about 120 km) beneath the Adamawa Plateau in the central part of the profile, and deeper elsewhere.

At continental scale, the lithospheric structure of Cameroon was deduced from various tomographic studies, including the works of Pasyanos and Nyblade (2007), Priestley et al. (2008) and Fishwick (2010). These studies generally indicate a thick lithosphere (about 250 km) beneath the Congo Craton and thinner lithosphere beneath the Pan-African Belt and Cameroon Volcanic line.

One way of mapping the thickness of the lithosphere is to determine the variation of the shear wave velocity with depth by inverting surface wave data. However, the estimation of lithospheric thickness from Vs(z) is not evident because the base of the lithosphere does not correspond to a step change in temperature or composition, and is therefore not strictly associated with a change in velocity (McKenzie and Priestley, 2008). Nevertheless, using the joint inversion of surface wave dispersion data and receiver functions, a Low Velocity Zone (LVZ) was identified beneath the East Africa Rift System (Julia et al., 2005), and inferences made regarding the mantle composition beneath Ethiopia and southern Brazil (Keranen et al., 2009; Julia et al., 2008).

Many petrological studies of ultramafic orogenic massifs and ultramafic xenoliths along the CVL (mainly around Mount Cameroon and the Adamawa Plateau) estimated the source of these xenoliths at 30-58 km depth in the Adamawa Plateau region (Nkouandou and Tenmdjim, 2011) and 40-70 km at other volcanic centres along the CVL (Lee et al., 1996; Matsukage and Oya, 2010). These observations provide additional evidencefor a weak lithosphere beneath the CVL. The composition of mantle xenoliths could also be used as a powerful tool to differentiate between both Archean and Proterozoic provinces (Durrheim and Mooney, 1994).

DATA AND METHODOLOGY

Rayleigh wave group velocities

Two competing Rayleigh wave tomography maps are available. The first one covering Africa and Arabia with a spatial resolution of about 200-300 km (Pasyanos et Nyblade, 2007), while the other, which is much more regional, focuses on the region covering Central Africa and the Southern Africa with a spatial resolution of ~100 km (Raveloson et al., in prep.). Single dispersion curves at each station from 7 to 100 s and 10 to 105 s were obtained respectively from the Pasyanos and Raveloson models. The curves were smoothed using a three-point running average before using them in the joint inversion. The comparison of both Rayleigh group velocity profiles at the different stations in Cameroon shows that both velocity curves are strongly convergent for periods <40s. The highest misfit between the two curves is about 0.1 km/s at this range. Meanwhile, for longer periods, the misfit increases up to 0.3 km/s at certain stations. This can be explained by two facts. First, the size of the cells in Pasyanos models is bigger and doesn't allow structures smaller than 200 km in width to be mapped. Secondly, the criteria used by Raveloson et al. (in prep.) to select events (only events within the African plate) is much more constrained and might be more efficient to map African Lithosphere. Therefore, for this study, we used a smooth version of both the Pasyanos and Raveloson group velocities for periods <40s and only the Raveloson models for periods of 40-105 s.

Rayleigh wave group velocities

Receiver functions are from obtained from Tokam et al. (2010). In order to average the effect of the lateral heterogeneities in the lithosphere, we use only the stations where at least two clusters of receiver function stacks were obtained. 28 stations out of 32 meet these criteria. The main back-azimuths covered by the stacks for all the stations are 80° and 240°, which are sensibly two opposite directions.

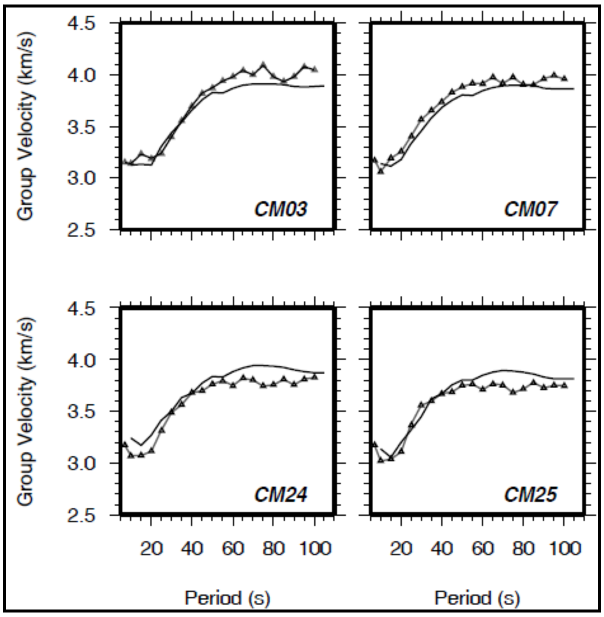


Figure 2. Comparison between Pasyanos and Raveloson dispersion curves at selected stations.

Joint inversion

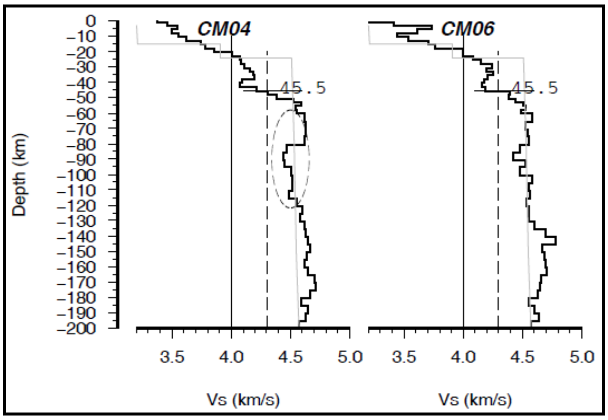
The joint inversion is conducted for 1D shear wave velocity models as in Tokam et al. (2010). It is based on a method developed and updated by Julia et al. (2000, 2008). For this study, stations CM02, CM08, CM09 and CM14 are excluded for further analyis. The model uncertainties are estimated using the same methology as in Tokam et al. (2010, are assumed to be not more than 0.2 km/s for crustal layers 0.3 km/s for the uppermost mantle layers..

RESULTS

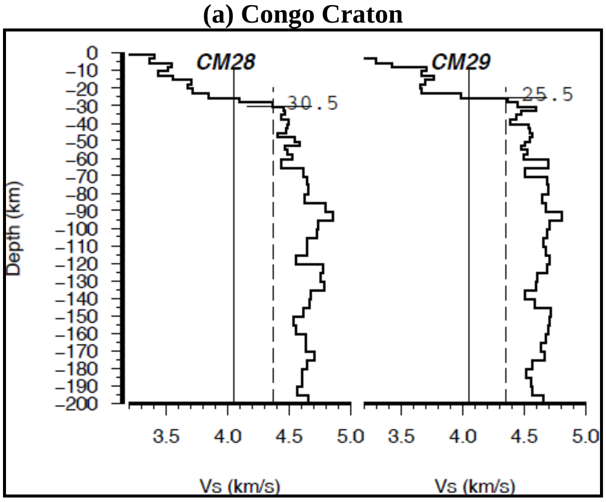
1-D velocity models

For the 28 stations used in the joint inversion, the results show good fit for both dispersion curves and receiver functions for all the stations. The better fit for long period dispersion curve suggests that the uppermost mantle is better resolved with the Raveloson dispersion curves.

The inverted models generally show a crustal part with Vs<4.3 km/s and upper mantle with Vs>4.3 km/s. At some stations and below 50 km depth (Figure 3), models show some features associated with a decrease of velocities in the mantle, which can be taken as the presence of a low-velocity zone (LVZ). Although, these features could be interpreted as LVZ, their presence could also be related to the influence of the lateral heterogeneities induced into receiver functions. Figure 3 shows the inverted model for the stations over the Congo Craton (Figure 3a) and Garoua Rift (Figure 3b). Vs generally varies between 4.5 and 4.7 km/s. Compared to the PREM model, the average of Vs between Moho and 200 km depths is about 4.6 km/s on Congo Craton, a little bit faster than in PREM. This value is about 4.5 km/s below the CVL and Garoua Rift. Although this average can indicate a difference in composition between the geological blocks, it did not point out the lateral variation of the lithosphere.



(a) Congo Craton



(b) Garoua Rift

Figure 3. 1D Vs models over selected stations

Lateral variation of Vs

To assess the evolution of the lithosphere within depth, the 1D velocity models have been used to construct contour maps of Vs within at various depths. Figure 4 (see end of paper) shows the lateral variation of Vs at depths 45, 90 and 150 km. At depth 45 km, which is the average Moho depth estimates for the Congo Craton, the lithosphere is faster beneath the Pan-African crust in the north (comprising the CVL and Garoua Rift) than beneath the Congo Craton (South). At this depth, the upper mantle structures are attained beneath the northern stations. Below this depth, the upper mantle is reached at all the stations and velocities are in the range of +/-2% compared to the reference value.

A cross-section over a profile crossing the Congo Craton, the CVL and the Garoua Rift basin (Figure 5) confirms the thinning of the crust from south to north. The lateral variation of Vs here suggests the presence of a higher velocity body (~4.6 km/s) beneath the CVL and Rift stations.

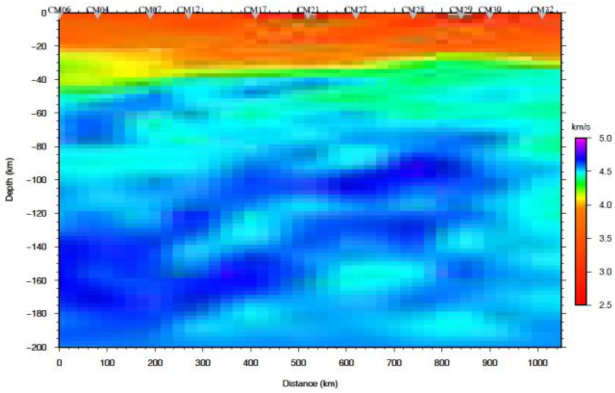


Figure 5. Vs cross-section across the Congo Craton (CM06-CM07), the CVL (CM17-CM28) and the Rift (CM29-CM32).

DISCUSSION AND CONCLUSIONS

Previous analysis on the structure of the crust made in the recent paper (Tokam et al., 2010) remains valid here. The location of the Moho discontinuity is perfectly matched with the results by Gallacher and Bastow (2011) at most of the stations. Assuming the crust is well constrained, we found in the 1D models that there is in general no sharp discontinuities that could be interpreted as lithosphere-asthenosphere transition. Many previous studies suggested Lithosphere is thicker than 250 km beneath Congo Craton, which is deeper than our resolved model (e.g. Fishwick et al., 2010); and as thin as 70 km beneath the Adamawa Plateau (e.g. Poudjom et al., 1997). The absence of a sharp velocity contrast is consistent with the fact that lithosphere-asthenosphere transition is not evident, since the base of the lithosphere does not correspond to a step change in temperature or composition, and is therefore not strictly associated with a change in velocity (McKenzie and Priestley, 2007). However, in the N-S cross-section (figure 6), a high velocity anomaly (Vs~4.6 km/s) appears beneath stations CM17-CM30, which cross the Adamawa Plateau. This anomaly is located at depth ~70 km, and at this depth, Poudjom et al. (1997) and Nnange et al. (2000) suggested an athenospheric uplift based on the interpretation of gravity data.

The average Vs in the Upper Mantle is in the range 4.4-4.7 km/s across Cameroon, which is relatively high compared to the East African Rift region where Vs has been found below 4.3 km/s using the same method (Keranen et al., 2009). In this area, the authors explain these anomalies by thermal anomalies in the lithosphere associated with the Rift development. This is not the case beneath the CVL and we suggest that, although the lithosphere has been perturbed by the asthenospheric uplift, the source should be located deeper in the asthenosphere. Pasyanos (2010), using dispersion curves from Western and Eastern Europe, shows that fast long-period group velocities (~4 km/s) are characteristic of thick lithosphere, while slower long-period group velocities (~3.5 km/s) are indicative of thinner lithosphere. At a period of around 100 s, the Rayleigh group velocity in Raveloson's model varies from 3.7 km/s at Pan-African (including CVL) stations, to about 3.9 km/s on Congo Craton stations. The gradient is no so large and may be additional evidence that the CVL anomaly across the Precambrian lithosphere is a localized feature that produced by a zone of weakness across the lithosphere rather than an internal process within the Lithosphere. This suggests that the source of volcanism along the CVL is consistent with the model of small scale convection in the asthenosphere and controlled by lithospheric fractures probably driven by the cold (and fast) edge of the Congo Craton, as suggested recently by Reusch et al. (2010; 2011).

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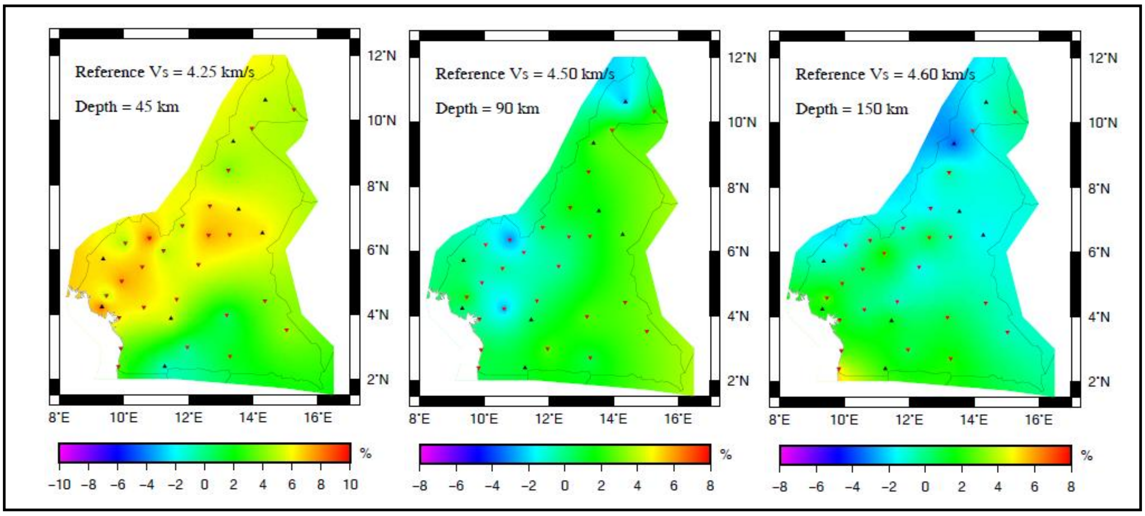

Figure 4. Spatial variation of Vs for depths 45, 90 and 150 km