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Upper Mantle beneath Tunisia from Joint Shear-Wave Splitting and Rayleigh Wave Dispersion Analysis

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Abstract **–** The current study aims to continue the analysis of the seismic anisotropy of Tunisia region and complete the previous studies of northwestern Africa, which helped to identify the deformations of the crust and the upper mantel, allowing us to obtain a geodynamic scenario for the southwestern Mediterranean. Tunisia is located on the boundary between the African and Eurasian plates. We used the method of splitting the shear wave SKS analysis of data from nine broadband seismic stations installed in Algeria, Tunisia, and the surrounding islands, Sardinia and Sicily, to explore the seismic anisotropy of this study area. We obtained 2D tomography of the shear wave velocity, Vs, structure of lithosphere and upper mantle depths ranging from 50 to 300 km using the Raleigh wave dispersion curve with the two-station technique in the 10-200 sec period domain. After analyzing hundreds of seismic data, we obtained the following results: multi-layer seismic anisotropy beneath TAMR and THTN seismic stations installed in northern Tunisia, while the southern station TATN has a single layer. The results of Vs-structure imaging of the second method also confirmed these results of the direction and depth of the deformed layers. Four distinct velocity bodies were found: two with low values (Vs is ~ 4 km/s) in the west and the east, and two with high values (Vs is ~ 5.5 km/s) in the north and the south of the study area.

Keywords – Seismic Anisotropy; Rayleigh Wave; Vs-Structure; Slab; Tunisia.

I. Introduction

The plate boundary between the Africa and Eurasia tectonic plates plays a great role in understanding the geodynamics in the western Mediterranean and the surrounding regions (Figure 1a). The boundary is due to the convergence between the Africa and Eurasia plates and translates to oceanic and crustal lithosphere deformation floating on and/or sinking in the upper mantle. For a precise spatial geometry of this boundary and its connection with the other boundaries of the global geodynamic, many techniques are used to image the lithosphere and the upper mantle in the Africa and Eurasia plate margins. In the present study, we compute three new seismic anisotropy measurements in the Tunisia region, using TAMR, THTN, and TATN stations (Figure 1a) in conjunction with dispersion curves derived from the two-station technique, using two stations from Algerian seismological stations of ADSN installed in northern-east Algeria, as well as TATN from the TT seismic network (in Tunisia) (Figure 1a). We investigated VSL (Sardina) and CLTB (Siciliya) stations on the east side of the Sicily Channel to create a tomographic image of Tunisia and the adjacent territories (Figure 1a).

The goal of this research is to examine the Vs-structure of the lithosphere and upper mantle using the most available ray routes, and then correlate it to anisotropy data to identify a relationship with the geodynamics of the western Mediterranean. In this investigation, we used teleseismic events from TAMR and THTN stations to compute seismic anisotropy using the available SKS splitting shear wave from [1] and SKS shear wave splitting dataset. The recorded Rayleigh wave dispersion curve is extracted using cross-correlation between selected station pairs from teleseismic events in the two-station technique.

II. Geological Framework

Geologically, three main domains cover the surface of the study area, from the north to the south are characterizes the study area: flesh domain, Tell domain, then the Tunisian Atlas [2]. The south Atlas front and Tell Atlas underline the contact between Tunisian Atlas and Saharan Platform by Maghrebides front [2]; Fig. 2). Reference [3] provide detailed geological and geophysical investigations for the ADSN stations of Fig 1a and 1D deep Vs-structure (crust and upper mantle) can be found in [4].

III. Method

In this section, we present the two techniques used for the computation of SKS shear wave splitting (seismic anisotropy) and the extraction of Rayleigh wave dispersion curve and its inversion to obtain the Vs-structure beneath the study area of Fig 1a.

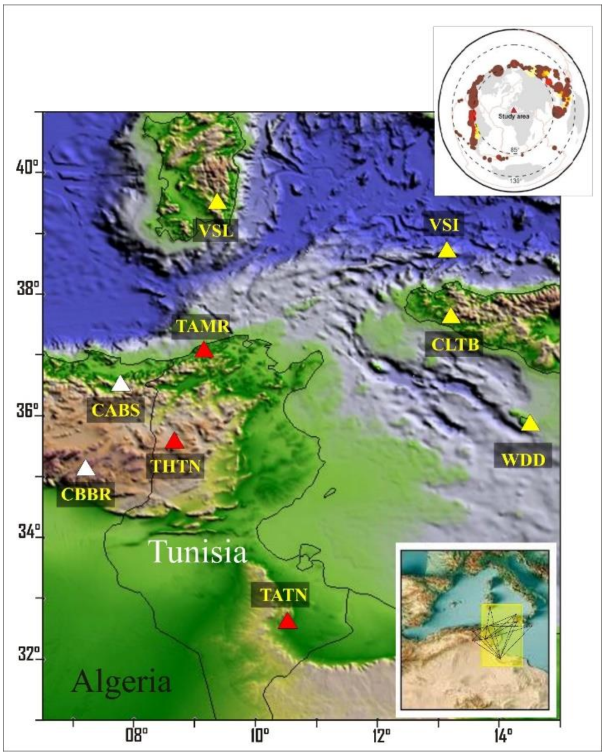

Fig 1: Geographical distribution of permanent stations of TT seismic network (in Tunisia) red triangles, tow station of ADSN (in Algeria) white triangles, and MN, IV seismic network yellow triangles.

A. *Seismic Anisotropy*

The teleseismic shear-wave splitting technique has been widely applied in the past decades for performing seismic anisotropy measurements that help reveal present or past mantle deformation processes (subduction zones, rifts, hotspots ... etc), and at scale atomic example [5], [6]. To obtain seismic anisotropy from shear-wave splitting of SKS phases, teleseismic events are taken with a minimum magnitude (Mw) 6.0 and epicentral distance (D) greater than 85°. Figure 1b shows the distribution of teleseismic events as a function of depth and epicentral distance. We use three methods for computing the two splitting parameters φ and δt, minimum energy (SC), eigenvalue method (EV) [7] and rotation–correlation (RC) [8] which are integrated in the SplitLab package [9]

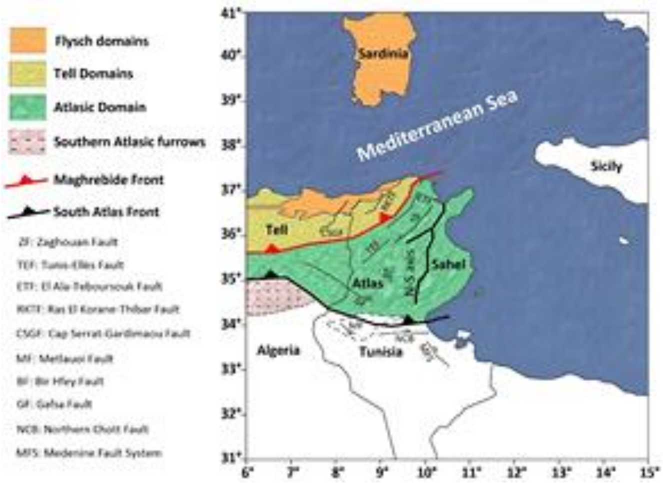

Fig 2: Map representing the main geological units of Northern Algeria inspired from [2].

B. *Rayleigh Wave Dispersion Curve Extraction*

Based on the concept that the output waveform recorded by one station is a convolution of the input waveform recorded by the second station, referred to as the reference station, and the unidentified filter, Vs-structure, comes the two-station technique. By measuring the phase travel time from the seismogram of the vertical component, Z, Fourier transform analysis can be used to determine the phase velocity.

The vertical component broadband seismograms from external stations installed in Tunisia (TAMR and TATN stations), Sardinia (CGL, VSL, and DGI stations), and from the Incorporated Research Institutions for Seismology are the data used in this study. In addition, they were obtained from the database of the selected permanent ADSN stations installed in the northeast Algeria region. The recorded vertical component waveforms were rectified by removing the instrumental responses using the TRANSFER command of the Seismic Analysis Code, SAC (Figure 3), with mean and trend corrections, due to the variation of the mentioned stations. Detailed processing on the TRANSFER command utilization can be found in [10].

A single phase velocity dispersion curve is obtained by merging group velocity dispersion curves with periods measured between two stations to determine the upper mantle phase velocity. In order to accomplish this, we used the [11] Computer Programs in Seismology Code Package. An optimized profile of the seismic 1D layered shear wave velocities of the upper mantle as a function of depth is produced by the iterative inversion code using the phase velocity dispersion curve taking into consideration the ak135 initial model of [12].

IV. RESULTS

The results of our analysis of seismic anisotropy of seismic stations installed in Tunisia region are plotted in Fig 3a for only the fast orientations of SKS waves. In Fig 3b, the fast orientation of Algeria region are taken from [1] and those of VSL and CLTB stations are from SKS shear wave splitting dataset (https://doi.org/10.18715/sks_splitting_database).

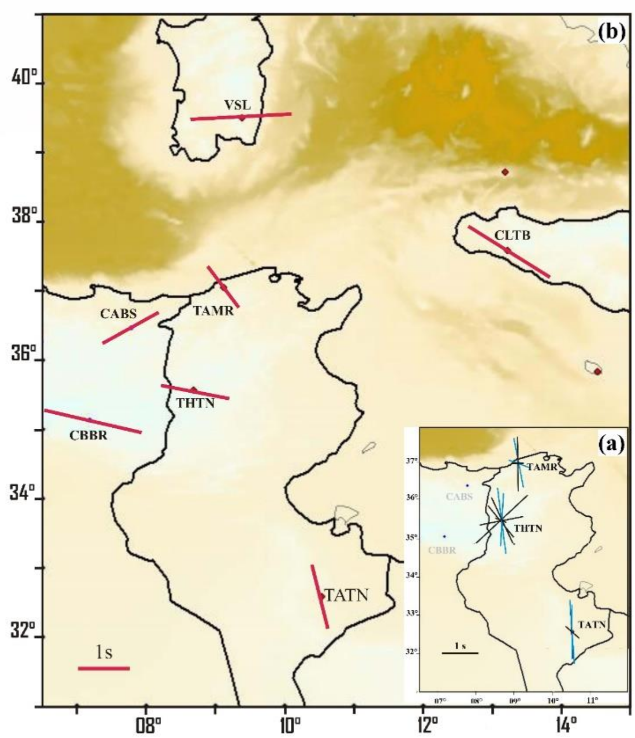

Fig 3: (a) Map showing the fast orientations of SKS waves plotted in Tunisia region, blue lines represent excellent quality and black line represents good quality. (b) Map showing the mean fast orientations of SKS waves plotted in study area of the considered stations.

The calculated 1D models beneath each station (example in [13]) are interpolated to create the 3D model and shown in Fig 4 for 50, 100, 150 and 200 km.

V. DISCUSSION

The average fast orientation of CABS and TAMR stations are the smallest compared to the rest of the stations. The general trend of the orientations is not uniform; it changes from a station to another (Fig 3). At TATN is NS, at CBBR, VSL and THTN stations is EW, for TAMR and CLTB the orientation is NW-SE, and at CABS station, it is NE-SW.

For Vs-structure tomography of the study area illustrates concentration of 4.5 km/s at 100-200 km beneath the sea of the eastern Tunisia part. At 50 km, this concentration is crossed by a high velocity zone of 5.5 km/s of NS direction, giving two separated low velocity zone of 4.5 km/s (Fig 4). This high-velocity entity may be created by the oceanic lithosphere subducting at around 30 Ma caused by the Africa-Iberia convergence conducted to the ALKAPECA terrane dispersion by transporting its various fragments to be collided at

Betic, Calabria Alps, Rif, and Kabylie ([4], [13], [14]).

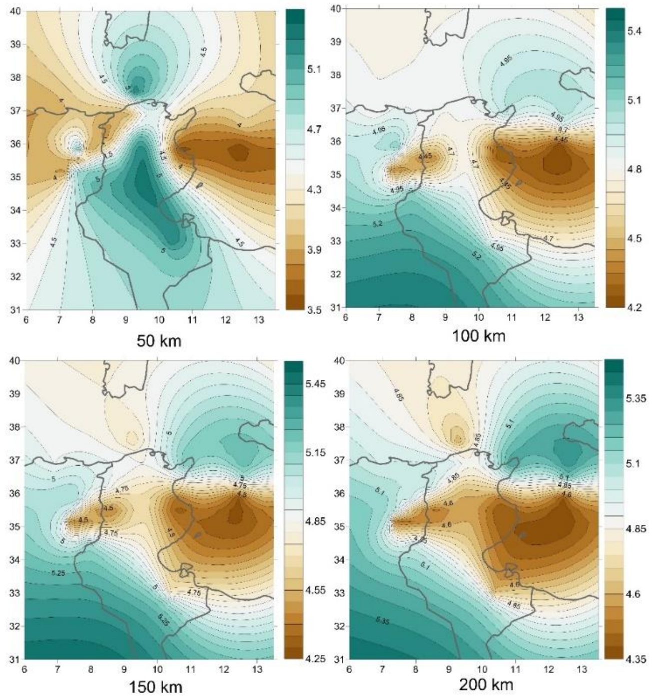

Fig 4: Presentation of the tomography Vs variation in area station obtained after the inversion of mean phase velocity dispersion curve at different depths from 50 to 200 km.

VI. CONCLUSION

In this study, we present a 3D shear wave velocity model of the crust and upper mantle from 50 to 200 km for the North-East Algeria, Tunisia, Sardinia and Sicily crusts with their sea basins, using Rayleigh waves in teleseismic recordings from. As a result, high and low velocity zones are significantly observed.

The seismic anisotropy measurements show different fast orientations, where in the south, it is NS, and toward the north it becomes EW.

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