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The Determination of Subduction Geometry under the Aegean-Anatolian Plate along Aegean and Cyprean Arcs in the Eastern Mediterranean

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Abstract

The southwestern Anatolia is part of the Aegean extensional province, located in a seismically active convergent zone between the African and Eurasian Plates in the Eastern Mediterranean. This region is one of the most active and swiftly deforming domains of the Alpine–Himalayan mountain belt in Turkey. The plate boundary is shaped by the subduction of the African Plate under the Aegean-Anatolian plate consists of the Aegean and Cyprean arcs. The two separate slabs occurred along the plate border related to these arcs. These subducted slabs are separated by a gap beneath Western Anatolia. These arcs intersect in the eastern Mediterranean region and form the tectonic structures, north cusps, the Isparta Angle depending on the subduction. The Isparta Angle caused by the slab is located to the North of Antalya Bay as reverse V shaped.

In this study, 3D seismic tomography method was applied to determine the subduction geometry of slabs along the Aegean and Cyprean arcs in the Eastern Mediterranean region. The 3-Dtomographic results obtained by using the arrival times data collected 39,059 earthquakes have revealed concrete results about subduction zones. P wave velocity structure has been compared with the tectonic structures. The tomographic results show that two separate slabs occurred along Aegean and Cyprean arcs. The tear zone between these two slabs is the Fethiye Burdur Fault Zone (FBFZ) and the Astenospheric upwelling occurs in the Fethiye Bay and continues northward from there. It has been determined that there are two slabs dipping to the northeast under the Antalya Bay and to the north under the Gökova Gulf. Based on the tomographic results, it has been determined that the subduction in these region continues to the depth of ~ 100 km. The subducted African lithosphere plays important role in the evolution of southwest Anatolian tectonic structures.

Keywords: 3-D seismic tomography, Aegean-Anatolian plate, Isparta Angle, subduction

1. Introduction

In this study, seismic velocity and subduction geometry of Southwest Anatolia have been investigated. The study region is highly complex in terms of seismotectonic structure. The region is within the thrust zone where the Aegean, Anatolian and African plates are responsible for the plate motions of the Alp-Himalayan orogenic belt in the Eastern Mediterranean (Ketin, 1977). The subduction of African lithosphere to the northward along the Aegean and Cyprean arcs plays an important role in the tectonic development in this region (Bozkurt, 2001, Fig. 1). The African

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Plate subducts under the Aegean-Anatolian plate along Turkey's southern boundary. Along the subduction zone, the friction and hydrodynamic forces occur on the upper surface of the subducted plate. These forces lead to hot magma upwelling into the Anatolian continental crust along the zone and cause an increase in the mantle volume. The Increasing volume causes the north-south movement of the Aegean Anatolian plate, high heat flow, increase in crustal structure and thickness. Therefore, these activities and tectonism within the crust affect the velocity structure of the medium. In the studies carried out so far, it has been revealed that the elastic wave propagation in the Aegean-Anatolian Plate has different properties. The elastic wave velocity structure of the study region needs to be examined in order to determine specific crust and mantle structure of the region.The tectonic features, crust and mantle structure and subduction geometry in the region were inferred from the change in velocity of the P wave.

Many studies have been carried out on the existence of subduction zones along the Aegean and Cyprean arcs in the study area (Buyukaşıkoğlu, 1979; Wortel and Spakmen, 1992; Barka et al. 1995; Bozkurt and Sözbilir 2004; Tokçaer et al. 2005; Aldanmaz 2006; Dilek and Altunkaynak, 2009; Hansen et al. 2019; Özbakır et al. 2020; Saltogianni et al. 2020; Meng et al. 2021; Kutoğlu and Becek, 2021). Additionally, there are studies of the neotectonic regime structure of the Southwest Anatolia (Şentürk and Yağmurlu 2003; Şahin et al., 2019). The well-known models for the subduction has been proposed by Barka et al. (1995), Dilek and Altunkaynak (2009), Meng et al. (2021) and Biryol et al. (2011). Wdowinski et al. (2006) proposed that the Cyrian arc is less active in terms of seismicity compared to the Aegean arc. Primallo and Morelli (2003) and Faccenna et al. (2006) determined the subduction portion of the African plate between southwest Anatolia and the Cyrus Island. The subduction along the Cyprus section of the arc is influenced by the collision of the Eratosthenes Seamount with the Cyprean arc (Robertson, 1994; Robertson and Grasso, 1995; Glovoer and Robertson, 1998). Biryol et al. (2011) provided constrained on the structure of the subducting African lithosphere along the Aegean and Cyprean arcs.

In this study, the seismic tomographic method was applied to determine these proposed tectonic models and identify the slabs in this study. The three-dimensional P-wave velocity distribution and its relation with tectonics have been determined. In previous studies, it has been observed that seismic activity is concentrated in the regions with low% Vp change in Southwest Anatolia and these regions have high heterogeneity in the crust (Salah et al., 2007; Şahin et al. 2019; Toker and Şahin, 2018). The geometries of the subduction along the Aegean and Cyprean arcs are determined along with their dimensions.

The study area is located between latitudes34.0–39.0 ° N and longitudes 24.0–32 ° E including the Aegean-Anatolian plate. This area is the most active region of the Eastern Mediterranean basin, which includes the Isparta Angle and the West Anatolian extensional province, Southwest Anatolia and the Aegean Sea (Fig. 1). The regional earthquake distributions vary depending on the subduction between the African and Anatolian plates. The subduction starts behind the Anaximander Mountain and continues towards the northeast in the Antalya Bay related to the Cyprean arc. In the west the subduction takes place in the Gökova Gulf related to the Aegean arc.

2. The Tectonic Structure of the Study Area

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Anatolia is located in the Alpine-Himalayan orogenic belt, which is the youngest orogenic belt in the world. The movement of the Arabian plate towards the north-northeast causes the formation of the East Anatolian and North Anatolian Faults as well as the movement of the Anatolian Plate towards the West. Thus, the formation of the North and East Anatolian Fault and the relative movements along them constitute the beginning of the new tectonic period in the vicinity of Turkey (Ketin, 1977). The important structural elements characterizing the new tectonic period are the Aegean Trench, the North Anatolian Fault Zone (NAFZ), the East Anatolian Fault Zone (EAFZ), and the Aegean graben system (Fig.1-2). The Aegean trench or subduction zone is a 1550 km long convex thrust belt between the west of Cyprus and the Gulf of Corinth, along this belt the African plate subducts under the Anatolian Plate at a rate of 2.5-2.7 cm/year (Le

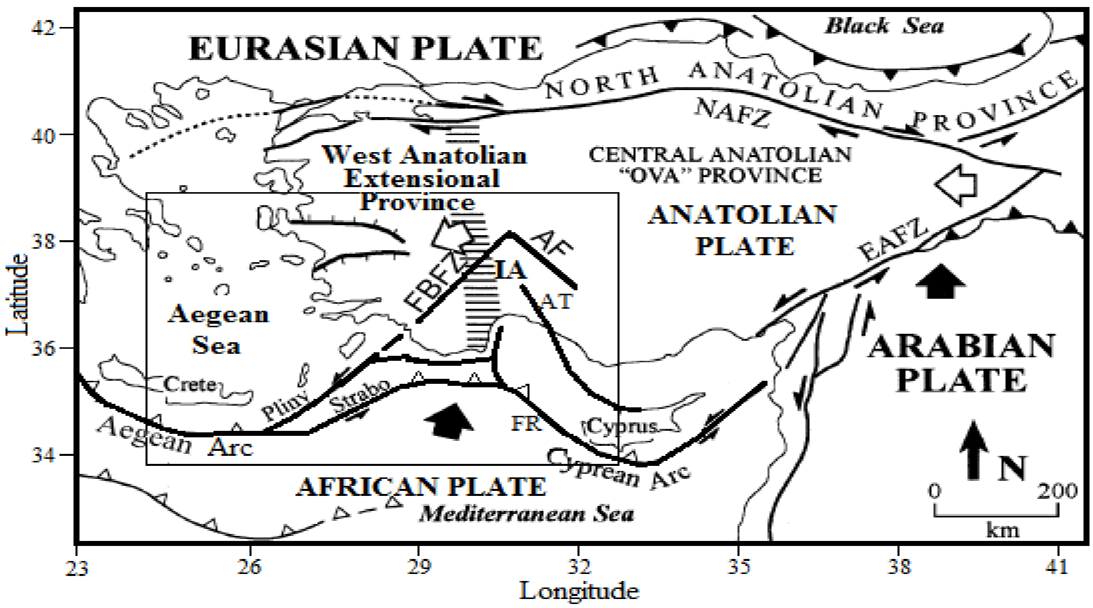

Figure 1. It is the map of Turkey's main tectonic structures and the study region's (rectangular area) simplified tectonic (compiled from Şengör et al., 1985; Barka, 1992; Bozkurt, 2001). Here, IA: Isparta Angle, FBFZ: Fethiye-Burdur Fault Zone, AF: Akşehir Fault, AT: Aksu Thrust Fault, FR: Florence Rise, EAFZ: East Anatolian Fault Zone, NAFZ: North Anatolian Fault Zone. The strike-slip faults denote with heavy lines with half arrows showing relative movement sense. The active subduction zone is shown with heavy lines with open triangles. The lines with hachures indicate move down side normal faults. The relative movements of the African and Arabian, and Anatolian plates are shown with bold filled arrows and open arrows respectively. The extensional province which is the transition zone between the western Anatolian province and ova are shown with the hatched.

Phichon et al., 1973; Papazachos, 1973). Isparta Angle and the West Anatolian extensional province are located in the most active region of this belt. The main active structures, that shape the neotectonics of Turkey and surroundings, constitute the Isparta Angle and the western Anatolian graben system according to Cyprean and Aegean subduction zone (Bozkurt and

Sözbilir 2004; Erkül et al. 2005; Koçyiğit 2005; Tokçaer et al. 2005; Dolmaz et al. 2005; Aldanmaz 2006; Hansen et al. 2019; Özbakır et al. 2020; Saltogianni et al. 2020; Meng et al. 2021; Kutoğlu and Becek, 2021).

The beginning of the new tectonic period in southwestern Anatolia is Late Miocene-Early Pliocene. (Koçyiğit, 1984). This region is characterized with terrestrial sedimentation, intra-continental volcanism and block faulting during the new tectonic period. The southwestern Anatolia started to rise at the end of Tortonian and today it is also under the control of the tension tectonic regime, which continues to draw tectonic activity. Due to this regime, the region has been subjected to block faulting. Block faults were formed by the development of normal faults intersecting each other in different directions. These fractures are faults with different directions but formed at the same time. The existence of NE-SW, NW-SE, E-W and N-S trending and

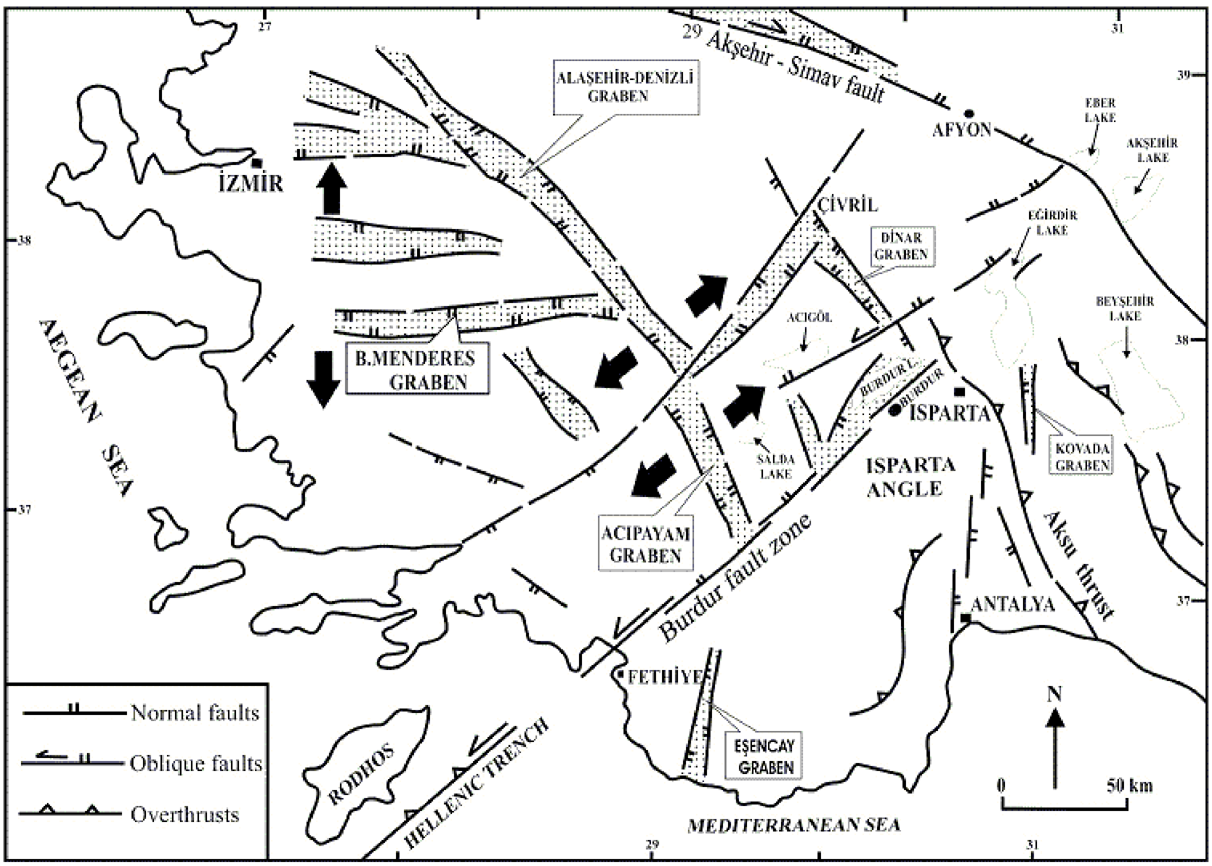

Figure 2. It is the map of geology and active tectonic structures of the Southwest Anatolia (Şentürk and Yağmurlu, 2003).

normal fault systems in Southwest Anatolia reveals that this region was shaped by block faulting developed under the control of tensile tectonics in the new tectonic period (Koçyiğit, 1984; Bozkurt 2001; Koçyiğit and Özacar, 2003; Aldanmaz 2006; Dilek and Rowland, 1993;

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Robertson and Woodcock, 1980; Robertson et al., 2003; Robertson, 2007; Kalyoncuoglu et al. 2011; Üner et al. 2015). After the Miocene-Pliocene phase, Quaternary grabenization is observed and the whole Aegean and Anatolia are affected by it. In the Quaternary, the whole Aegean and Anatolia are under pressure. The stress tectonics prevail in the Aegean and Western Anatolia still (Papazachos ve Comninakis, 1977).

According to the tectonic structures in the study region, earthquakes have normal fault mechanism in the West Anatolia since this province has the horst-graben system. It is seen that the faults mostly consist of NE-SE normal faults developed under the NE-SW direction. On the other hand, along the subduction zone, Eagean and Cyprean arcs, it is seen that the reverse faulting system from focal mechanism (Fig. 3).

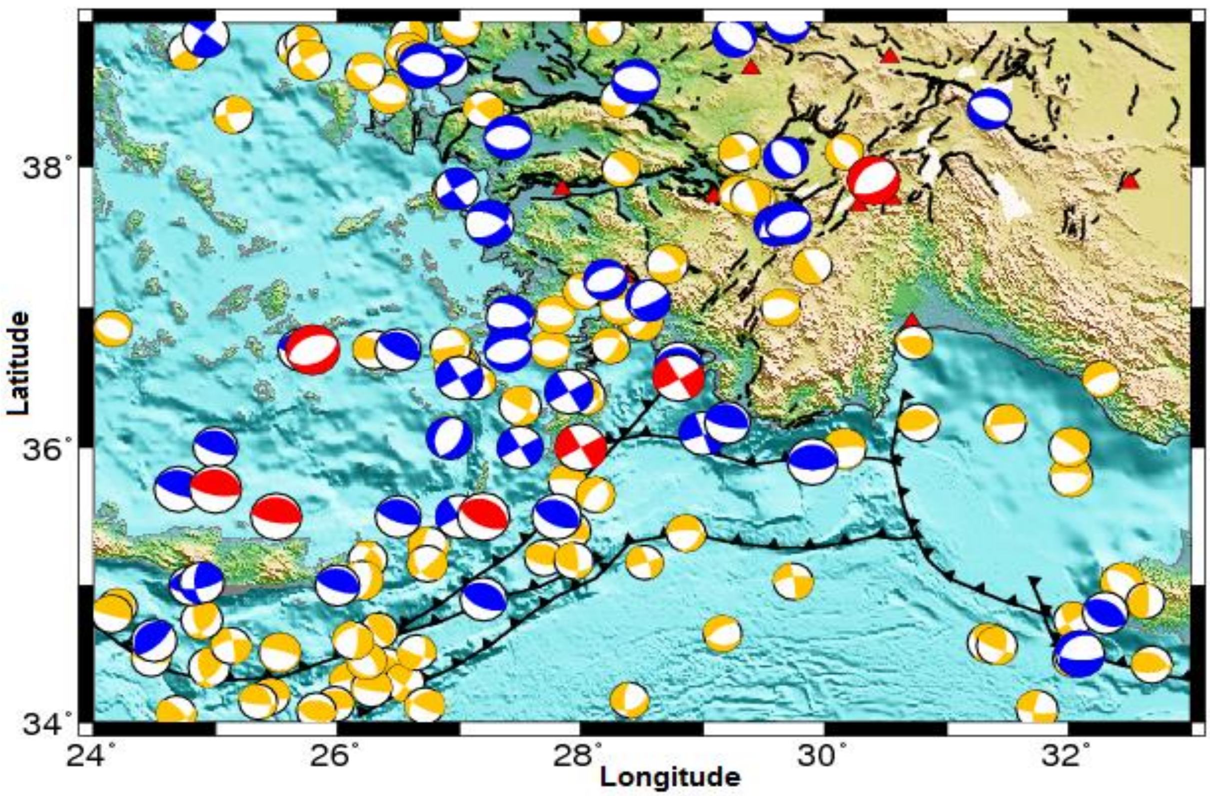

Figure 3. The solutions of focal mechanism are obtained from earthquakes which occurred from 1957 to 2016 and 5 and higher magnitude in the study area. The solution with red, blue and yellow colors belongs to earthquakes with a magnitude between 7 and 8, 6 and 7, and 5 and 6 respectively.

Generally, shallow and medium-depth earthquakes occur in Southwest Anatolia (Fig. 4). These are related to the subduction (mantle) of the African plate under the Aegean-Anatolian plate. The large earthquakes occur at different times in subduction zones. The earthquakes occur in large collision belts and indicate that the deformations on there are complex. Earthquakes in southwestern Anatolia are related to the westward movement of the Aegean-Anatolian block and the Aegean and Cyprean subduction zones. These arc-shaped belts intersect around Burdur (Alptekin, 1978).

There have been many studies on the tectonic structure and development of Isparta Angle (IA) shaped by the Cyprean subduction belt (Boray et al. 1985; Glover and Robertson 1998; Poisson et al. 2003; Aldanmaz 2006; Hansen et al. 2019; Toker and Şahin 2018). The Isparta Angle and the West Anatolian extensional province are among the most seismically active regions of the Eastern Mediterranean Basin (Şentürk and Yağmurlu, 2003). The Isparta Angle was first described and reported by Blumenthal (1963), and then the first study for its formation was done by Dumont et al. (1976). Kelling et al. (2005) also defined the Isparta Angle as a regional structure extending to the Menderes-Taurus microcontinent and also separating the western and central Taurus Mountains.

The IA is a complex zone as tectonically. It is consisting of SE-and SW-vergent allochthons that were placed between the Late Cretaceous and the Late Miocene (Robertson et al. 2003; 2009). IA is bordered by the NW-SE trending Sultandağ Fault (SF) to the east (Boray et al. 1985) and transtensional left-lateral NE-SW striking Fethiye-Burdur Fault Zone (FBFZ) to the west (Dumont et al. 1979; Taymaz and Price, 1992; Price and Scott, 1994, Fig. 2). The southernmost, the Anaximander Mountains marks offshore part of the IA. This sectionis the Anatolian Plate and is placed at the cusp where the Aegean and western Cyprean arc (Florence Rise) collide (Zitter et al. 2003; ten Veen et al. 2004, Fig. 1). The complexity of the region is by the Aksu-Kyrenia thrust at the center of the IA (McCallum and Robertson, 1995; Poisson et al. 2003, Fig. 1).

The northern part of the IA indicates the border between the Western Anatolia Extensional Province (WAEP) and the Central Anatolia Province (Barka and Reilinger, 1997; Glover and Robertson, 1998; Bozkurt, 2001, Fig. 1). The WAEP is shaped by N-S extension and related grabens (Taymaz et al. 1991; Jackson et al. 1992; Jackson, 1994). In the west, the extension is controlled by the westward extrusion of the Anatolia Plate since 12 Ma (Bozkurt, 2001). The subduction roll-back model is proposed that SW pullback of the Aegean arc results in backarc extension in the Aegean Region and Western Anatolia (Fig. 1). The orogenic collapse model suggests that the extension and thinning of the thickened crust following the closure of the Neotethys ocean. A lot of studies about the crustal properties of the WAEP obtained crustal thicknesses changing between 28 and 35 km (Kalafat et al. 1987; Saunders et al. 1998; Sodoudi et al., 2006; Zhu et al. 2006). The presence of the steeply dipping Eastern Mediterranean lithosphere underneath the Aegean region is obtained the results of seismic tomography studies. The top idea is subduction roll-back plays an important role in the evolution of the region (Spakman et al. 1988; Faccenna et al. 2003; 2006; Promallo and Morelli, 2003). The geothermal studies indicated that the evolution of volcanics in the region could be related to the vertical tear in the subducting Mediterranean lithosphere (De Boorder et al. 1998; Tokçaer et al. 2005; Dilek and Altunkaynak, 2009; Dilek and Sandvol, 2009).

3. Data

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In this study, 39059 earthquakes that occurred from 2012 to 2020 and latitudes between 34°- 39° N and longitudes 24° - 32° Ewere used (Fig. 3). Approximately 405808P wave arrival time data are inverted collected these earthquakes. These earthquakes were recorded by 109 stations belonging to the National Earthquake-Tsunami Monitoring Center Seismic network operated by Boğaziçi University, Kandilli Observatory and Earthquake Research Institute (KOERI). This network has 106 broadband, 100 Hz sampling frequency and 3 short period seismic stations. Dynamic range is 140 dB for broadband stations and between 164 and 184 dB for short period stations. The Herrin's (1968) crust model and HYPO71 source code were used to obtain the hypo central parameters (Lee and Lahr 1972). The study region is limited with the seismic station distribution and epicenters of the earthquakes evaluated (Fig. 4). The level of seismicity is low in the south of Aegean and Cyprean arcs and in the Aegean Sea in the studied region. On the other hand, earthquakes have been clustered in the western and central regions. The homogenous distribution of earthquakes and the ray-path intensity in most parts of the study region are very important for the reliability of the obtained P wave velocity change (Widiyantoro et al. 1999; Gorbatov and Kennett 2003). The ray-path distribution covers the entire study area and goes down to a depth of 120 km in vertical cross-sections (Fig. 5). The RMS values were determined as 0.15. All residuals were examined step by step according to the initial velocity model, and data outside the ± 1 s limit were excluded from the tomographic inverse solution. However, more than 65% of the residuals are within the limits of ± 0.3 sec.

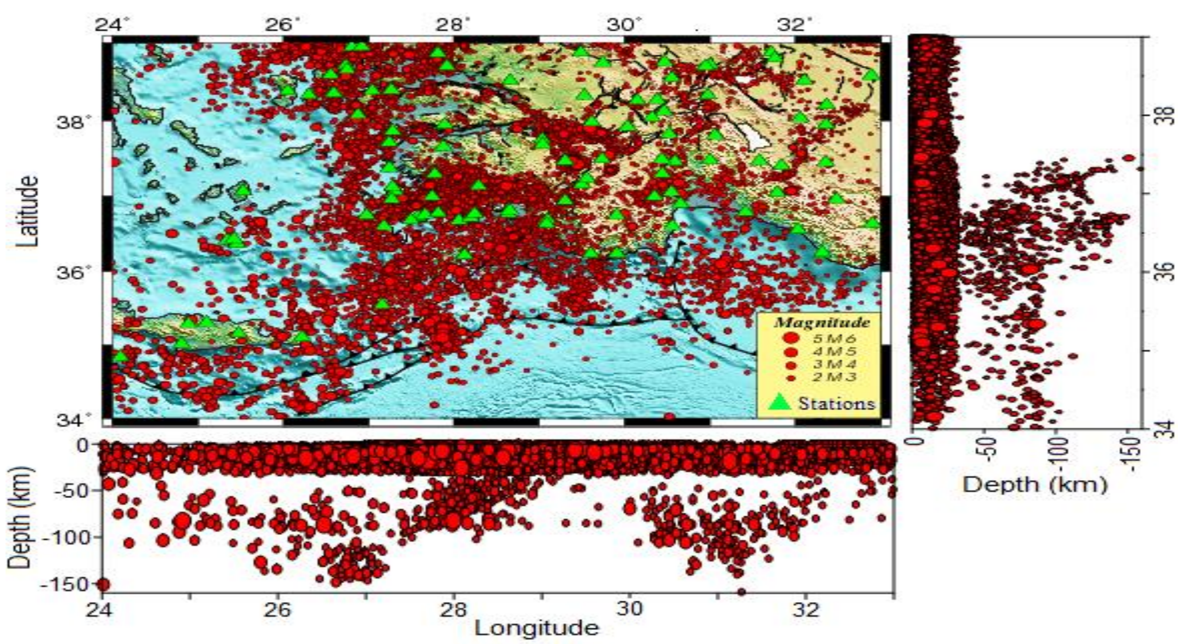

Figure 4. The epicenter and depth distribution map of earthquakes with magnitude 2 and bigger used in this study. These earthquakes occurred between 2012 and 2020, and collected totally 109 seismic stations as shown the green triangles.

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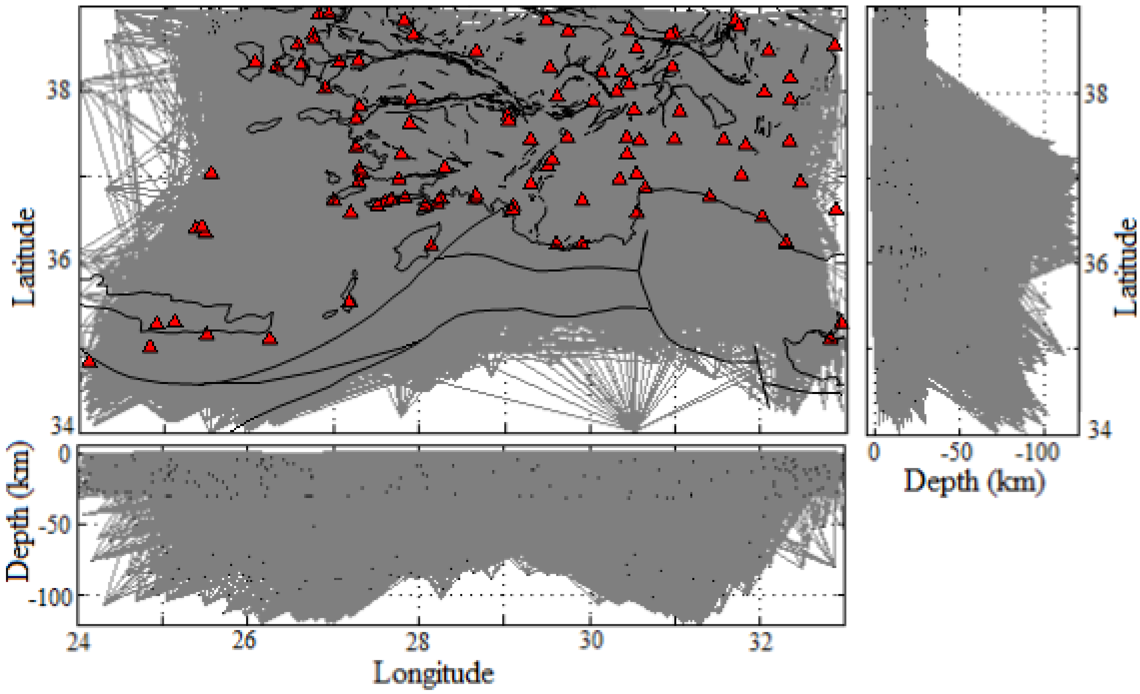

Figure 5. The ray-path coverage of P-wave data set. The paths are drawn as a straight line from focal of earthquake to the station.

4. Method

In this study, the seismic tomography method developed by Zhao et al. (1992) was used to analyze the time of arrival data. (Salah et al., 2007; 2011; 2014; Şahin et al. 2019; Toker and Şahin, 2019). This method is applied to the structures containing various complex velocity discontinuities. It is also a successful method for determining 3-D velocity changes in the crust and mantle (Zhao et al. 1996; 2001). Discontinuities, Moho discontinuities and/or sub ducted plate boundaries etc. represent known geological boundaries. A 3-D grid net is arranged in the model to obtain the 3-D velocity structure (Figs. 6 and 7). The velocity perturbation is calculated by linear interpolation of velocity perturbations at the eight nodes surrounding a point. The rate perturbation at grid nodes is taken as unknown parameters. The pseudo-bending technique (Um and Thurber 1987) and an efficient 3D ray tracing technique using Snell's law recursively were used to calculate travel times and ray-path accurately and quickly (Zhao et al., 1992). To solve the system of observational equations the least squares method algorithm (Paige and Saunders 1982) is used. It allows the use of large numbers of data to solve the tomographic problem. Perturbations for the hypo central parameters and rate structure are obtained simultaneously. For this study, a 0,5° grid spacing was applied in the horizontal direction. The details of the method are given in Zhao et al (1992, 1994) and Zhao (2001).

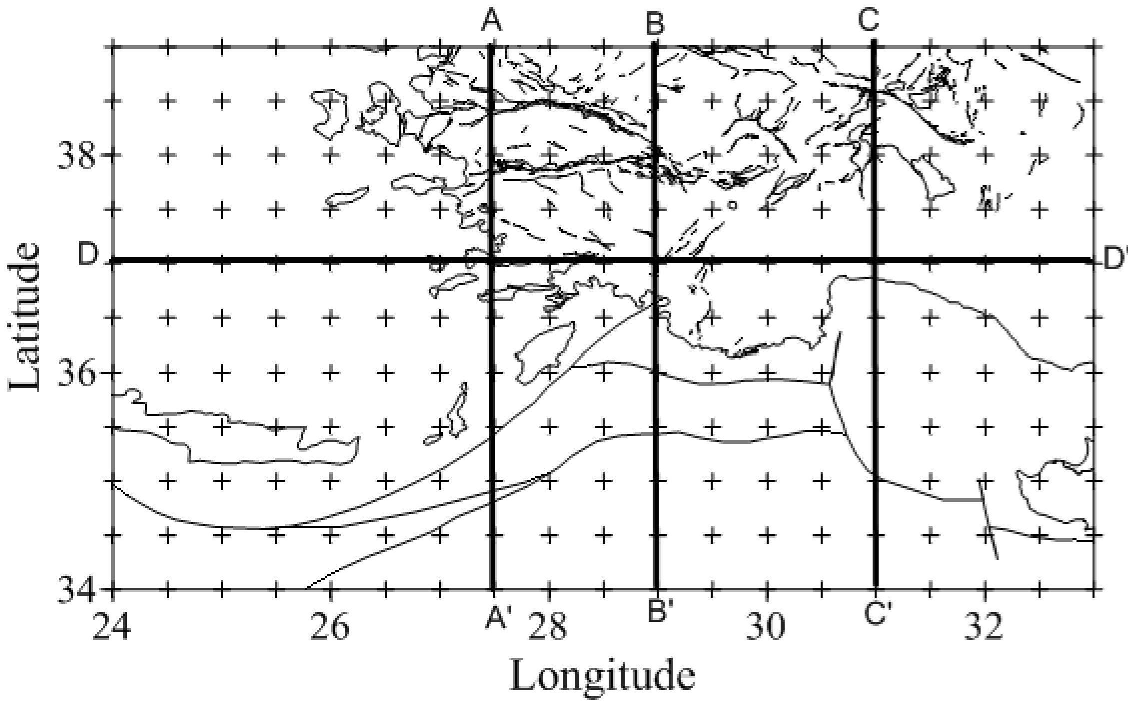

Figure 6. It is the grid net configure to the study region in horizontal spacing as 0.5^{o}x0.5^o. The vertical cross-sections are shown with the straight lines. The active faults are shown by thin lines.

We used the software of tomotools based on tomographic method of Zhao et al. (1992). The tomotools software (Abdewahed and Zhao, 2006) is a Fortran-Quick win application to perform seismic 3-D tomography images using Zhao (1992) code. The program consists of all the requirements of the tomography inversion of P and S waves. The Model 1-D and grid net are constructed easily by using the Model makertool.

The construction of cross sections and the associated post files like volcanoes, faults, events, etc, are all included. Tomotoolspreserves the original file formats (I/O) used in "Tomog3d"code (Zhao, 1992). Therefore, the tomography tools in "Tomotools" can be applied directly to the output results of the original code without any modifications. One of the most important features of Tomotoolsis the generality of the code. It is valid for all grid numbers (in the allowed limits). The control parameters; input and output file names and paths are inserted directly in the run time. The 1-D velocity model can be changed in any step of the tomography job.

Grid Maker mode is the minimum and maximum limits and interval of grids are inserted to automatically constructed grid nodes. The depth grids are constructed according to the following relation:

$$G(I,J,K) = G(I,J,K-1) * (Interval) \quad (1)$$

Where G(I,J,K) is the grid node of 1st longitude and Jth latitude and Kth depth. The computer algorithm TOMOG3D is designed to use arrival time data from local earthquakes recorded by a

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network of seismic stations to derive a 3-D seismic velocity model for the crust (and the upper mantle) beneath the network. The conceptual approach parallels the conventional tomography method, being composed of the following steps as clearly shown in the main part of the program.

Because of these advantages, TOMOG3D is considered to be powerful in the 3-D studies in regions such as subduction zones, fault zones and continent regions with large depth variations of the Conrad and the Moho discontinuities (Fig. 7). The role of a subroutine played is usually given as comments inserted in the subroutine and will not be repeated here. Here NPC=23, NRC=13, i.e., 23 rows and 13 columns of grid points are set in the latitude and longitude directions, respectively, for the upper mantle. However, the same as in the depth direction, only the internal (23-2)*(13-2) grid points are taken to be unknowns for each layer, the outer ring of the grid points are used only to interpolate velocities at points between the outer ring and the internal grid points. Thus the total number of grid points which are taken to be unknown are

$$\begin{aligned} NODETOT &= (NPA-2)*(NRA-2)*(NHA-2) + (NPB-2)*(NRB-2)*(NHB-2) \\ &+ (NPC-2)*(NRC-2)*(NHC-2) + (NPD-2)*(NRD-2)*(NHD-2) \end{aligned} \tag{2}$$

The initial velocity model is an important step in a tomographic inverse solution. It affects the distribution of the velocity anomalies and amplitudes. The P wave crust velocity model developed by Kalafat et al. (1987) was used as the initial velocity model. This model is based on four layers for the lower crust up to a velocity of 8.30 km/sec and a depth of 31.6 km (accepted Moho depth). However, the velocity in the shallowest layer is limited due to the lack of head waves and refracting waves on the surface in their dataset. The initial velocity model is given in Table 1.

Table 1. The initial seismic velocity crustal model according to depths. In this study, Vp/Vs has been applied as 1.73 (Kalafat et al. 1987).

Depth (km)	Vp	Vs
0.00	4.50	2.60
5.40	5.91	3.42
31.60	7.80	4.51
89.00	8.30	5.80

5. Resolution and discussion

The grid node resolution test was performed first to determine the spatial resolution of the data set (Inoue et al. 1990; Zhao et al. 1992) (Figs. 6 and 7). The synthetic arrival times are calculated for this grid model. A checkerboard test was conducted to obtain areal resolution at depths by using data set (Inoue et al. 1990). The negative and positive velocity anomaly values were set within the range of ± 3%. The velocity model is applied to 3-D grid nodes (Fig. 8). Synthetic arrival times have been determined for the checkerboard model. The number of stations and ray-paths are the same both in the synthetic data and in the data set. The random errors of 0.1-0.15

seconds were added to the synthetic data, and the inversion technic was applied with the same algorithm to the real data. The results of tests for Vp% structures for 4-, 14-, 35-, 55-, 75- and 100-km depths are given Figure 9. The checkerboard test results give a good and uniform resolution for the 0.5° grid nodes and horizontally for Vp% values in the study region. This is because many horizontal ray-paths have even more distribution and vertical ray-paths that pass through specified depths (Fig. 5).

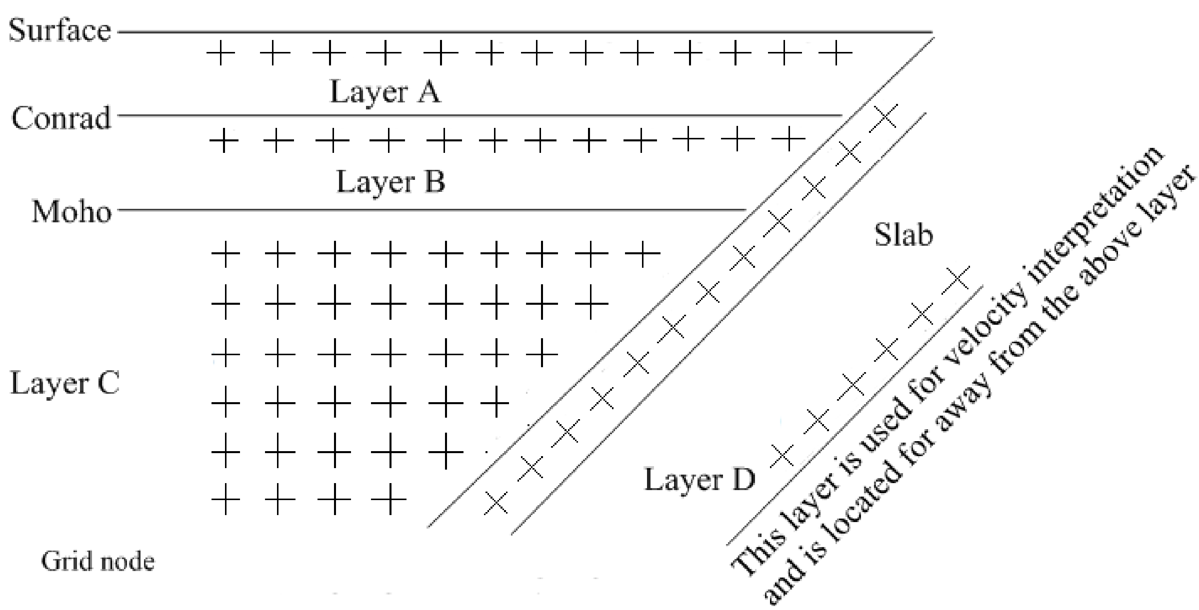

Figure 7. The velocity and structural model of subduction geometry.

In addition, model recovery synthetic tests were performed to show the recovery of Vp % amplitudes in the study region (Lei ve Zhao 2005; Kounoudis et al. 2020). Maximum velocity anomalies in each grid nodes were entered as 6%, and then Vp % values were calculated for each grid nodes by using inversion technic. Although there are some minor differences at big depths, it is seen that Vp % amplitudes are obtained as clear to depth of 100 km. To apply the tomographic method to the data set, a 3-D grid model with a horizontal grid spacing of 0.5 ° was established in the study region (Fig. 6). In addition, the grid nodes were established for six different levels at 4-, 14-, 35-, 55-, 75- and 100-km depths.

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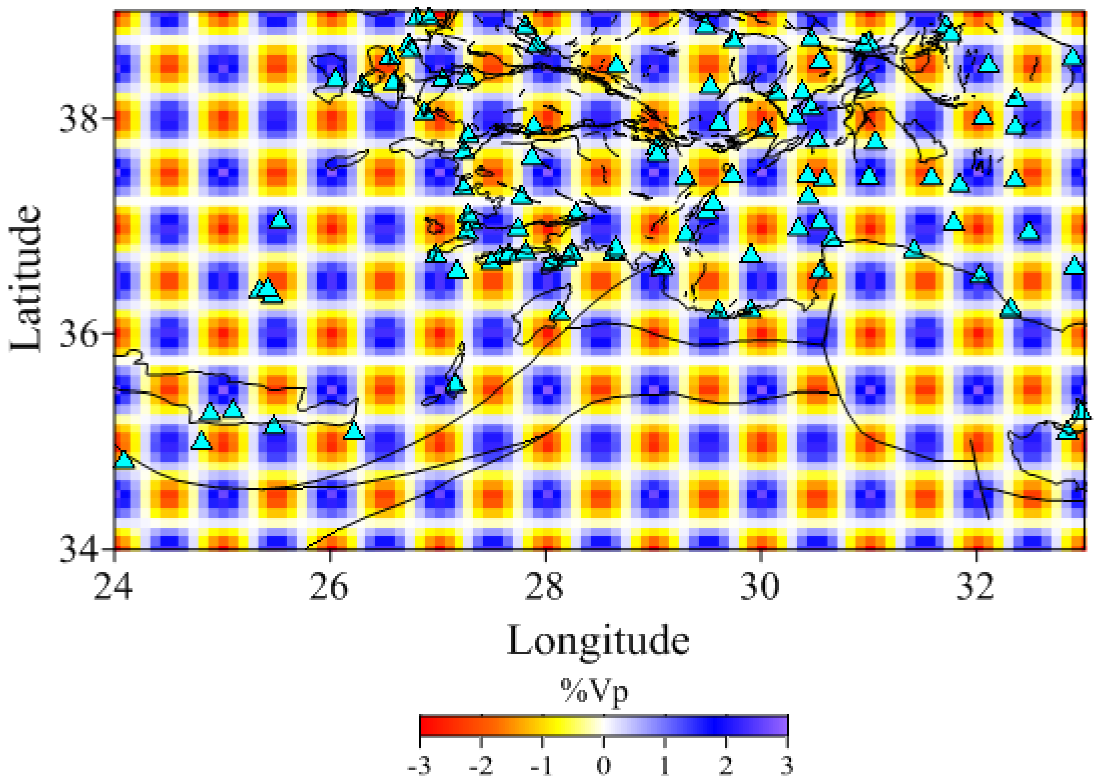

Figure 8. The initial checkerboard synthetic model is for P-wave data. For each grid node, the positive and negative synthetic velocity perturbations (± 3%) denote with red and blue colors respectively. The seismic stations are shown with blue triangles. The solid lines show active faults.

These results show the velocity perturbations as percentages from the initial velocity models at each depth obtained from the 3-D inversion method. In addition, a number of inversions have been carried out by adopting several different initial models and using different subsets of data. The Vp% changes obtained as a result of inversion are shown in Figures 10, 11 and 12. Significant variations of up to 6 % for velocity (Vp %) have been demonstrated in the study region.

In general, the low velocity anomalies are distributed according to the active tectonic structures in the region and microsismic activities are intense in such areas (Fig. 3 and 10). The High Vp % anomalies have been obtained mostly in the oceanic crust and continental lithospheric mantle. The low Vp % values are seen in active fault zones and in the upper part of the subducted oceanic crust. In this area, the surface geology is very complex, because there are many volcanic structures and many east-west oriented graben basins (Yılmaz et al.2000). These correspond to a large number of heterogeneous seismic velocity structures. The large earthquakes in the crust generally occur in transition zones with low Vp % anomalies.

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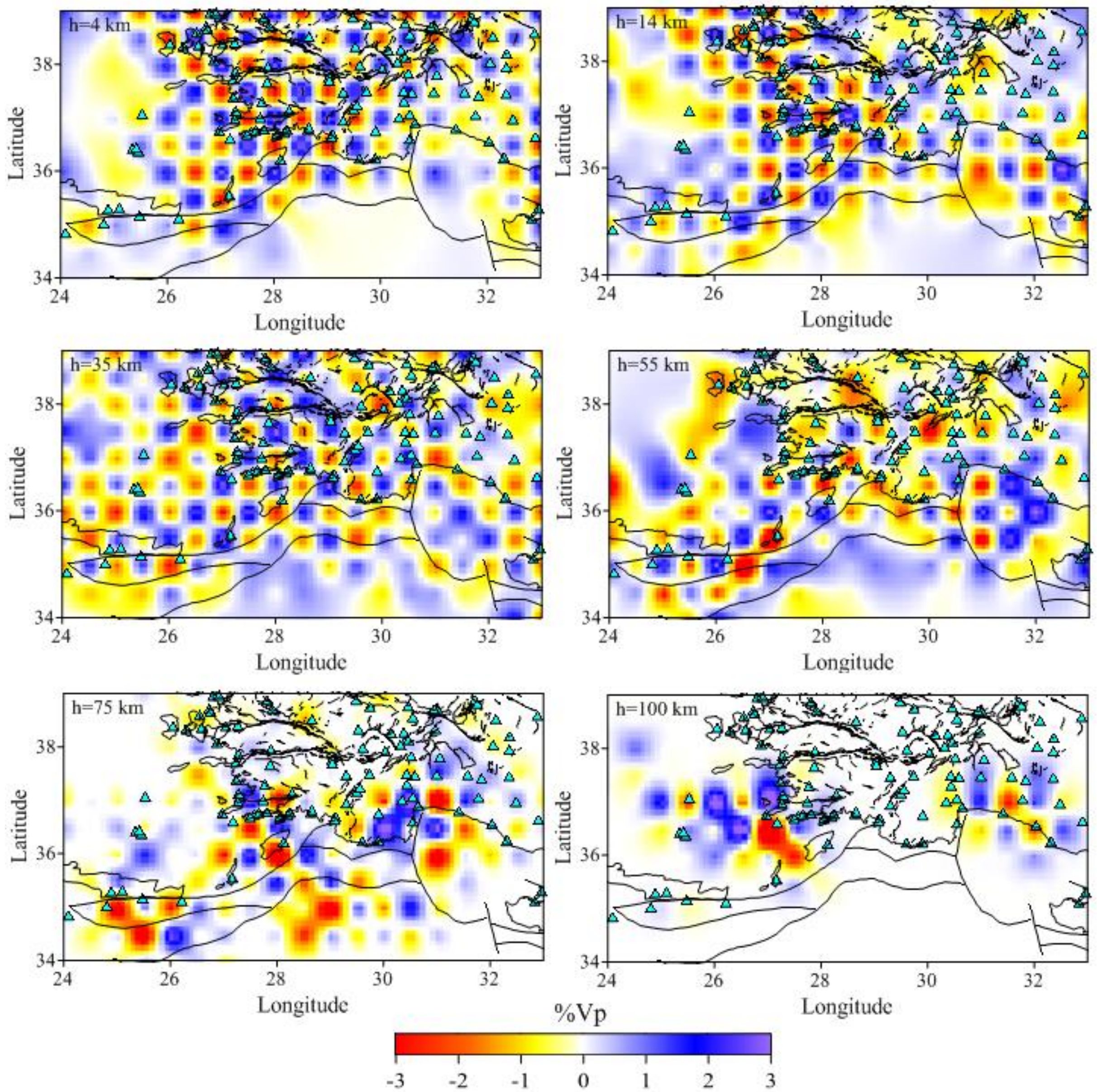

Figure 9. The results of checkerboard resolution test at six depths of 4-, 14-, 35-, 55-, 75- and 100-km. The high and low velocities are shown with red and blue colors respectively. The solid lines show active faults.

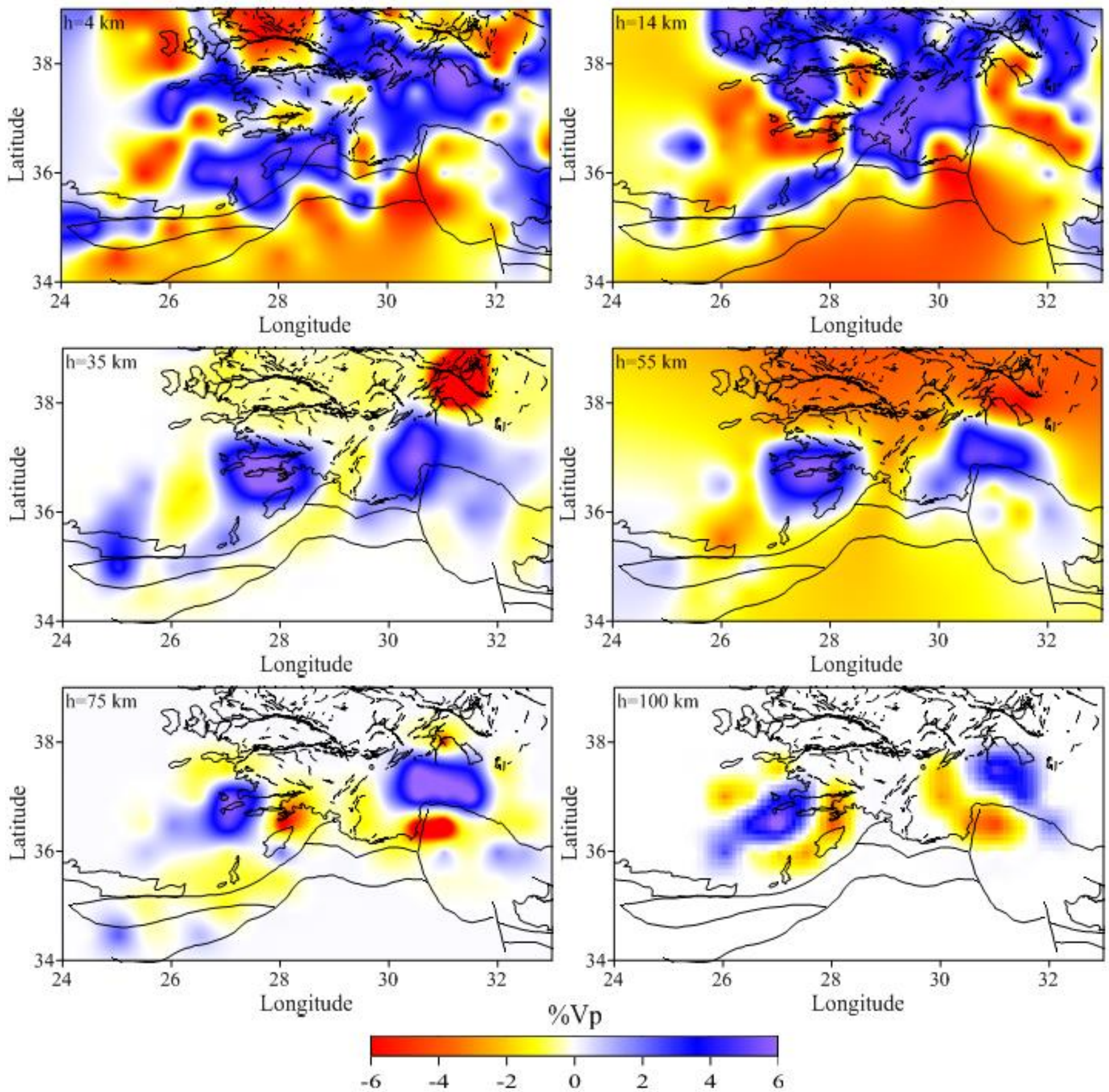

Figure 10. P-Wave velocity values (in %) at six depths of 4-, 14-, 35-, 55-, 75- and 100-km. The solid lines show active faults.

In this region there are two slabs along the Aegean and Cyprean arcs located in the Gökova Gulf and the Antalya Gulf respectively. Figures 10, 11 and 12 shows Vp % image horizontal maps and as block diagram along vertical cross-sections (see Fig. 6 for the location of cross-sections). The change of Vp% values at the depths mentioned above are seen in Figure 10. The low Vp % indicates the seismo-tectonically active regions. As seen in this figure the subduction slabs start from approximately 30-km depth. The effect of these slabs denotes ashigh Vp % values (areas seen in purple and blue) on the 35-, 55-, 75- and 100-km depths at the horizontal maps. This refers to the parts where the seismotectonic activity is high where the African plate subduction under the continental Anatolian plate. A similar situation is seen in the vertical sections given in Figs. 11 and 12. In the cross-sections taken in the N-S direction along the 27°, 29° and 31° longitudes given in Figure 6 the effect of the slabs is clearly seen as the high Vp % values (areas seen in purple and blue) at 27° and 31° longitudes (Fig. 11). In the cross-section taken along the latitude 37 in the E-W direction, the locations of the slabs are revealed. It was determined that the slab formed in the Antalya Bay and Gökova Gulf reached the depth of 100 km (Fig. 12).

Figure 12 shows the two slabs' positions in the vertical cross-section taken along latitude of 37° in the E-W direction. Here, the crust structure of the Aegean Sea has not been determined. The interpretation of the crustal thickness and the geometry of the dive in the Aegean Sea will only be possible with the data obtained from the stations to be established in the region. It can be seen from the cross section that the crust thickness in the Anatolian plate becomes thicker from west to east.

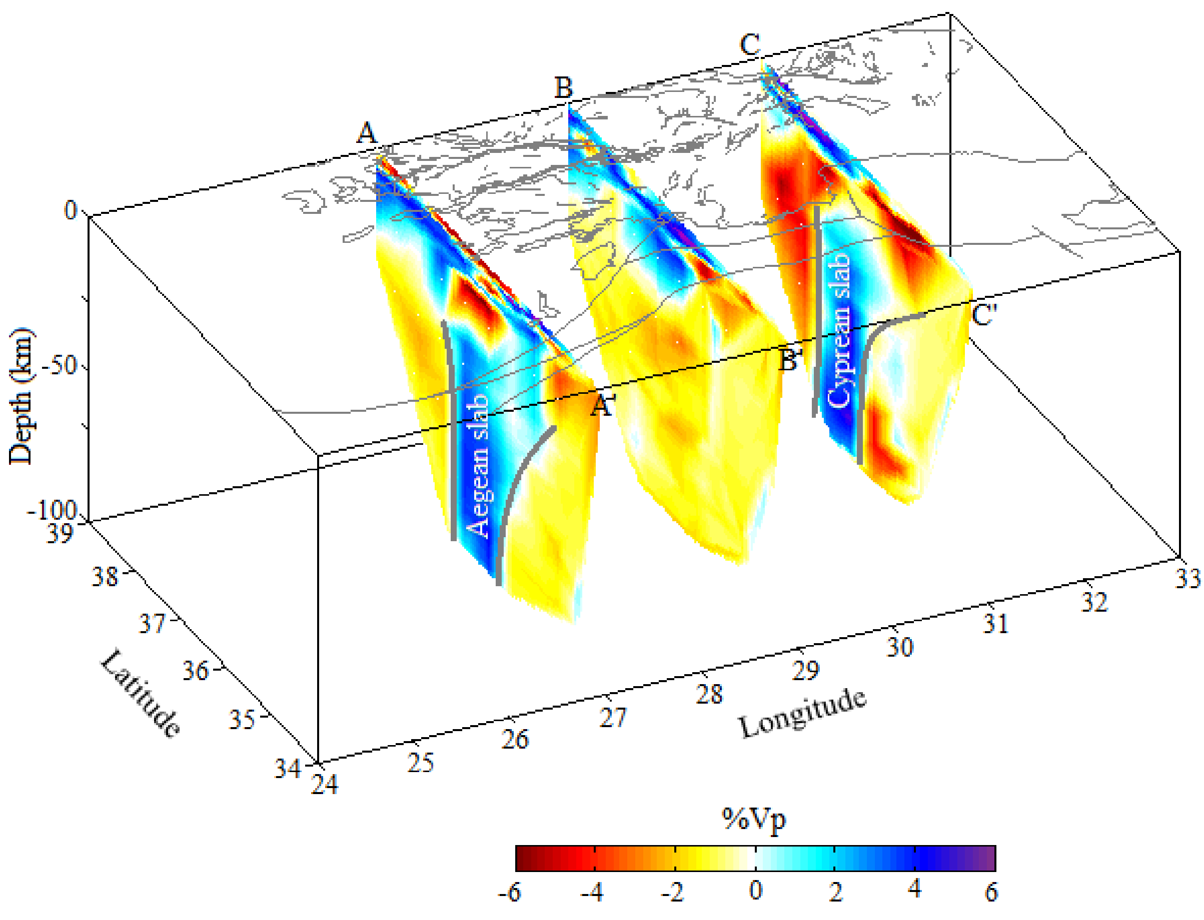

Figure 11. It is the block diagram of the vertical cross sections of Vp % along lines AA', BB' and CC' configured as N-S direction shown in Fig. 6. The red color denotes high, blue color denotes the low Vp % values.

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Many researchers have studied about evolution of subduction in the region. There are some models that are put forward by Wortel and Spakmen, 1992, Barka et al 1995 and Dilek and Altunkaynak, 2009 about the subduction evolution of Isparta Angle. There is a subduction zone along the Florence Rise (Buyukaşıkoğlu, 1980; Jackson and McKenzie, 1984). According to these researchers, the Anaximander sea mountain is an important structure between the Aegean and the Cyprean arcs. The Florence Rise near the Cyprean arc is located in the compression zone between Anaximander Sea Mountain and Antalya Gulf (Biju-Duval et al., 1978; Kempler and Ben-Avraham, 1987; Poisson, 1990). The angle of slab along the Cyprean arc is shallower than the Aegean arc (Kempler and Ben-Avraham, 1987; Wortel and Spakmen, 1992). The rise of the Taurus Mountains may be related to the parallel detachment of the African plate subducting under the Cyprean arc. The Plini-Strabon coincides with Fethiye-Burdur fault zone (Wortel and Spakmen, 1992; Barka et al., 1995).

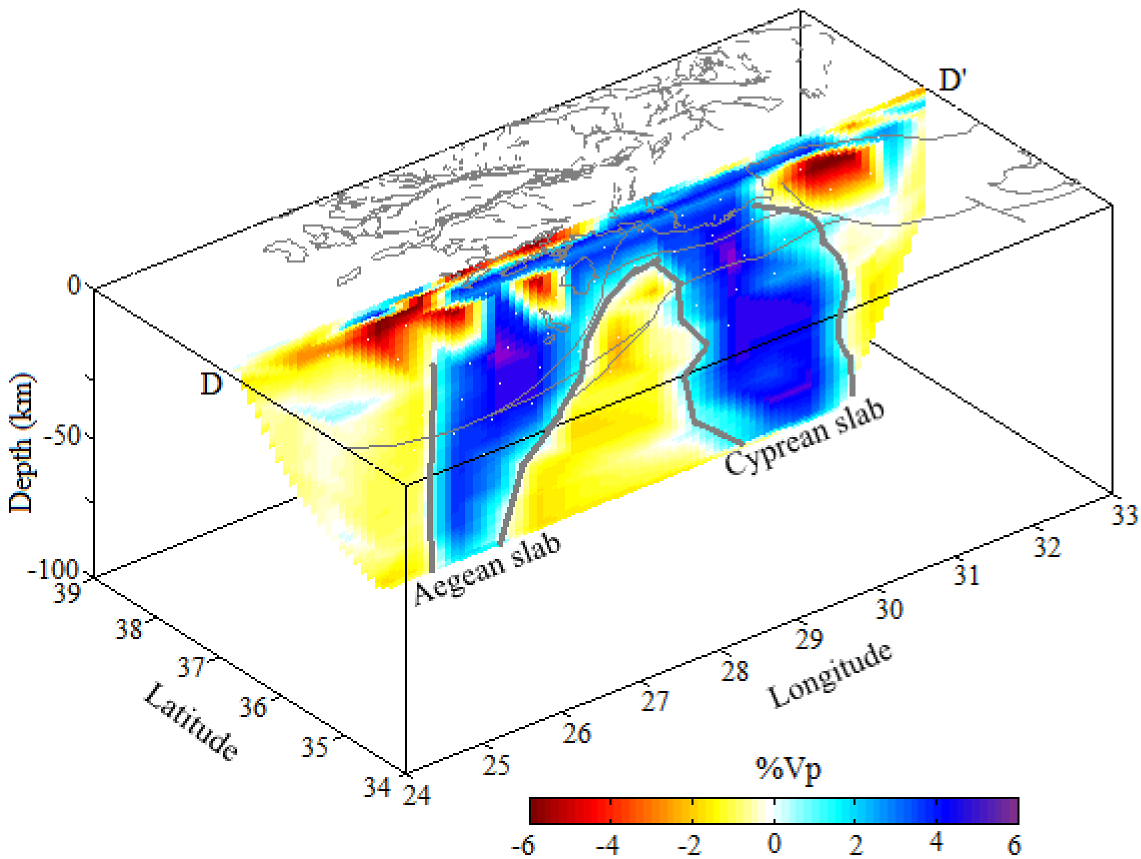

Figure 12. It is the block diagram of Vertical cross section of Vp% along line DD' configured as E-W direction shown in Fig. 6. The red color denotes high, blue color denotes the low Vp % values

According to Dilek and Altunkaynak (2009) the subduction zone magmatism related to the Aegean arc is responsible for the southward migration of this arc since the end of the Miocene. The cusp between the Aegean and the Cyprean arc and the significant differences in the convergence velocities (40 mm/a, 10 mm/a at the Aegean and Cyprean arcs, respectively) of the African lithosphere in these arcs may have probably caused a lithospheric rupture in the subducting African plate causing the mantle upwelling below Southwest Anatolia (Doglioni et al. 2002; Pe-Piper and Piper 2006Agostini et al. 2007). This suggestion is similar to the lithospheric rupture on the Subduction-Transform Edge Propagator (STEP) fault described by Govers and Wortel (2005). In all these cases, the STEPs propagate in the opposite direction to the subducting and asthenospheric upwelling occurs behind and below the propagation. This upwelling causes shallow asthenospheric decompression melting and leads to the formation of linearly distributed alkaline magmatism in the direction of rupture (Dilek and Altunkaynak, 2009; Biryol et al 2011).

In this study, the subduction geometry along the Aegean and Cyprean arc was determined using 3-D tomographic method and compared with other models suggested by Barka et al (1995) and Dilek and Altunkaynak, 2009. It is concluded that the African plate subducts under the Anatolian-Aegean plate along the Aegean and Cypriot arcs. The obtained 3D tomography results revealed the tectonic structure and subduction geometries as compatible. The effects of subduction zones, Plinius-Strabo-Fethiye-Burdur Fault Zone and Aksu Thrust were observed on the tomographic results (Fig. 10). The two slabs from a depth of 30 km are clearly seen (Figs. 10-12). These two slabs are separated by a rupture zone around Fethiye Gulf. The Aegean and Cyprean arcs intersect in this area and form a north-facing cusp and it causes a lithospheric rupture of the subducting African plate that allows the asthenospheric upwelling under Southwest Anatolia. The aastenospheric upwelling was detected in this rupture zone. It may also have caused a lateral tear zone separating these arcs. The lateral ruptured Plini-Strabon coincide Fethiye-Burdur fault zone. The slab in the Antalya Gulf is related to the Cyprean arc and also the slab in the Gökova Gulf is related to the Aegean arc (Fig. 10-12). The deeper slab related to the Aegean arc is due to the counter-clockwise movement of the Anatolian block in SW Anatolia.

Asthenospheric upwelling is shown along the tear zone along the 29^{o} (Fig. 12). The cusp between the Aegean and Cyprean arcs is likely to have resulted in a lithospheric tear in the down going African plate that allowed the asthenospheric mantle to rise beneath SW Anatolia. Asthenospheric upwelling induces decompression melting of shallow asthenosphere, leading to linearly distributed alkaline magmatism younging in the direction of tear propagation. According to Al-Lazki et al. (2004), Asthenospheric low velocities in this region support the existence of shallow Asthenospherein the study region. Dilek and Altunkaynak, (2009) infers that magmas were produced by melting of asthenospheric upwelling in the Kirka, Afyon–Suhut, and Isparta–Golcük. But these slabs are limited in Isparta-Golcuk in the east and in Menderes Graben in the west.

6. Conclusions

In this study, the tectonic structure of the Aegean-Anatolian plate and the subduction geometry were determined by 3-D seismic tomography method based on P wave arrival time inversion. The tomographic results are compared with tectonic structures and previous geophysical observations in the study region. Although there are some differences, the results obtained from this study are generally consistent with previous suggested models.

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The results of synthetic and checkerboard resolution tests have shown that the imaged anomalies give reliable results to the depth of 120 km. The border between the Aegean-Anatolian plate and the African plate consists of the Aegean and the Cyprwan arcs. The tectonic and geophysical evidence obtained from the distribution of the Vp distribution and the interpretation of the Vp values indicate the existence of two separate subduction zones along to the Aegean and Cyprean arcs. The tomographic images show that the fracture could extend from the west of Cyprus to the Aegean arc. The subduction along the Cyprean arc is in the Antalya Gulf, the subduction along the Aegean arc takes place around the Gokova Gulf.

In order to view the slabs, the vertical changes of Vp % anomalies have been plotted and compared with the tectonic structures in the region. It has been determined that the slab related to the Cyprean and Cyprean arcs has reached to the depth of 100-km. The tomographic results from this study showed the northward subducting African lithosphere slabs beneath Anatolia along the Aegean and Cyprean arcs. The Aegean and Cyprean slabs separated by tear zone occupied by slow anomalies. They are possibly associated with hot upwelling asthenosphere. The low Vp % anomalies seen in the N-S trending cross-sections indicate the subducting African plate perpendicular to the trench axis. In the subduction zone the Vp% values are described by crustal velocities and are lower than average continental values. The obtained low velocities may be associated with high crustal temperatures, high fracture or the flow of liquids at high pore pressure (Al-Shukri and Mitchell 1988; Mitchell et al. 1997). The sourceof these fluids is due tothe subduction of the African plate under the Aegean-Anatolian blocks. It is thought that the gradual addition of these fluids caused the partial melting forming different orogenic magmas and may also trigger large crustal earthquakes.

In the study area, there are many structural elements that give the Mediterranean coasts its present shape. These structural elements are shaped according to the subduction mechanism in the region. In the continental crust shallow earthquakes occur on dip-slip normal and reverse faults and the deep earthquakes occur in the subduction zone in the region. Earthquakes occur with oblique faulting (including normal and strike slip) in the Fethiye-Burdur Fault Zone, which is one of the most important tectonic structures of the region. The Eastern Taurus is still rising due to compression and expansion caused by many shallow earthquakes.

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