The velocity structure of the North of Iran from seismic travel times

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Abstract

Introduction: Body and Surfer waves have been produced with earthquake. So that regional seismic Networks have been recorded all local events. Travel time of body waves, between source and stations, to be used for crustal study and Joint Inversion modeling.

Aim: Travel times of earthquakes between sources and stations in the north of Iran are used to develop P- and S-wave velocity models across southern Caspian. Errors in travel times are minimized using sources for which locations and origin times are constrained by local data (Sari Network).

Material and Methods: The method at this survey base on recorded earthquake in the seismic network, North of Iran. There are the minimum errors of the travel time for local data. The body waves do exist with avalute in the Sari seismic four stations. So that, the travel time curves have been calculated for crustal (Pg, Sg) and Mantel (Pn, Sn) waves. Then we can evaluate the velocity of the wave, with use of modeling of body wave. This study determined Conrad and Moho discontinue depth.

Results: Apparent velocities are calculated between 10 and 150 km for P (6.25 km/sec) and S (3.55 km/sec). The value of velocity for P (8.05 km/sec) and S (4.71 km/sec) are calculated in distance ranges of 200-1000 km, which is correspond to depth of Conrad discontinuity, 17-18 km. Moho discontinuity is determined to be at a depth of 36-40 km.

Conclusion: We use times from stations in Sari north of Iran and published local summary times as a guide for interpretation at greater ranges. Allowing for known differences in local travel-time residuals between the southern and northern of Iran, the P times are best fit by a model that has a small velocity forward at the base of the crust, and the S times are best fit by a model with a more substantial reduction in velocities. Both P- and S-wave traveltimes are concordant with global averages such as the 1-D earth model AK135. Thus, the velocities inferred beneath the crust are relatively low than those of the crust but not necessarily low relative to global averages

Keywords: Velocity structure, Alborz, Travel time

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Introduction

The Iranian plateau is relatively a wide zone of compression deformation along the Alpine-Himalayan active mountain belt, which is entrapped between two stable platforms, the Arabian plate in the southwest and Eurasia plate in the northeast. Iran is one of the seismically active areas of the world and is frequently affected by destructive earthquakes, imposing heavy losses in human lives and widespread damage. [1] Numbers of geologists have been studied on seismotectonic provinces in Iran and have produced geological, geophysical and seismological information. [1-7] Gap data cased seismotectonic province different and the important these show in Figure (1) **.** [2] The Alborz is a narrow mountain range only 100 km wide which wraps around the South Caspian Sea. The mean elevation in the Alborz drops sharply from 3000 m in the inner belt to 28 m at the Caspian shoreline to the North**.** Suggesting that the tectonics of the north of Iran continue to be driven by processes within the crust and Moho discontinue the plateau. To better understand the effects of continental collision on the crust and upper mantel structure beneath the plateau, we used traveltimes from local earthquakes to direction and refraction phases the lateral variations in the P-wave and S-wave velocity structures beneath the north of Iran.

Geological background

Mazandaran province is along the central Alborz seismic zone which consists of a broad arch of parallel anticlines and synclines forming the southern border of the vast depression Caspian Sea. [8,9] In its western part, the range shows structural axes trending NW-SE, roughly parallel to the northern part of the Zagros seismic zone and to the structural alinements of Caucasus. [10-12] On the other hand, the eastern part of Alborz is characterized by structural axes trending approximately NE-SW, parallel to the Great Kavir (Doruneh) fault. [13,14] These two different structural trends meet in the central Alborz, which thus shows a critical position in the framework of the range and in this zone of convergence of two different alignment that the great quaternary volcano of Damavand has been built. Geological evidences and fault plane solutions of earthquakes in central Alborz indicate the existence of both thrust and strike-slip faulting. [15-17] In the regional scale, the Arabian and Eurasian plates are converging in a north-east direction and Alborz Mountains are undergoing shortening and shear motions. The oblique motion results in dominantly right-lateral, strike-slip earthquakes and in frequent strike-slip earthquakes that indicate slip partitioning. [18,19]

Using the geological information and the works done by Berberian (1976), Jackson and McKenzie (1984) and Allen et al., (2003) [20], a simplified tectonic map including the epicentral distribution of instrumentally recorded strong earthquakes, reported during 1925-2008 by international agencies, and the available faults was provided in this region which is presented in Figure (2). As indicated in this figure, several major faults, anticlines and synclines could be known almost parallel to the southern border of the vast depression of the Caspian Sea. In addition, central Alborz includes a remarkable number of minor faults indicating a complicated pattern of deformation.

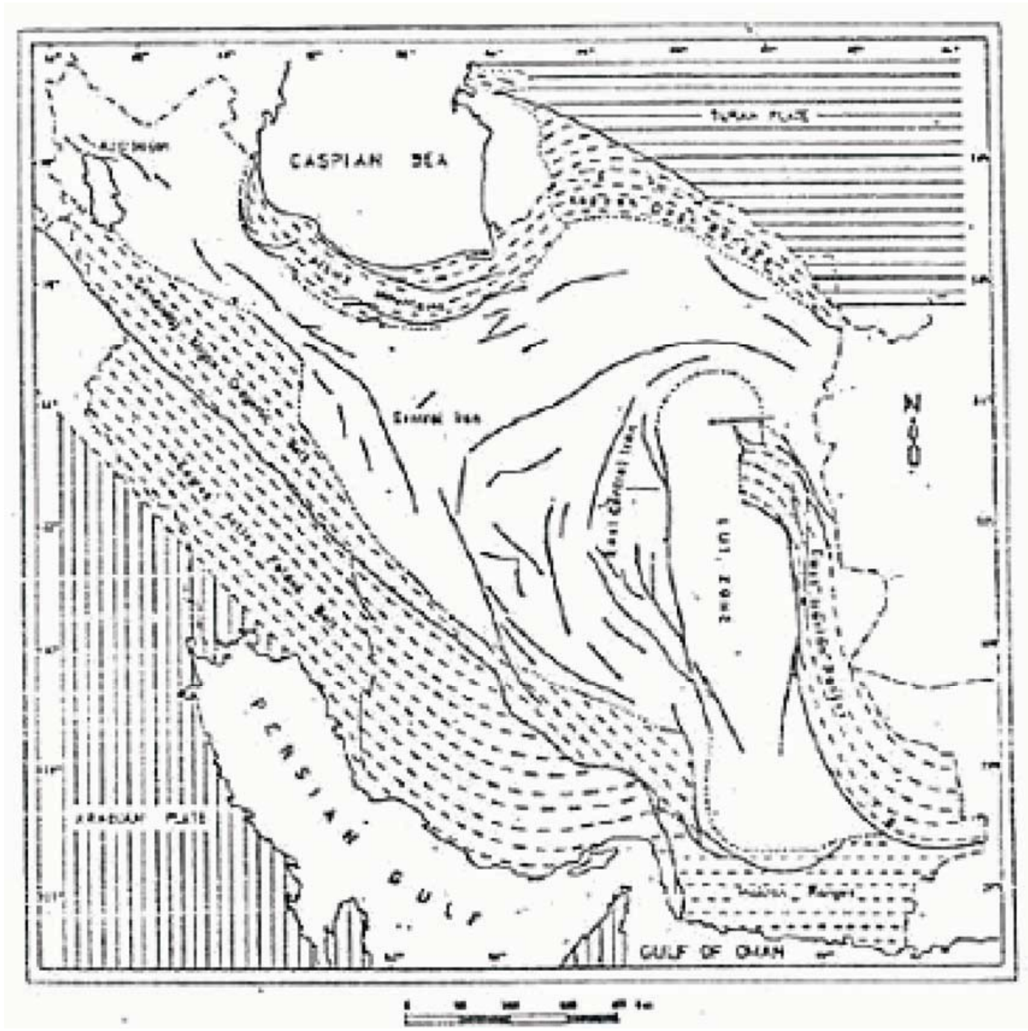


Figure 1- Seisotectonic provinces in Iran (2)

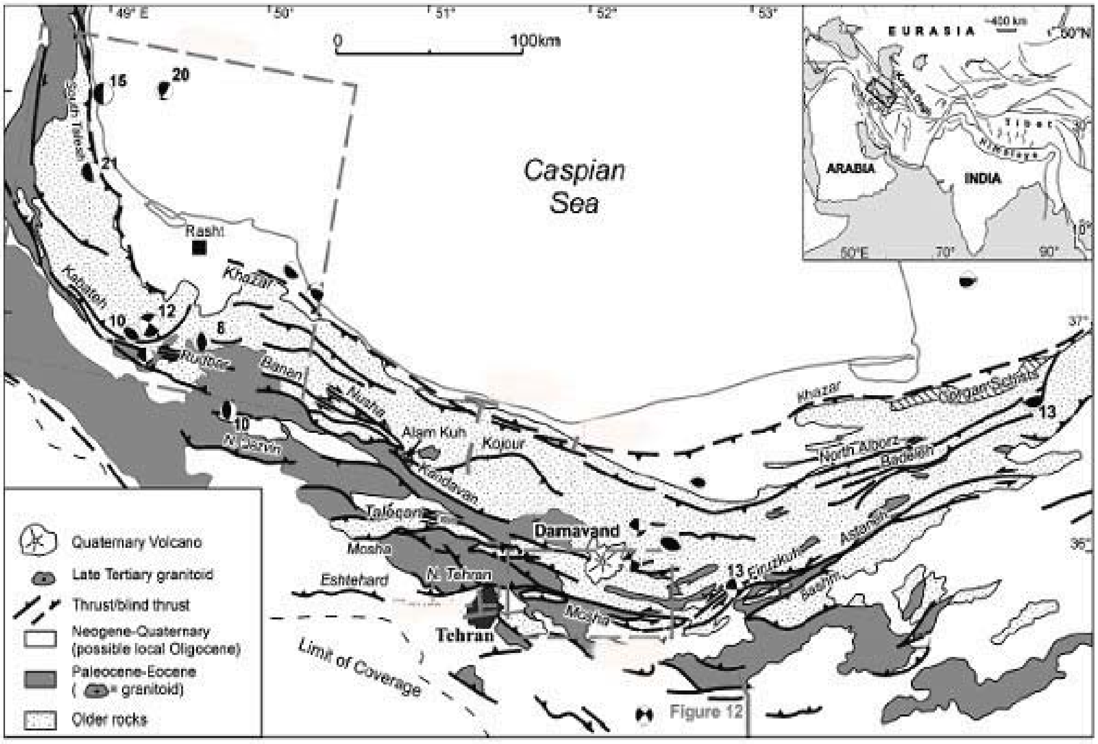


Figure 2- Map of Alborz tectonic [20]

Seismological background

Deformation of Iranian plateau is related to the continuing convergent movement between the Arabian plate and the Eurasia; by north- northeastward drift of Afro-Arabia towards Eurasia. Iran is one of the seismically active areas of the world and is frequently affected by destructive earthquake, imposing heavy losses in human lives and widespread damage. The continental-continental collision zone of Zagros in southwest Iran highly seismic region of Alborz-Azerbaijan covering north and northwest of Iran, which constitute a part of northern limit of Alpine-Himalayan organic belt, intraplate environment of central-east –Iran, continental collision zone of Kopeh Dagh in northeast, and oceanic-continental subduction zone of Makran in southeast Iran. Earthquakes occur in different seismotectonic provinces.[2] The topographic contrast is less pronounced to the south where the connection whit the lowlands of the Central Iranian desert is progressive. The Alborz Mountains are branch of the Alpine Himalayan orogeny in Iran (Figure 1).

Seismic Sources

In Alborz-Azarbayejan major seismotectonic province, The Khachak fault, extended for over 34 km in an N-S direction in south of Kojour. The Baladeh fault, which had a mechanism involving thrusting and east-west right-lateral strike-slip with NS slip vector in Baladeh Valley. The Azad-Kuh thrust fault extends to 76 km in a NW-SE direction from southwest Kojour to north of Kandowan. Geomorphic investigation along the North Alborz fault, which is located north of Iran, provided some new constraints on the activity of this region. [21] This fault extends to 300 km in a NE-SW direction which had a mechanism involving thrusting with SW slip vector from east of Gorgan to southwest Tonkabun. The Khazar-Mazandaran fault extends 600 km in an E-W direction in north of Kojour. The

Kandowan thrust had a WNW-ESE direction whit north slip (Figure 3) Historical earthquake of Iranian plateau, including central Alborz, has already been studied.[2,22,23] Though the historical earthquakes are imperfectly known, these studies suggest that central Alborz has experienced many destructive earthquakes in historical time. A brief explanation of significant historical earthquakes is given tabel (1) . [23]

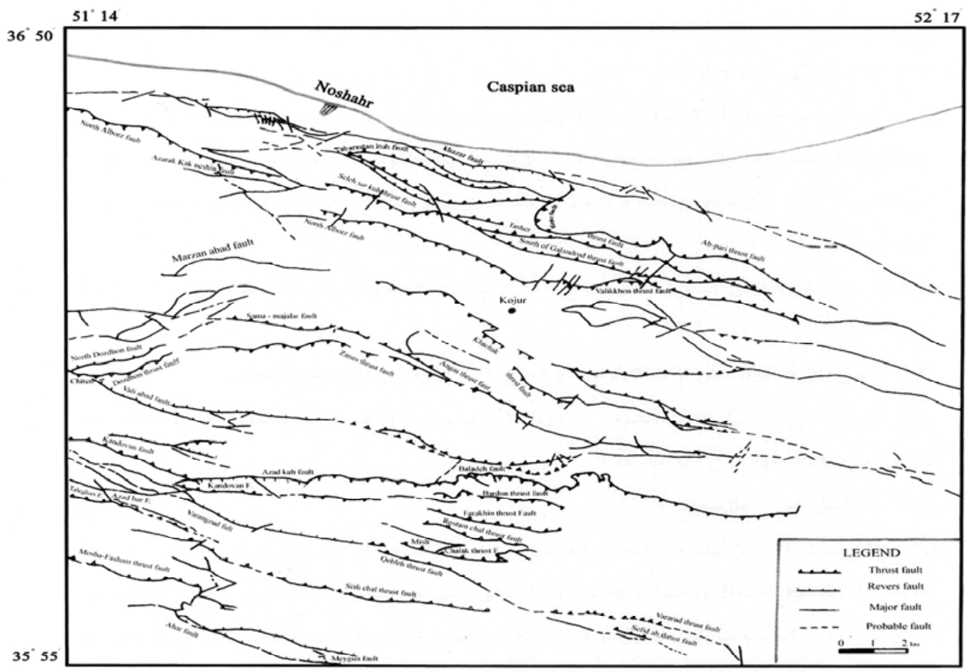


Figure 3-: Fault map of Alborz tectonic

Table 1- Historical earthquakes in the North of Iran

No.	YEAR	Lat. (^{0}N)	Long. (^{0}E)	Mag	Region	Reference
1	856/12/22	-	-	5	Eastern Alborz	AMB
2	874	37	54	7	Gorgan	AMB
3	958/02/23	-	-	7	North central Iran	AMB
4	1117/05/1	-	-	7	Southern Alborz	AMB
5	1119/12/10	36	50	6	Qazvin	AMB
6	1470	36	56	5	Gorgan and Gonbad-e Kavus	AMB
7	1485/08/15	37	50	7	Gilan	AMB
8	1489	37	54	7	Gorgan	AMB
9	1608/04/20	37	50	6	southern Gilan	AMB
10	1639	36	50	7	Qazvin	AMB
11	1678/02/3	37	51	6	Lahijan	AMB
12	1808/12/16	36	53	6	Amol	AMB
13	1815/06/1	36	52	6	Damavand	AMB
14	1830/03/27	36	53	7	Southern Mazandaran	AMB

AMB: Ambraseys (23)

On 11th April 1935, an earthquake in Kasut, followed by many aftershocks, ruined many houses, mosques and bridges and more than 480 people were killed. In 1957, on Tuesday June 2, there was a catastrophic earthquake in Northern Alborz and more than 1500 people were killed. The Rudbar earthquake of June 21, 1990 occurred in the north of Alborz in Gilan province. The fault trace followed old faults with many topographical features of recent activity. The shock was in Manjil, Rudbar, Lushan and Tarom in Zanjan province. This earthquake killed more than 13000 people and left thousand homeless. On 28th May 2004 a moderate but relatively destructive earthquake occurred in Baladeh-Kojour. According to official reports, at least 35 people were killed and 400 others were injured in this earthquake. More details about these earthquakes are given by Ambraseys and Melville (1982) and Berberian et al., (1994) (24). The seismicity of Central Alborz is better understood in the present century. However, due to the lack of a seismological network operating full time with an acceptable quality, the source parameters of earthquake are relatively high. [21,22,25] Local events whit magnitudes smaller than 4.5 richter either are not located or do not have reliable source parameters . [26,27]

Results and discussion

Data processing and crustal structure in the Mazandaran region

The local travel times are all modeled as body phases. The simplest approach to the inverse problem of determining velocity at depth from travel times treats the earth as flat layers of uniform-velocity material. We thus are being by deriving the travel time curves for such a model, which show when seismic waves arrive at a particular distance from a seismic source.[28] The travel times, especially those of waves that are critically refracted at the interfaces, are used to find the velocities of the layers and underlying half space and layer thicknesses. The crustal imaging, the main objective is to determine the basic layered structure of the crust; the P and S velocities as a function of depth, including the depth and contrasts across any internal boundaries, and the overall crustal thickness, or depth to the crust-mantle boundary.

The data used in this study are traveltimes from local events that are listed by the Institute of Geophysics University of Tehran (IGUT 2004-2008). Local earthquakes are defined here as events recorded at distances ranging from approximately 10 km to 1100 km (Figure 4). Local arrivals include true Pg, Sg direct wave and Pn, Sn headwave arrivals at the shorter distances and waves bottoming at depth of 2-35 km at the farthest distances. We refer to all these arrivals as the body phase. Pn traveltimes are sensitive to both variations in crustal thickness and velocity and to the laterally varying velocity structure of the uppermost mantle. Our forward method uses the local traveltimes to model both the lateral variations in crustal structure and the lateral velocity variations in the crust and uppermost mantle. Similar studies have been applied to Pn and Pg data from southern California [29,30] and to regional arrivals of the western United States. [31] Number of first and second arrival times for events and receivers were selected for rays traveling between 10 km and 1100 km in the Sari region shown in Figure (5). These traveltimes were corrected for stations elevation and screened by event depth (<30 km), event size (>10 arrivals recorded local per event), IGUT listed recording precision (<0.01s), and IGUT residual (<0.26s). An iterative selection procedure then eliminated insufficiently recorded events and stations and removed obvious outliers from the data set (15). The final data set was fit by a straight line regression of travel time to distance and residuals computed relative to that fit. In the final data set, each event was recorded by at least four stations and each station recorded at least 10 events. The number of arrivals per station ranges from the impost minimum of 10 arrivals to a maximum of 180 arrivals. As one might expect from the distribution of earthquakes and seismic stations, number of phases is highest beneath the Peran station.

The boundary between crust and mantel is known as the Mohorovičić discontinuity, or Moho. We now denote the head wave as Pn and the direct wave as Pg (g for granite). Corresponding arrivals are also observed for S waves..[28] A representative travel time from Mazandaran is shown in Figure (6) and continental crustal thickness from this region shown in Figures (7,8). Refraction studies show regional variations in crustal thickness and Pn, Sn velocities, as illustrated for north of Iran, the Conrad discontinue is typically thick 17-18 km, and the Moho discontinue is 36-40 km. The Pg arrival indicates a velocity of 6.26±0.04 km/s and Sg is 3.55±0.08 km/s, the Pn velocity is 8.05±0.05 km/s and Sg is 4.71±0.02 km/s. table (2) lists the permanent Sari seismic networks in our area of study which are also shown in Figure(9).

The AK135 tables represent and update of the iasp91 travel time tables [32] to try to match the behavior of a wider range of phases. The construction process for the ak135 model was described by Kennett, Engdahl and Buland (1995), and was based on new empirical traveltime tables obtained by relocating events using the isp91 model. Like its predecessor, AK135 is a radially stratified velocity model and the traveltime tables are derived from the model so that a consistent basis exists for all phases. The P wave traveltimes are very similar to isp91, but more significant changes are introduced for S and particularly the core phases. The AK135 tables have been used as the basis for the systematic relocation of events by Kennett et al, and the subsequent updates of their catalogue. Figure (10) shows the comparison of the AK135 model [32] and a newer model in north of Iran. The body wave traveltimes compared with the predicitions of the global seismic velocity model AK135. The Pn and Sn velocities observations are confirmed by a new model that shows variation in seismic velocities in the crust and uppermost mantel (<50km) across the north of Iran.

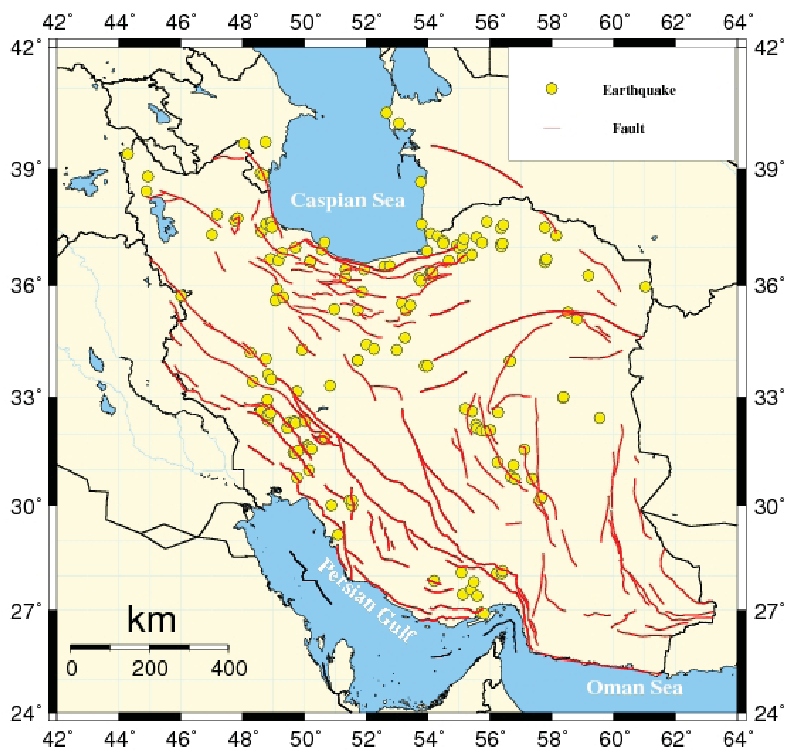


Figure 4- Seismotectonics map of Mazandaran Province. Circles show local seismicity of earthquakes, which are used in present study.

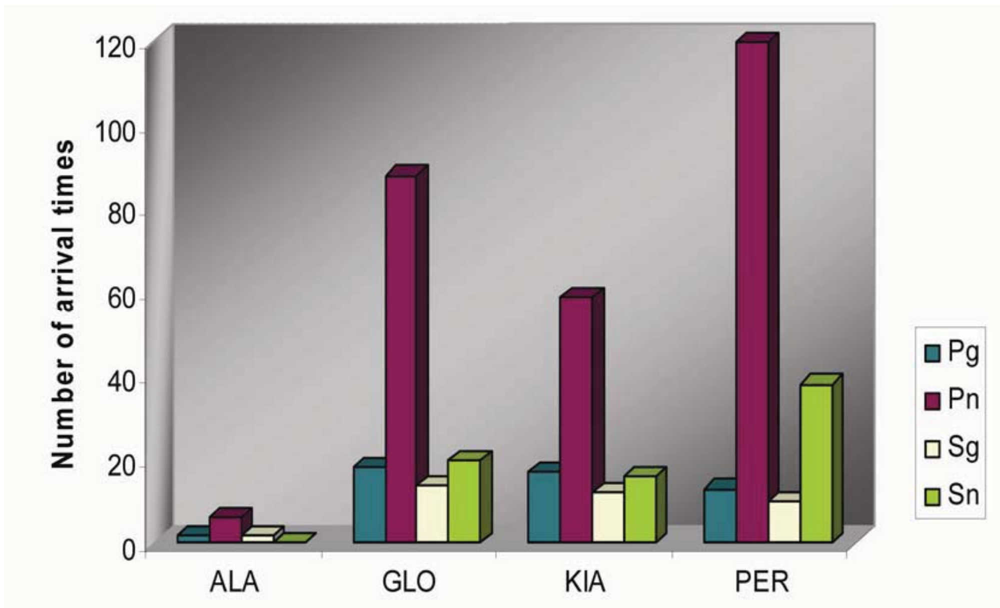


Figure 5- Number of body phases recorded in Sari Seismic Network

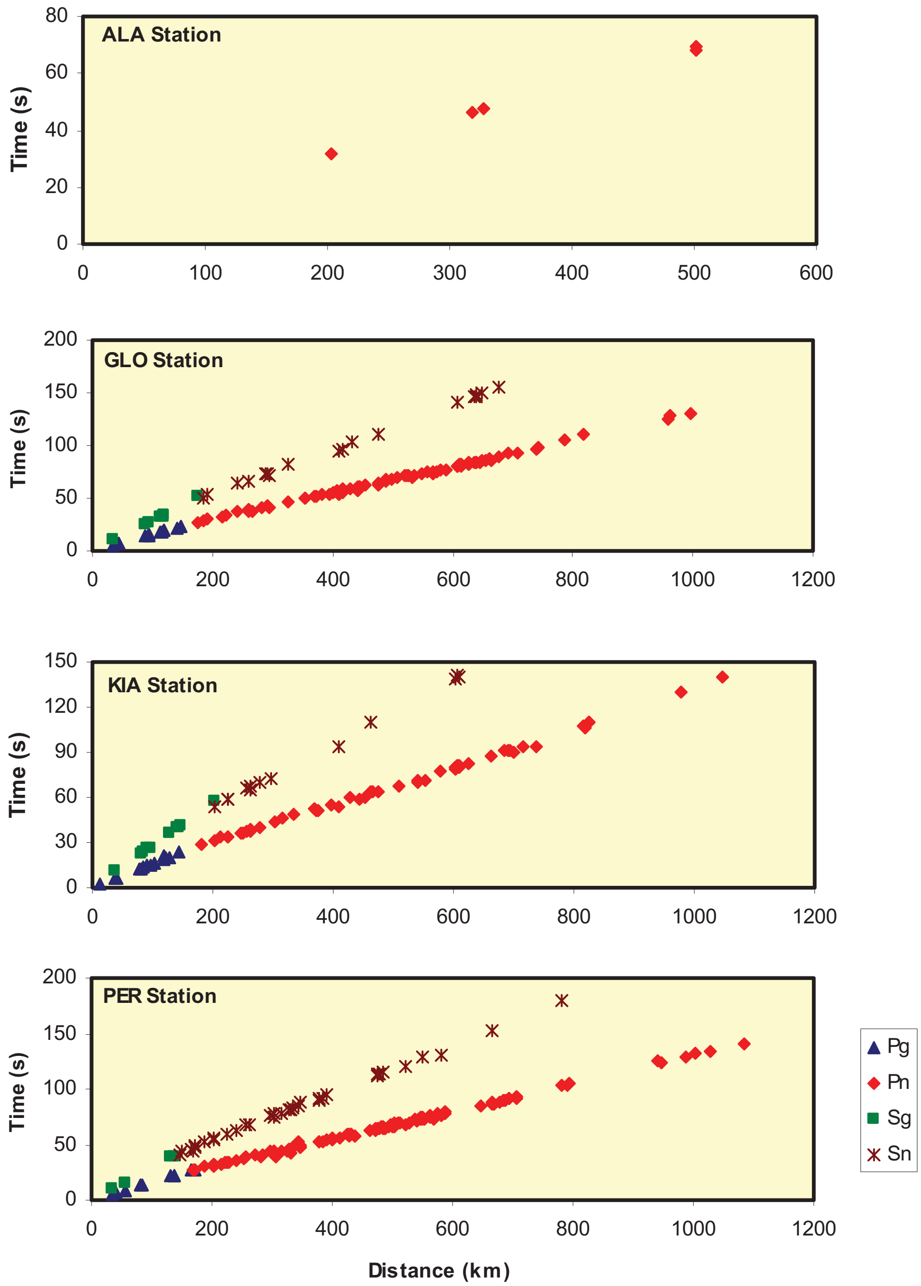
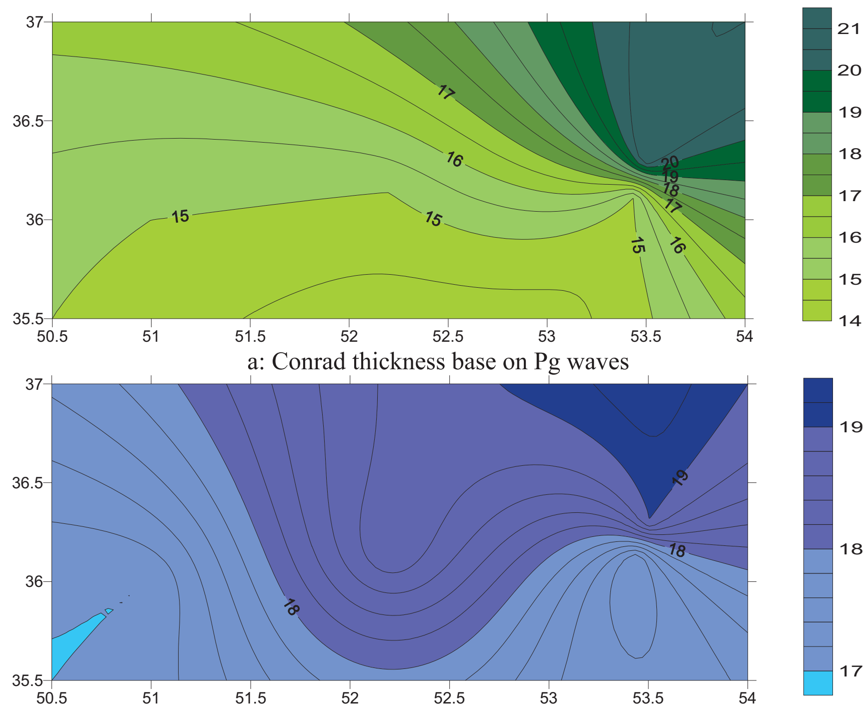


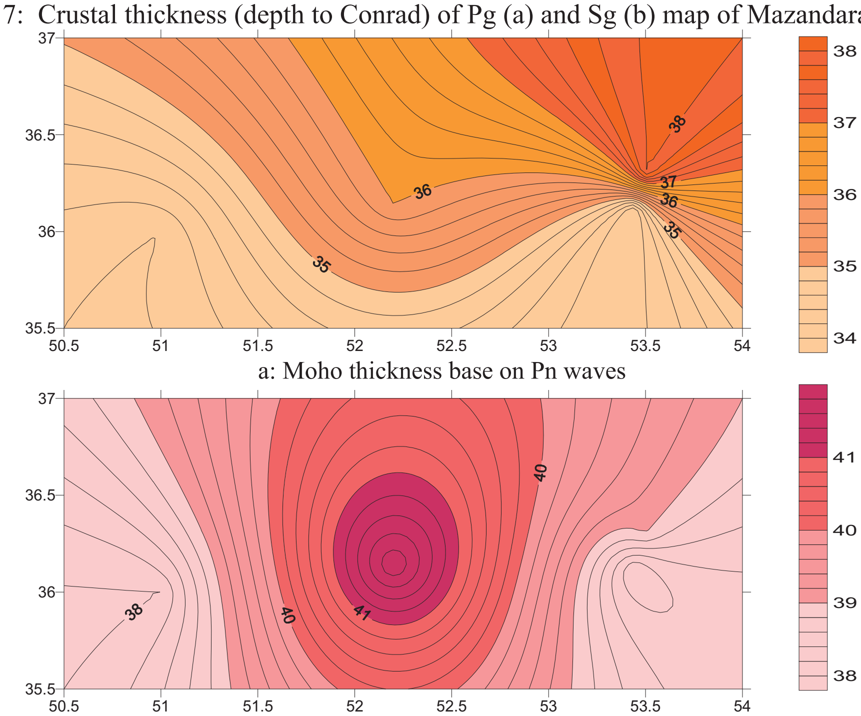
Figure 6- The travel time curves are labeled using forward method the direct waves are Pg and Sg, and the head waves are Pn and Sn.



a: Conrad thickness base on Pg waves

b: Conrad thickness base on Sg waves

Figure 7: Crustal thickness (depth to Conrad) of Pg (a) and Sg (b) map of Mazandaran region



a: Moho thickness base on Pn waves

b: Moho thickness base on Sn waves

Figure 8- Crustal thickness (depth to Moho) of Pn (a) and Sn (b) map of Mazandaran region

Table 2- Station locals and Parameter the crust model in Mazandaran region

Network	Station Name	Station Cod	Latitude N°	Longitude E°	Vpg(km/s)	Vpn(km/s)	Vsg(km/s)	Vsn(km/s)	H (km)	ho (km)
	Alasht	ALA	36.5	52.483	-	8.05±0.05	-	-	-	-
Sari	Ghalughah	GLO	36.3	53.498	6.31±0.04	8.08±0.08	3.50±0.14	4.72±0.03	38±1	20±1
	Kiasar	KIA	36.12	53.44	6.22±0.05	8.01±0.01	3.56±0.07	4.70±0.00	36±2	16±1
	Peran	PRN	36.15	52.203	6.24±0.03	8.06±0.06	3.60±0.03	4.72±0.03	39±3	17±2
Average Velocity (km/s) and Average depth (km)					6.26±0.04	8.05±0.05	3.55±0.08	4.71±0.02	38±2	18±1

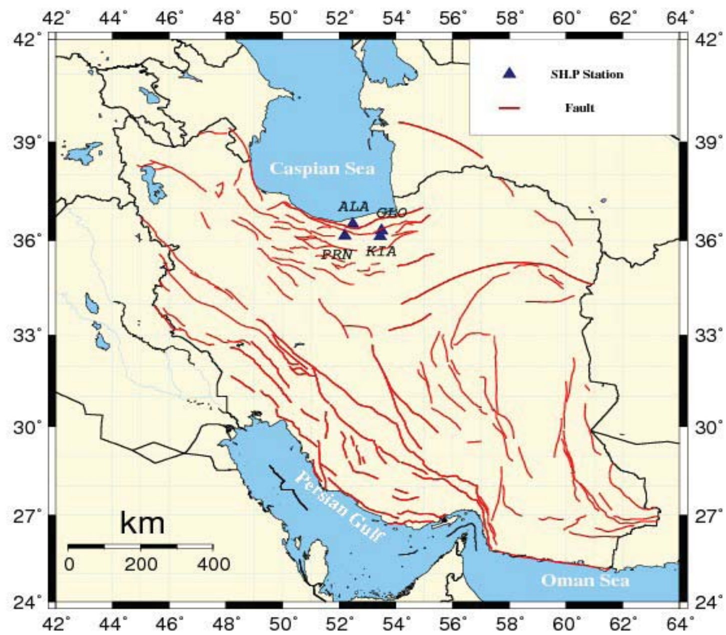


Figure 9-Distribution of seismic stations in the north of Iran, Sari network

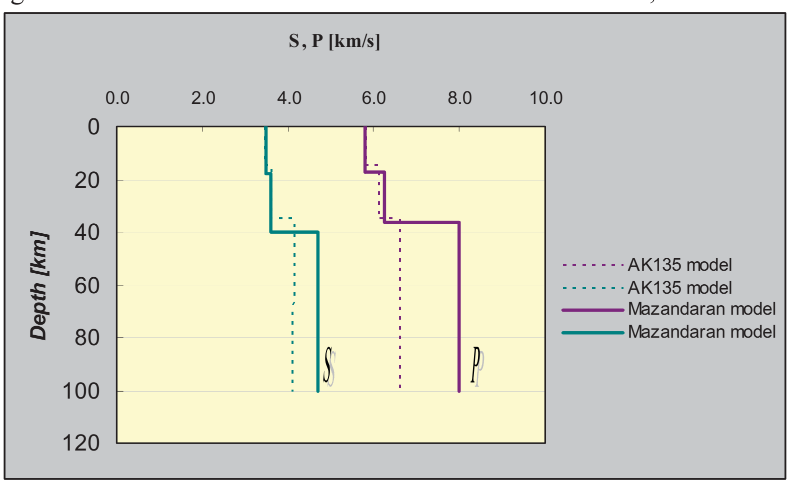


Figure 10- Comparison of the AK135 model [33] and a newer model

Conclusions

The apparent velocity curves indicate that the transition zone change rather than a sharp jump. The 450 arrival times have been recorded in Sari stations since 2004-2007. It is concluded that the gradual change is not due to gradual increase of velocity but is mainly predicted by the two point method of calculation which is used in this study. The events have a depth range of 2-35 km. there were several large earthquakes north of Iran, which were recorded by temporary local networks.[33,34] Using two- station methods, which is independent of mislocation errors, Pn velocity is determined along several paths in Iran. [35] This value for north of Iran is consistent with the model obtained in this study. Using local data, the original straight line fit to the data set indicates a mean Pg and Sg crustal velocities of 6.26±0.04 km/s and 3.55±0.08 km/s, and assumed mean source depth of 18 km. an assumed Pn velocity of 8.05±0.05 km/s and Sn velocity of 4.71±0.02 km/s, the Conrad discontinue is typically thick 18±1 km, and the Moho discontinue is 38±2 km. However, both P- and S-wave traveltimes can be satisfied with models that have velocities below 50 km that are concordant with global averages such as the 1-D earth model AK135. Thus, the velocities inferred beneath the crust are low relative to those of the crust but not necessarily low relative to global averages.

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