

SEISMICITY, SEISMOTECTONICS, CRUSTAL STRUCTURE AND ATTENUATION DATA ON IRAQ

“A TETHYSIDES OROGENIC BELT REVIEW”

SAHIL A. ALSINAWI

12190 Abington Hall Place #201, Reston, VA 20190, USA

salsinawi@comcast.net

ABSTRACT

The Arabian subcontinent Plate is one of the Earth's largest blocks that has held together and moved many kilometers as a unit since the late Cretaceous experiencing relative transitional motion with respect to the Eurasian, African, Somalian Iranian, Anatolian, and Aegean Plates. This plate is subducted under the Anatolian and Iranian Plates Compressing the Tethys geosyncline belt as part of the Alpine movement which reached its climax in the Tertiary and continued until the Oligocene and early Pliocene, where the Tethys sea was completely closed in the region .The Zagros belt took a NE-SE trend, while the Taurus Belt took an E-W trend. These plate boundaries have complicated patterns and their associated seismicity is diffused without sharp borders. The forces that have formed the plate boundaries are still active.

The tectonic framework of Iraq has a NE-SW classification starting with (i) The stable shelf restricted by a set of deep faults of AbuJir, Euphrates and Palmyra fault zones and characterized by reduced thickness of sedimentary cover. (ii) The Mesopotamian Zone, (iii) The Simply Folded Zone which lies to the northeast of the Mesopotamian zone, most foldings are buckle folds e.g. Hatra-Bekhme fault, Fatha –Horan fault and Diyala faults. (iv) The Thrust Zone which compromises the Alpine Euogeosynclinal rocks, characterized by complex thrust structures and subjected to orogenic movements in late Triassic, Upper Cretaceous, Miocene and Pliocene The latest movements were ascertained by ophiolite facies and flysch sediments. (v) The Central Iranian Zone, which is characterized by a chain of Mesozoic and Cenozoic volcanics .The region, was folded and faulted during the Alpine movement in the Tertiary.

Iraq has an intermediate shallow focus; level of seismicity .The seismicity is characterized by having 90% of the events with mb magnitudes 4-5 and focal depths

range of 30-50 kms for 54% of the events. Magnitudes higher than 5.5 are less than 8%. The seismicity is controlled by the activity of the Zagros-Tauros belts. Space-time distribution of seismicity reveals three stages of seismicity 1900-1930, 1930-1960, and 1960-present, with this average recurrence relationship: $\text{Log}N = 5.8 - 0.7 b$. The overall seismicity of Iraq is influenced mainly by the Zagros and Taurus systems with partial effect of the neotectonic activation of the upper crust

Fault plane solutions gave a trend parallel to the structural trends of the Zagros-Taurus Belts and the pressure axes are approximately perpendicular to the major structures. A composite fault plane solution was also carried using microearthquake records from north central Iraq and the results were in conformity with the data collected from the literature.

A seismotectonic map is constructed using all the available seismic, tectonic and geological information. The map shows the non-homogeneous distribution of seismic activity. This may indicate deformation along the belt to be nonhomogeneous and also reflects the change of geometry of the Arabian Plate edge due to its rotational movement.

Microearthquake recording was initiated in Iraq in a time when there was no permanent seismic monitoring in the country. They were carried out during the period 1974-1982 covering different physiographic and tectonic provinces, for a total recording period of 8550 hours (approx. one year). The microseismicity shows an increase in a southwest northeast direction. The rate of microseismicity varies between 1.15 to 8 events/day. An overall correlation was found between the macro and microseismicity of the country with minor deviations in certain areas..

A crustal structure determination in Iraq was conducted utilizing 91 events in the distance range of 30-100 degrees. The Iraqi Seismological Network (ISN) by four stations namely Baghdad (BHD), Mosul (MSL), Rutba (RTB) and Sulymania (SLY) recorded events. Four different methods were utilized for the crustal determination. (a) The one layer crustal transfer function model, (b) the spectral ratio method compared to one and three layer models, (c) the relative travel time residuals (d) The M-converted Sp phases observed on long period seismograms from three events recorded by the (ISN) from the S-Sp time difference and the Sp/S amplitude ratios.

The crustal thickness was found to increase towards the Zagros thrust zone in agreement with gravity interpretation; the results are also consistent with the regional crustal values. The crustal values varied in thickness, the range in Baghdad region was 38 kms (V_c 6.3 km/sec), Rutba 33-35 kms (V_c 5.9 km/sec, V_m 8.2 km/sec), Mosul 31-34 Kms (V_c 6.0 km/sec, V_m 8.3 km/sec) and Sulymania 41-43 kms (V_c 6.1 km/sec, V_m 8.0 km/sec).

Two transect projects were carried out. The first was an EW transect of 650 kms that passes through Baghdad starting from the Jordanian to the Iranian borders. The crustal thickness along the transect ranges between 31-37 kms with an average of 34 kms. The geologic and tectonic data along the transect are compared with the available aeromagnetic, Bouguer gravity and seismic reflection data.

The second transect profile was a NW-SE trend with 605 kms long and 100 kms wide. This was the first GGT project in Iraq. The thickness of the sedimentary layers ranged between six to seven kilometers. The Moho was calculated to be around 37 kms with V_c 6.8 km/sec, V_m 7.95 km/sec. The Conrad discontinuity around 20 kms with V_c changes between 6.10 km/sec to 6.50 kms/sec.

The attenuation of earthquake generated P waves in Iraq was attempted where P waves recorded at Baghdad (BHD) and Mosul (MSL) seismological observatories were picked from earthquakes originating in the neighboring Turkey and Iran. Thirty-seven such events were chosen, twenty-three were recorded at (BHD) and fourteen at (MSL) observatories. The earthquake paths were along the northern and central regions of Iraq, with magnitudes ($m_b=4.1-5.7$). The amplitude distance curve of Nuttli(1980) was utilized in this investigation and the mean attenuation value obtained for the whole area was $\alpha=0.0035 \text{ Km}^{-1}$. The value obtained for Iran by Nuttli (1980) was $\alpha=0.0045 \text{ Km}^{-1}$. The difference is attributed in terms of different tectonic stability.

A newly established research group, "Almashriq Geophysical Research Group "A.G.R.G, is set to conduct coordinated research on the Eastern Mediterranean Geophysics with emphasis on seismology, more on this group is announced on the **MESF** website.

1. GEOLOGY AND TECTONICS:

The Arabian subcontinent Plate is one of the Earth's largest blocks that has held together and moved many kilometers as a unit since the late Cretaceous experiencing relative transitional motion with respect to the Eurasian, African, Somalian, Iranian, Anatolian, and Aegean Plates. The Arabian platform is comprised of Paleozoic intracratonic basins overlying crystalline basement. The Mesozoic basins formed as the results of the Late Permian and Early Triassic opening of the adjacent Neo-Tethysides Ocean and the development of its passive margins. Tectonic setting of the Arabian plate shows that it is almost surrounded by active plate boundaries. The western boundary is marked by the left-lateral Dead Sea fault system that extends from the Gulf of Aqaba in the south to the northern Triple Junction of Cyprus subduction zone, Bitlis suture and the Dead Sea Transform, Beydoun (1991), Alsinawi & Al Dilaimi (1993) and Best et.al(1993).

The Arabian Subcontinent Plate is subducted under the Anatolian and Iranian Plates Compressing the Tethyside geosyncline belt as part of the Alpine movement, which reached its climax in the Tertiary and continued until the Oligocene and early Pliocene, where the Tethys Sea was completely closed in the region. The Zagros Mountains which are part of the Alpine-Himalayan orogenic system can be divided into three structural zones: an inner crystalline zone of overthrusting, an imbricated belt, and a zone of folding often referred to as the Simply Folded Belt. The Taurus Belt took an E-W trend. These two plate boundaries have complicated patterns and their seismicity is diffused without sharp borders. It is believed that the forces that have formed these plate boundaries are still active, Figure 1, Ghalib & Alsinawi (1974), Jassim (2000).

The tectonic framework of Iraq has a NE-SW classification starting with (i) The stable shelf restricted by a set of deep faults of AbuJir, Euphrates and Palmyra fault zones and characterized by reduced thickness of sedimentary cover. (ii) The Mesopotamian Zone, (iii) The Simply Folded Zone which lies to the northeast of the Mesopotamian zone, most foldings are buckle folds e.g. Hatra-Bekhme fault, Fatha –Houran fault and Diyala faults. (iv) The Thrust Zone which compromises the Alpine Euogeosynclinal rocks, characterized by complex thrust structures and subjected to orogenic movements in late Triassic, Upper Cretaceous, Miocene and Pliocene The latest movements were ascertained by ophiolite facies and flysch sediments. (v) The Central Iranian Zone which is characterized by a chain of Mesozoic and Cenozoic volcanics .The region was folded and faulted during the Alpine movement in the Tertiary, More comprehensive analysis are given by Al Naqib (1967), Ditmar et. al. (1971) and Buday & Jassim (1987),

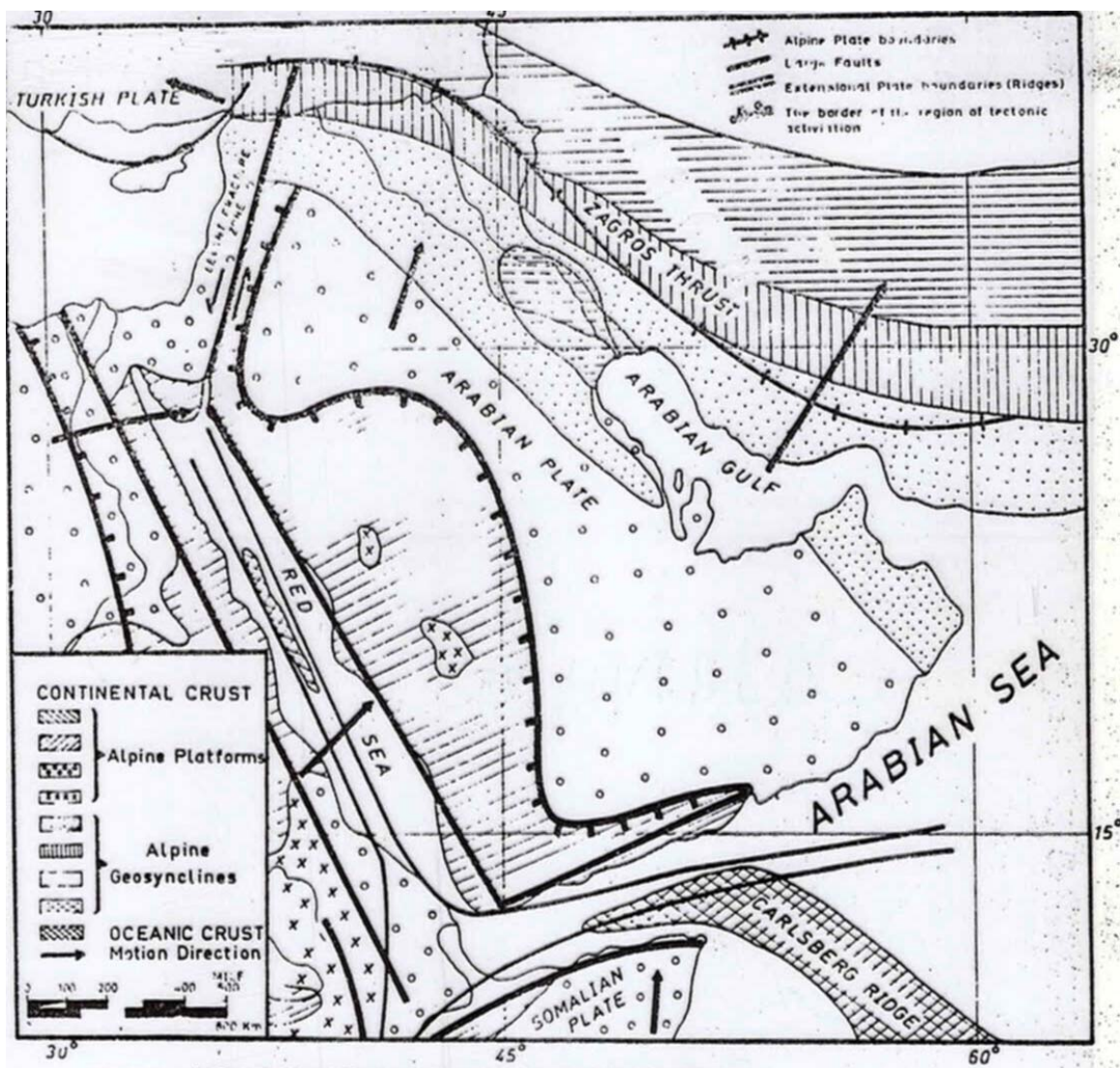


FIGURE 1: GEODYNAMIC SETTING OF THE ARABIAN SUBCONTINENT (Ghalib & Alsinawi 1974)

2. SEISMICITY AND SEISMOTECTONICS SETTING:

Iraq has an intermediate shallow focus; having 90% of the events with magnitudes 4-5 and focal depths range of 30-50 kms for 54% of the events characterize level of seismicity. The seismicity. Magnitudes higher than 5.5 are less than 8%. The seismicity is controlled by the activity of the Zagros-Taurus belts. Space-time distribution of seismicity reveals three stages of seismicity 1900-1930, 1930-1960, and 1960-present, with this average recurrence relationship:

$$\text{Log N} = 5.8 - 0.7 b$$

The overall seismicity of Iraq is influenced mainly by the Zagros and Taurus systems with partial effect of the neotectonic activation of the upper crust. More detailed accounts for Iraq's seismicity is given by Alsinawi & Ghalib (1975), Alsinawi & Issa (1986) and Alsinawi & Al Qasrani (2003).

Fault plane solutions gave a trend parallel to the structural trends of the Zagros-Taurus Belts and the pressure axes are approximately perpendicular to the major structures. A composite fault plane solution was also carried using microearthquake records from north central Iraq and the results were in conformity with the data collected from the literature, Alsinawi & Ghalib, Alsinawi and Issa (1986),

A seismotectonic map, Figure 2, is constructed using all the available seismic, tectonic and geological information. The map shows the non-homogeneous distribution of seismic activity. This may indicate deformation along the belt to be nonhomogeneous and also reflects the change of geometry of the Arabian Plate edge due to its rotational movement.

Microearthquake recording was initiated in Iraq in a time when there was no permanent seismic monitoring in the country. They were carried out during the period 1974-1982 covering different physiographic and tectonic provinces, for a total recording period of 8550 hours (approx. one year). The microseismicity shows an increase in a southwest northeast direction. The rate of microseismicity varies between 1.15 to 8 events/day. An overall correlation was found between the macro and microseismicity of the country with minor deviations in certain areas, Alsinawi & Al Ridha (1988).

3. CRUSTAL STUDIES :

Crustal depth determinations in Iraq were carried earlier depending on potential field data. The average thickness values obtained varied between 30-38 kms, from regions on the central, western, and southern regions, Alsinawi & Hassan (1977), Alsinawi & Alrawi (1978), Alsinawi & Al Banna (1983). Dahgani & Markis (1984) used gravity data to study the crust in Iran and arrived at values of 26-55 kms, his crustal thickness near Sulimaniyah region in NE Iraq was 43 kms.

Other investigators who used seismic methods include Knopoff and Found (1975) who studied the northern parts of the Arabian subcontinent using surface wave dispersion data coming up with an average crustal thickness of 34 kms. Patton (1980) also used surface wave data to arrive at an average value of 38 kms. El Isa et. Al (1987) used seismic

reflection data to study the crustal thickness in Jordan and arrived at an average thickness of 32-35 kms.

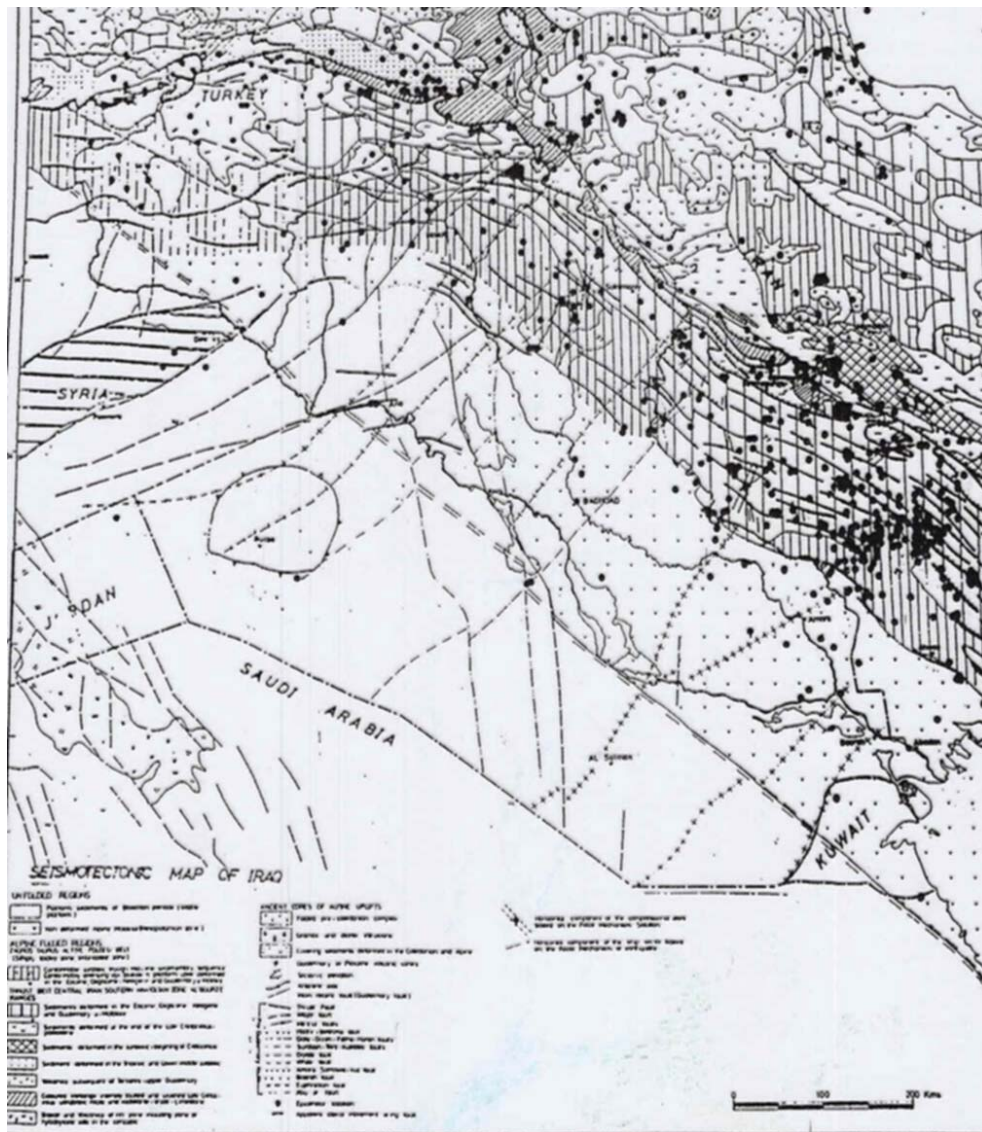


FIGURE 2: SEISMOTECTONIC MAP OF IRAQ (Alsinawi & Issa 1986)

A crustal structure determination in Iraq was conducted utilizing 91 events in the distance range of 30-100 degrees. The Iraqi Seismological Network (ISN) of four stations namely Baghdad (BHD), Mosul (MSL), Sulymania (SLY) and Rutba (RTB) was utilized in the investigation, Teleseismic body wave forms have been used to infer crustal structure beneath Iraqi seismic stations. The data have been modeled in both frequency and time domains to determine the crustal structure Alsinawi & Al Heety (1994). They utilized four different methods for the crustal determination. (a) The one layer crustal transfer function model, (b) the spectral ratio method compared to one and three layer models,

(c) the relative travel time residuals (d) The M-converted Sp phases observed on long period seismograms from three events recorded by the (ISN) from the S-Sp time difference and the Sp/S amplitude ratios. Figure 3 shows samples of the best fitting one-layer models beneath the ISN stations .

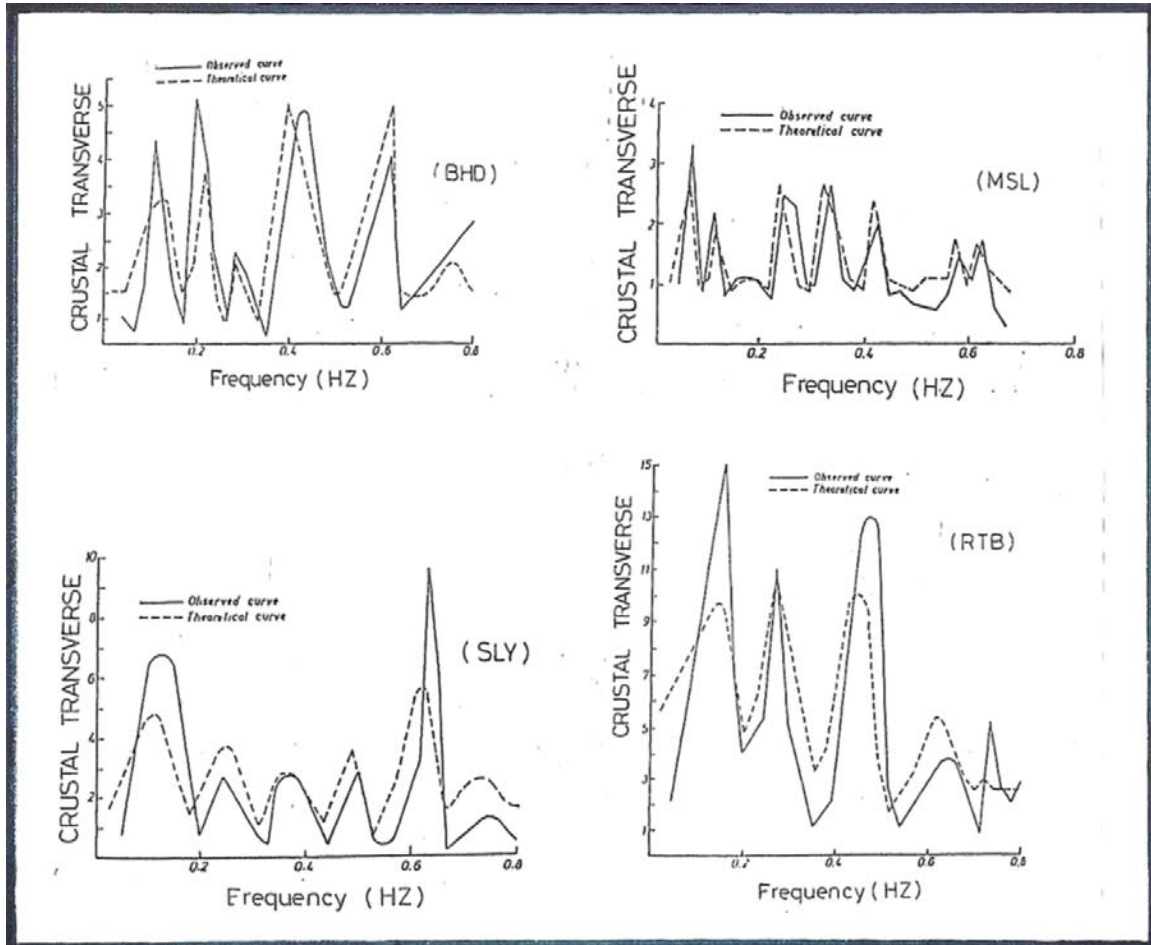


FIGURE 3: BEST FITTING ONE LAYER MODEL TRANSFER FUNCTION RATIOS FROM THE IRAQI SEISMOLOGICAL STATIONS BHD, MSL, SLY & RTB (Alsinawi & Al Heety 1994).

The crustal thickness was found to increase towards the Zagros thrust zone in agreement with gravity interpretation; the results were also consistent with the regional crustal values. Figure 4 is a panel diagram displaying the crustal values and seismic P velocity in Iraq. The thickness values varie, the range in Baghdad region was 38 kms (V_c 6.3 km/sec), Rutba 33-35 kms (V_c 5.9 km/sec, V_m 8.2 km/sec), Mosul 31-34 Kms (V_c 6.0 km/sec, V_m 8.3 km/sec) and Sulymania 41-43 kms (V_c 6.1 km/sec, V_m 8.0 km/sec. Table 1 is a Crustal velocity and Depth Model for Iraq , Alsinawi & Al Heety (1994).

4. TRANSECT INVESTIGATIONS:

Two transect projects were carried out in Iraq as shown in Figure 5. The first was an EW transect of 650 kms that passes through Baghdad starting from the Jordanian to the Iranian borders. The crustal thickness along the transect ranges between 31-37 kms with an average of 34 kms. The geologic and tectonic data along the transect are compared with the available aeromagnetic, Bouguer gravity and seismic reflection data, as shown in Figure 6, Alsinawi & Al Banna (1990).

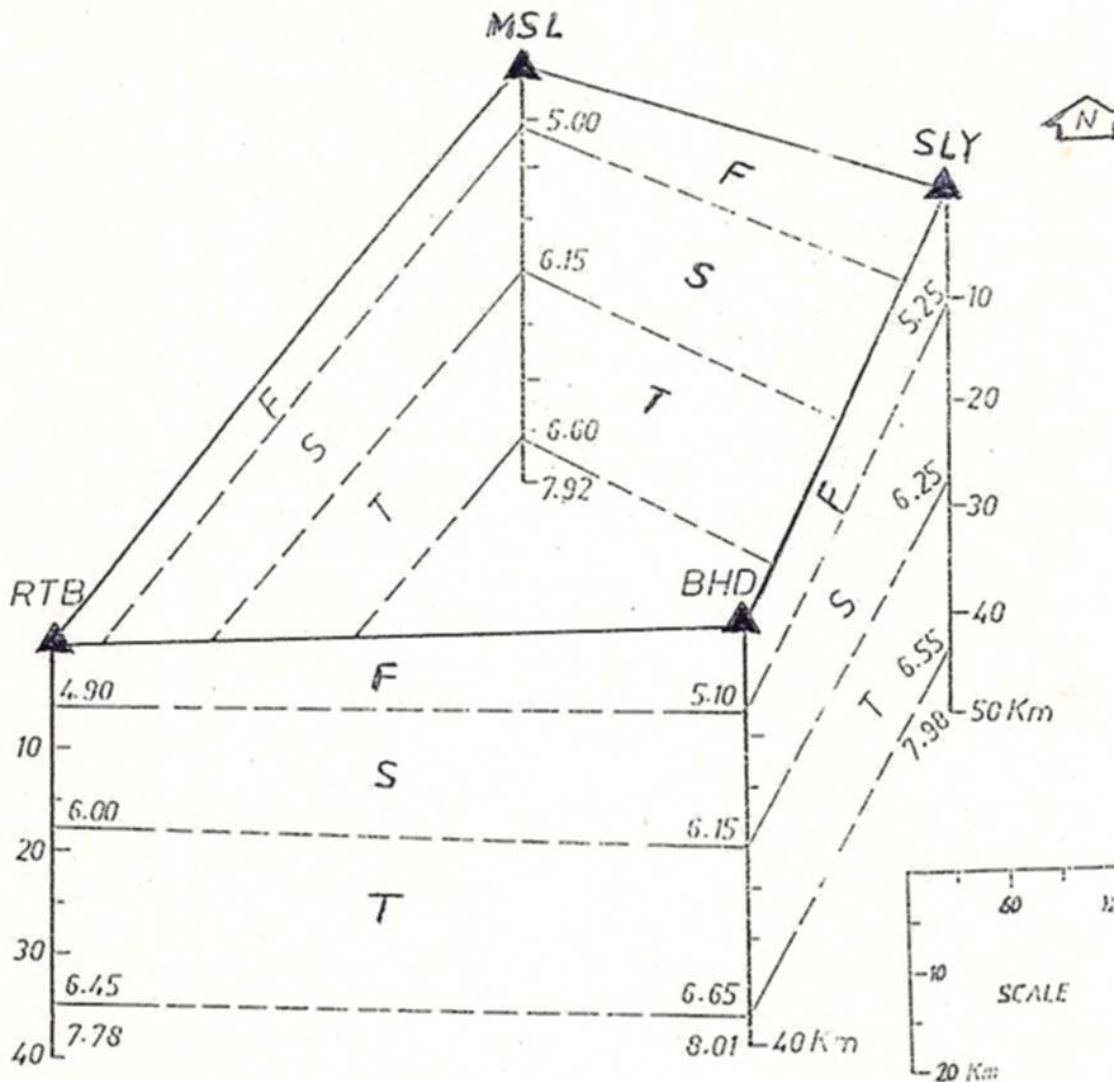
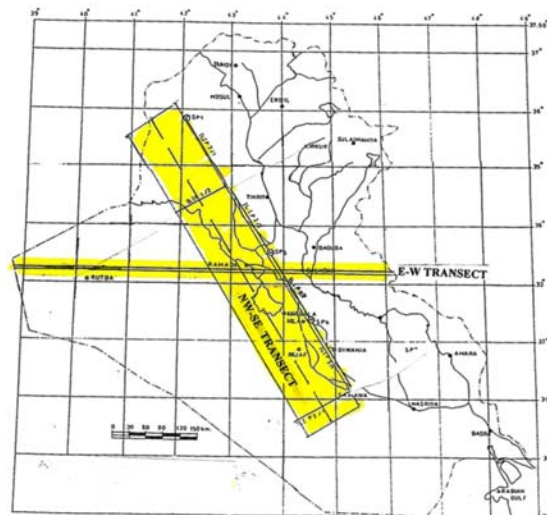


FIGURE 4: A PANEL DIAGRAM OF THE CRUSTAL THICKNESS AND SEISMIC VELOCITY IN IRAQ (Alsinawi & Al Heety 1994).

| <i>IRAQI SW ESIMOLOGICAL STATIONS (ISN)</i> | Seismic Velocity VP km/sec | Seismic Velocity Vs Km/sec | Density gm/cubiccm | Depth (H) Kms |
|---|---|---|-------------------------------|--------------------------|
| <i>Baghdad (BHD)</i> | 5.2 6.2 6.7 7.9 | 3.0 3.6 3.9 4.7 | 2.52 2.71 2.84 3.20 | 8 13 17 - |
| <i>Mosul (MSL)</i> | 5.0 6.2 6.6 7.9 | 2.9 3.6 3.8 4.8 | 2,49 2.71 2.81 3.22 | 5 13 17 - |
| <i>Rutba (RTB)</i> | 4.9 5.9 6.4 7.8 | 2,8 3.4 3.7 4.7 | 2.48 2.65 2.77 3.17 | 5 12 17 - |
| <i>Sulaimaniyah(SLM)</i> | 5.2 6.3 6.7 7.8 | 3.0 3.6 3.7 4.7 | 2.52 2.74 2.84 3.17 | 10 16 17 - |

TABLE 1: CRUSTAL MODEL FOR IRAQ (Alsinawi & Al Heety 1994)



**FIGURE 5: A MAP SHOWING THE TWO TRANSECT
PROFILES IN IRAQ.**

The second transect profile was a NW-SE trend parallel to the Syrian border with 605 kms long and 100 kms wide. This was the first GGT project in Iraq ,Alsinawi, Al Rahim & Al Din (1995).

Background surface and subsurface data was compiled from various sources to arrive at a comprehensive geologic setting of the studied region which extends from the Iraqi-Syrian border on the NW to the Salman Depression on the SW .The thickness of the sedimentary layers ranged between 6-7 kms in Al Jezira region with acidic basement accompanied with high heat gradient and positive gravity and magnetic anomalies. This is geodynamically related to the Euphrates Fault system, The thickness of the sedimentary layers ranged between six to seven kilometers .The Moho was calculated to be around 37 kms with V_c 6.8 km/sec, V_m 7.95 km/sec. The Conrad discontinuity around 20 kms with V_c changes between 6.10 km/sec to 6.50 kms/sec. Although this work was carried out in the early ninties, this is the first chance to publish a minor part of the investigation. Figure 7 is an NW-SE crustal model in Iraq ,Alsinawi, Al Rahim & Al Din (1995).

5. ATTENUATION STUDY :

There are insufficient ,and in our case, no strong motion data to allow the determination of attenuations laws for Iraq. The attenuation measurements are difficult and many sources of interference take place such as source mechanism, geometric spreading of the wave front and various attenuation mechanisms. The work carried by Alsinawi & Al Tikriti(2000) which was actually conducted in the late eighties is the only work along the lines of Nuttli(1980).The only other published work on attenuation was carried by Fahmi et.al(1989) where field seismic intensity mapping in Taktaq region in north central Iraq was utilized to compute the attenuation values in that region.

The attenuation of earthquake generated P waves in Iraq was attempted where P waves recorded at Baghdad (BHD) and Mosul (MSL) seismological observatories were picked from earthquakes originating in the neighboring Turkey and Iran . Thirty-seven such events were chosen, twenty-three were recorded at (BHD) and fourteen at (MSL) observatories, Figure 8.

. The earthquake paths were along the northern and central regions of Iraq, with magnitudes ($m_b=4.1-5.7$). The amplitude distance curve of Nuttli(1980) was utilized in this investigation and the mean attenuation value obtained for the whole area was $\alpha=0.0035 \text{ Km}^{-1}$.The value obtained for Iran by Nuttli (1980) was $\alpha=0.0045 \text{ Km}^{-1}$.The difference is attributed in terms of different tectonic stability. The attenuation values in the eastern parts of Iraq have higher values than those in the northern parts .The mean attenuation factor values recorded by the two stations resulted in higher values for events originating in Iran than those events originating in Turkey. Figure 9 shows an amplitude distance curve for earthquakes recorded at the two stations (BHD) and (MSL) with epicenters located in Turkey and Iran.

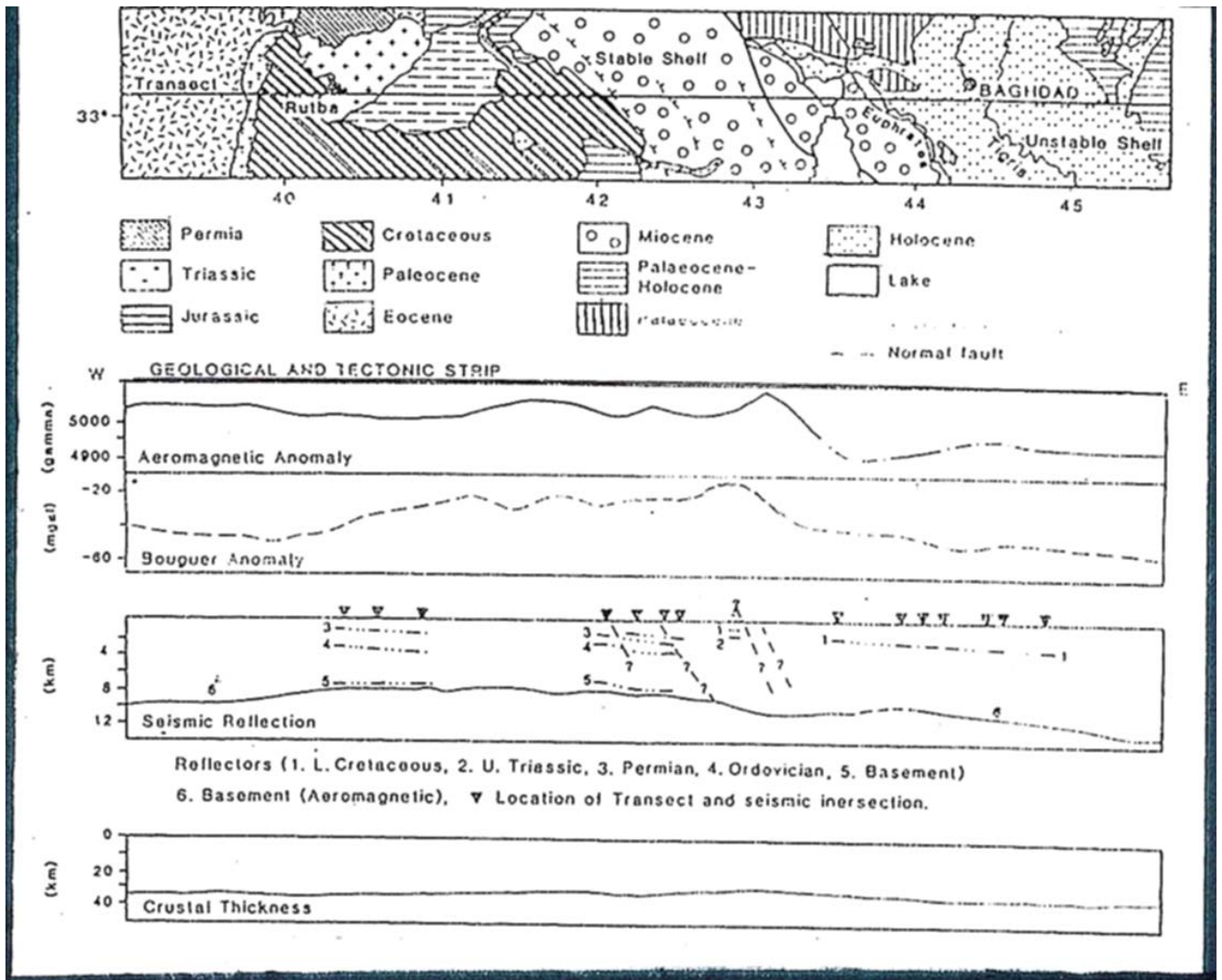


FIGURE 6: AN E-W TRANSECT PROFILE IN CENTRAL IRAQ (Alsinawi & Al Banna 1990).

6. ALMASHRIQ GEOPHYSICAL RESEARCH GROUP :

A newly established research group, "Almashriq Geophysical Research Group "A.G.R.G", is set to conduct coordinated research on the eastern Mediterranean Geophysics with emphasis on seismology, more on this group is announced on the MESF website URL: <http://www.meseisforum.net>. The AGRC is initiated to carry out the following tasks: Create awareness of the available geophysical research activities

conducted on the Almashriq Region. Conduct coordinated research and make available publications contributing to an understanding of the internal structure and evolution of Almashriq region including, but not limited to the following lines of research(a): Seismicity (paleoseismology, observational seismology and macro , micro and induced seismicity studies).(b) Seismotectonics and seismic hazard analyses of Almashriq region. Geodynamics and stress distribution of the Arabian Subcontinent (defining the Arabian Plate) with special emphasis on the Zagros Thrust zone, the Dead Sea Transform, the Red Sea Divergence, the Gulf of Aden and the Afar Triple Junction.(c)Promote research in the fields of Applied and Environmental geophysics.

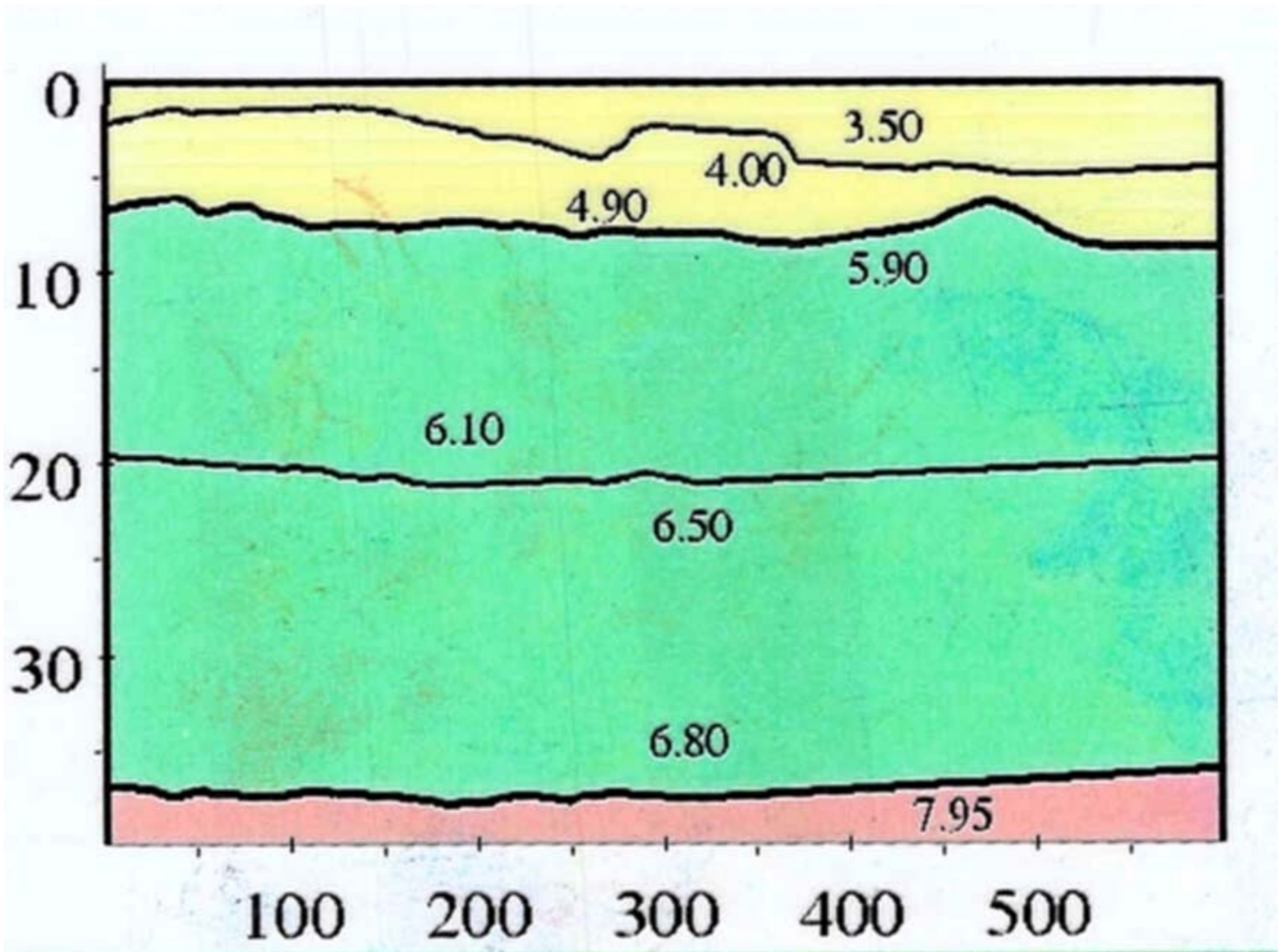


FIGURE 7: A NW-SE CRUSTAL MODEL IN IRAQ (Alsinawi ,Al Rahim & Al Din 1995)

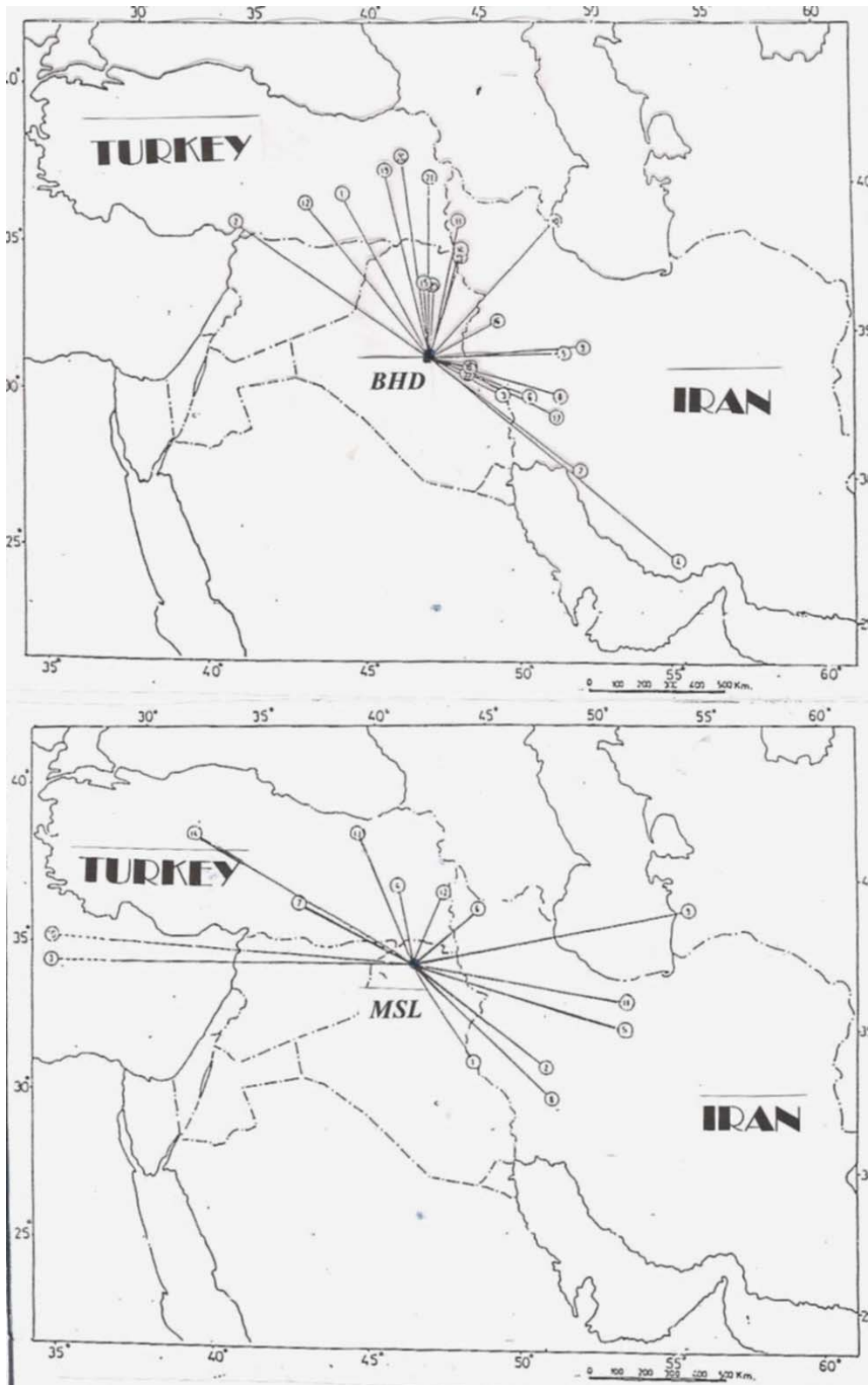


FIGURE 8 : EPICENTRAL LOCATIONS OF THE EVENTS IN TURKEY AND IRAN RECORDED AT BHD AND MSL STATIONS (Alsinawi & Al Tikriti 2000).

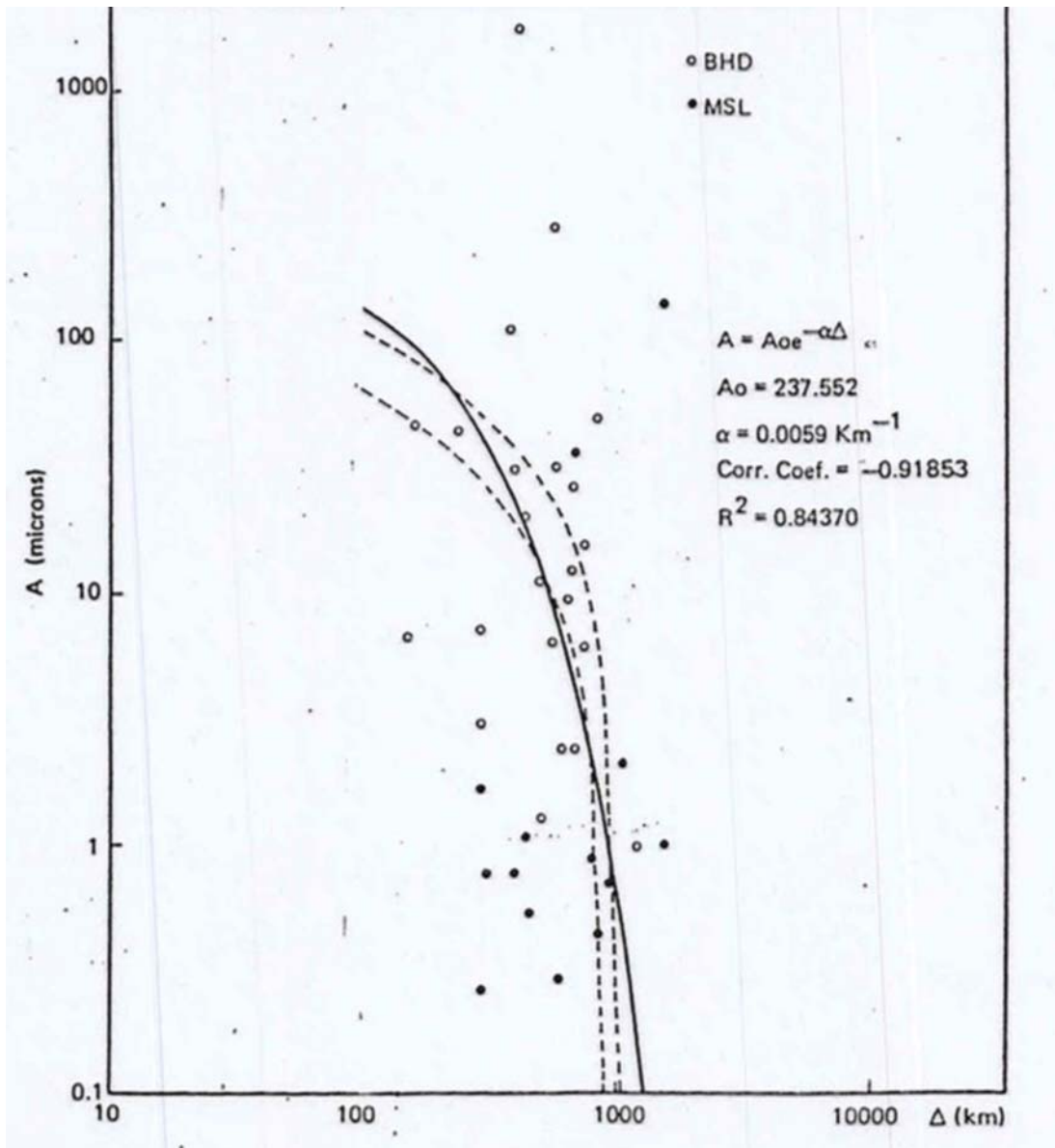


FIGURE 9 : AMPLITUDE DISTANCE CURVES FOR EARTHQUAKES RECORDED BHD AND MSL OBSERVATORIES WITH EPICENTRAL LOCATIONS IN TURKEY AND (Alsinawi & Al Tikriti 2000)

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