*Tikrit Journal of Pure Science 17 (2) 2012* *ISSN: 1813 - 1662*

# Crustal and uppermost mantel structure study of N-NE Iraq Using Rayleigh wave Analyses

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(**Received:** 16 / 9 / 2011 ---- **Accepted:** 26 / 10 / 2011)

## Abstract

The crust and uppermost mantle structure of N/NE of Iraq between lat. (34°12' - 37°12') and long. (41°36' – 46° 04') are investigated using Rayleigh surface wave analysis and inversion. Data sets of several regional Earthquakes occurred over the period between 1998 and 2000, were recorded by two broad-band seismic stations (HITJ and RUWJ) that were located in Jordan. Multiple filter analysis in the frequency range (0.02-0.25) Hz have been employed to determine fundamental mode Rayleigh group velocities dispersion. Inversion method is performed to find the average structure along seventy ray paths for fifty one recorded events located around Zagros-Taurus plateau which produced a good coverage of the study area.

One dimensional crustal velocity models with theoretical group velocity dispersion curve that best fits and match the observed dispersion are considered as representative crustal structure of the event-station path. The thickness of the upper crust ranges between (6-14 Km) low-velocity layers, its primary wave velocity (Vp) varies between 5 and 6 km/s. Mid crustal layer has a P-wave velocity from 6 to 6.5 km/s down to around 28 km depth. A P-wave velocity from 6.4 to around 7.5 km/s characterizes the lower crust. In general the crustal structure revealed lateral and vertical variations in shear wave velocity within the crust, the resulting models display the average S-wave velocities range between 3 to 4 km / s in Earth's crustal layer. The high P-wave velocities greater than 7.8 km/s and about 4.5 km/s for S-wave used to identify the Earth's uppermost mantle.

The crustal thickness was found to increase towards the Zagros thrust zone and the interplate seismicity is significantly more dominant than the intraplate activity. Those observations, the variation in crustal thickness and the seismic activity are related to the collision of the Arabian plate with Eurasia.

## 1-Introduction

The knowledge of the crustal structure beneath any region is of vital importance for both the understanding and teleseismic travel time studies ( 1). The lithosphere behaves as a rigid spherical shell or plate, it rest on a dense mantel and consists of cold and rigid materials (2). Surface waves are cornerstones of seismology which are used for determination of Earth's structure (3,4). The travel time curves are used to learn about the velocity structure between the source and the receiver. The study of the surface wave whose energy is concentrated near the Earth's surface holds a special place in seismology because of their large amplitudes compared to body waves for teleseisms. These waves are also significant as they arise from boundary conditions near the Earth's surface (5).

The aim of this research is to process the data set waveforms and extract the fundamental mode Rayleigh waves from the vertical component records and to obtain the dispersion frequency and group velocity dispersion using advance multiple filter technique (MFT). Then invert the dispersion group velocities to one dimensional velocity structure in order to get a satisfactory conclusion from this analysis on the crustal structure in the N-NE Iraq beneath the studied area.

## 2-Location of the studied area

This investigation covers the north and northeastern part of the Iraqi territories, its boundaries can be represented by the latitudes 34°12'- 37°12' and longitude 41°36' - 46°04', see Fig.1.

## 3-Data Acquisition

In this study the crust and upper most mantle structure of north and northeast Iraq are investigated using surface wave analysis. Multiple filter analysis techniques in the frequency range 0.02-0.25 Hz is employed to determine the fundamental mode Rayleigh group velocities through extracting the dispersion values and inversion method to find the earth structure beneath the northern most of Arabian plate.

Seventy earthquakes to station propagation paths were chosen in this study resulted from fifty one recorded regional events which traversed the studied area, Fig 1.

A multiple filter analysis is performed to estimate group velocities along event to receiver path. The maximum amplitude of the Rayleigh waves that have been picked from the seismogram over the period range between 4 to 50 sec appeared on the vertical component and represented by the square shapes in the fig 2.

## 4-Crustal Structure

In this study the observations are surface wave group velocity dispersion from fundamental mode Rayleigh waves that were inverted for crustal structure. This inversion is sought to resolve the upper crustal structure in term of the shear velocity in order to better understand how energy passes through the region of study (6,7).

The inversion process is repeated through iterations where the model is perturbed and the resulting fit is observe. The number of iterations is monitored to minimize extraneous artifacts being introduced into the model (8). One type of inversion is called a stochactic least squares inversion which includes a damping factor that limits the amount variation between iterations and reduces the standard misfit to the observation (9) (10).

The initial velocity model for one of the selected events is listed in the table (1). Inversion is used to determined model parameters. Velocity data dispersion are given in table (2). The final velocity model for this event is listed in table (3).

To elucidate the calculations of shear velocity models from the inversion of the Rayleigh waves to velocity structure and Moho depth and performing the isolation of fundamental signals from the original ones along different station to receiver paths, an example of one event is given in Fig. 3 and Fig. 4

## 5-Discussion and Conclusions

The crustal structure in this study is characterized by an upper crust with primary velocity between 5 to 6 km / s at shallow depths with about 6 to 14 km thickness. Underlying layer is a mid-crustal layer has a positive gradient p-wave velocity ranging from 6 to 6.5 down to around 28 km depth. A P-wave velocity gradient from 6.4 to 7.5 km/s characterizes the lower most crust. The resulting models display the average S-wave velocities range between 3 to 4 km / s in the Earth's crustal layers. The relatively high P-wave velocities (grater than 7.8 km/s) that noticed underneath the crust and about 4.5 km/s for S-waves at 38 to 48 km depth overall the region tend to identify the Earth's uppermost mantle. So we can reach to the following conclusions:

**1)** The velocity changes with depth at the upper 15km show a clear dependency on the lithology.

**2)** The inversion method revealed increasing lithospheric shear velocity distributions and density with depth as well as relatively high values for the upper mantle (grater than 7.8km/s).

**3)** The causes of most earthquakes taken place in the area are probably due to stresses generated by the Arabian plate movement to the north and north east and its collision with the Iranian-Turkish plateau in addition to the effect of neo tectonic activation of the upper crust.

**4)** In general, the crustal and upper mantle velocity values resulted from the event to receiver paths along the Iranian plateau are relatively higher than the values obtained along the Turkish plateau.

**5)** The epicentral distribution follows the general trend of Zagros-Taurus belt which is influenced mainly by these systems.

**6)** The presence of a-low velocity layer has not been seen in the inversion modeling results along the source to receiver paths beneath the area of study.

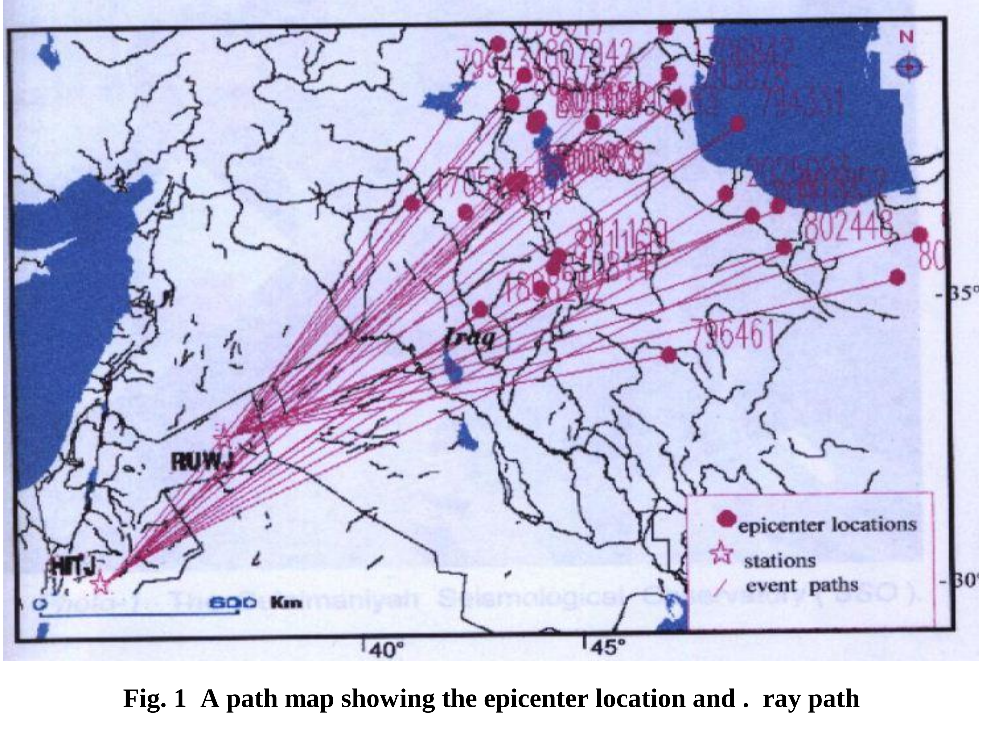


**Fig. 1 A path map showing the epicenter location and . ray path**

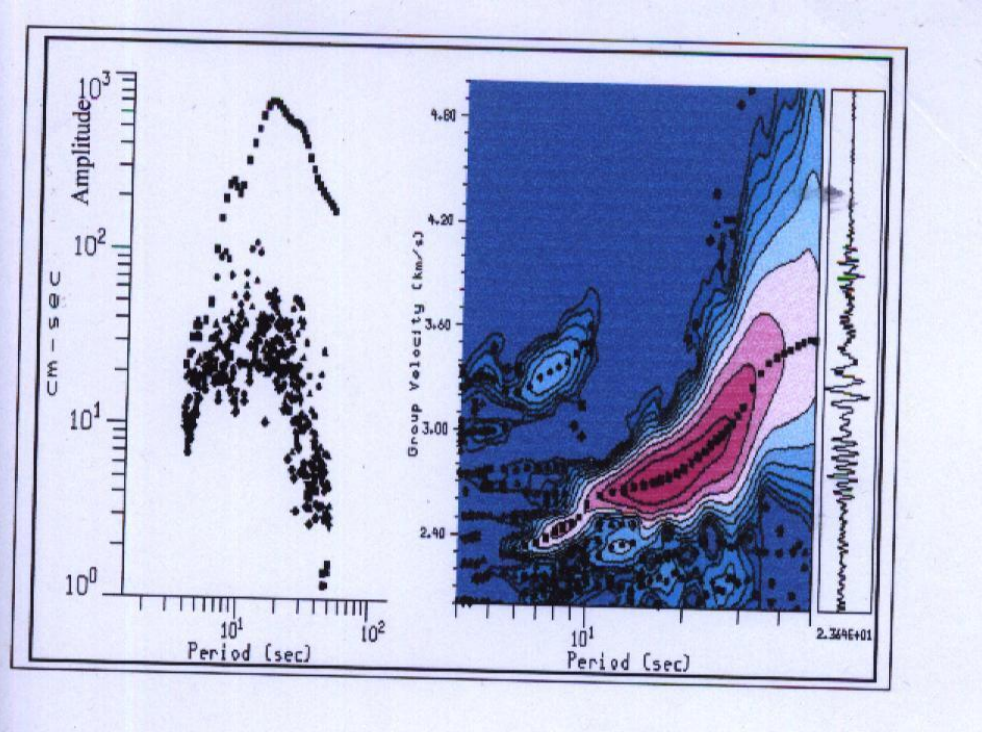
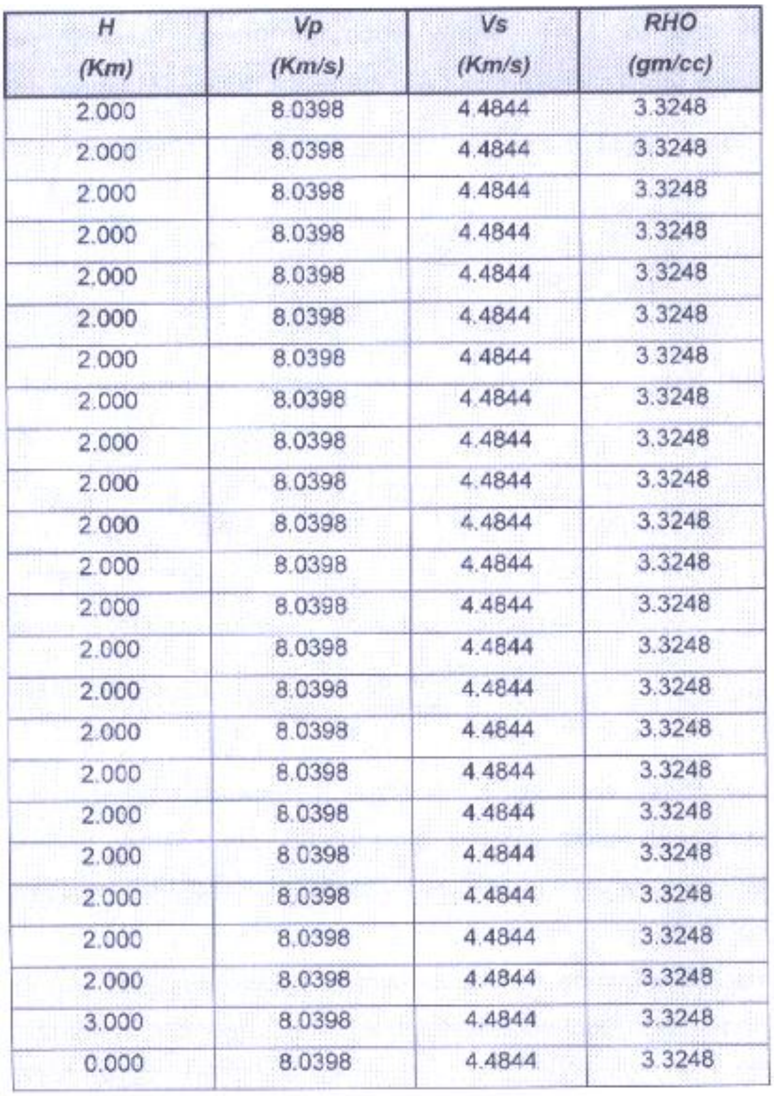


**Fig. 2 The original seismogram for the event recorded. at (HITJ) station**

**Table 1 Initial velocity values of the Vp and Vs and the crustal density for one of the selected event**



| H<br>(Km) | Vp<br>(Km/s) | Vs<br>(Km/s) | RHO<br>(gm/cc) |
|---|---|---|---|
| 2.000 | 8.0398 | 4.4844 | 3.3248 |
| 2.000 | 8.0398 | 4.4844 | 3.3248 |
| 2.000 | 8.0398 | 4.4844 | 3.3248 |
| 2.000 | 8.0398 | 4.4844 | 3.3248 |
| 2.000 | 8.0398 | 4.4844 | 3.3248 |
| 2.000 | 8.0398 | 4.4844 | 3.3248 |
| 2.000 | 8.0398 | 4.4844 | 3.3248 |
| 2.000 | 8.0398 | 4.4844 | 3.3248 |
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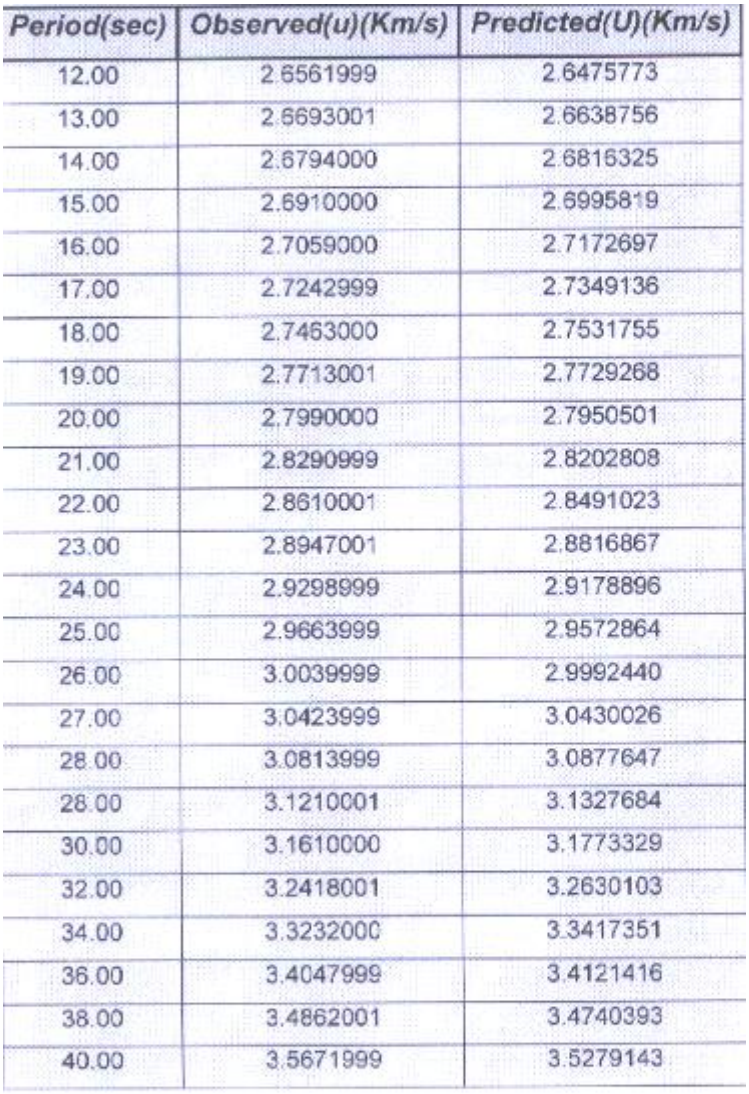
| 2.000 | 8.0398 | 4.4844 | 3.3248 |
| 2.000 | 8.0398 | 4.4844 | 3.3248 |
| 2.000 | 8.0398 | 4.4844 | 3.3248 |
| 2.000 | 8.0398 | 4.4844 | 3.3248 |
| 3.000 | 8.0398 | 4.4844 | 3.3248 |
| 0.000 | 8.0398 | 4.4844 | 3.3248 |

**Table 2 Velocity data dispersion for the period 12 to 40 sec for the selected event**



| Period(sec) | Observed(u)(Km/s) | Predicted(U)(Km/s) |
|---|---|---|
| 12.00 | 2.6561999 | 2.6475773 |
| 13.00 | 2.6693001 | 2.6638756 |
| 14.00 | 2.6794000 | 2.6816325 |
| 15.00 | 2.6910000 | 2.6995819 |
| 16.00 | 2.7059000 | 2.7172697 |
| 17.00 | 2.7242999 | 2.7349136 |
| 18.00 | 2.7463000 | 2.7531755 |
| 19.00 | 2.7713001 | 2.7729268 |
| 20.00 | 2.7990000 | 2.7950501 |
| 21.00 | 2.8290999 | 2.8202808 |
| 22.00 | 2.8610001 | 2.8491023 |
| 23.00 | 2.8947001 | 2.8816867 |
| 24.00 | 2.9298999 | 2.9178896 |
| 25.00 | 2.9663999 | 2.9572864 |
| 26.00 | 3.0039999 | 2.9992440 |
| 27.00 | 3.0423999 | 3.0430026 |
| 28.00 | 3.0813999 | 3.0877647 |
| 28.00 | 3.1210001 | 3.1327684 |
| 30.00 | 3.1610000 | 3.1773329 |
| 32.00 | 3.2418001 | 3.2630103 |
| 34.00 | 3.3232000 | 3.3417351 |
| 36.00 | 3.4047999 | 3.4121416 |
| 38.00 | 3.4862001 | 3.4740393 |
| 40.00 | 3.5671999 | 3.5279143 |

**Table 3 The final velocity values of the Vp and Vs and the density of the selected event**

| *Depth (H)* *Km* | *Vp* *Km/sec* | *Vs* *Km/sec* | *Rho* *gm/cc* |
|---|---|---|---|
| 1.000 | 4.6078 | 2.5703 | 2.4146 |
| 2.000 | 4.6282 | 2.5815 | 2.4191 |
| 2.000 | 4.7706 | 2.6610 | 2.4501 |
| 2.000 | 5.1379 | 2.8660 | 2.5276 |
| 2.000 | 5.6066 | 3.1284 | 2.6212 |
| 2.000 | 6.0225 | 3.3590 | 2.7058 |
| 2.000 | 6.2993 | 3.5138 | 2.7892 |
| 2.000 | 6.4409 | 3.5926 | 2.8322 |
| 2.000 | 6.4889 | 3.6194 | 2.8471 |
| 2.000 | 6.4932 | 3.6221 | 2.8487 |
| 2.000 | 6.4918 | 3.6208 | 2.8483 |
| 2.000 | 6.5153 | 3.6340 | 2.8543 |
| 2.000 | 6.5745 | 3.6670 | 2.8693 |
| 2.000 | 6.6652 | 3.7175 | 2.8925 |
| 2.000 | 6.7772 | 3.7802 | 2.9214 |
| 2.000 | 6.9012 | 3.8492 | 2.9536 |
| 2.000 | 7.0301 | 3.9210 | 2.9889 |
| 2.000 | 7.1615 | 3.9947 | 3.0312 |
| 2.000 | 7.2965 | 4.0697 | 3.0748 |
| 2.000 | 7.4372 | 4.1482 | 3.1202 |
| 3.000 | 7.5934 | 4.2429 | 3.1724 |
| 0.000 | 7.660 | 4.3391 | 3.2312 |

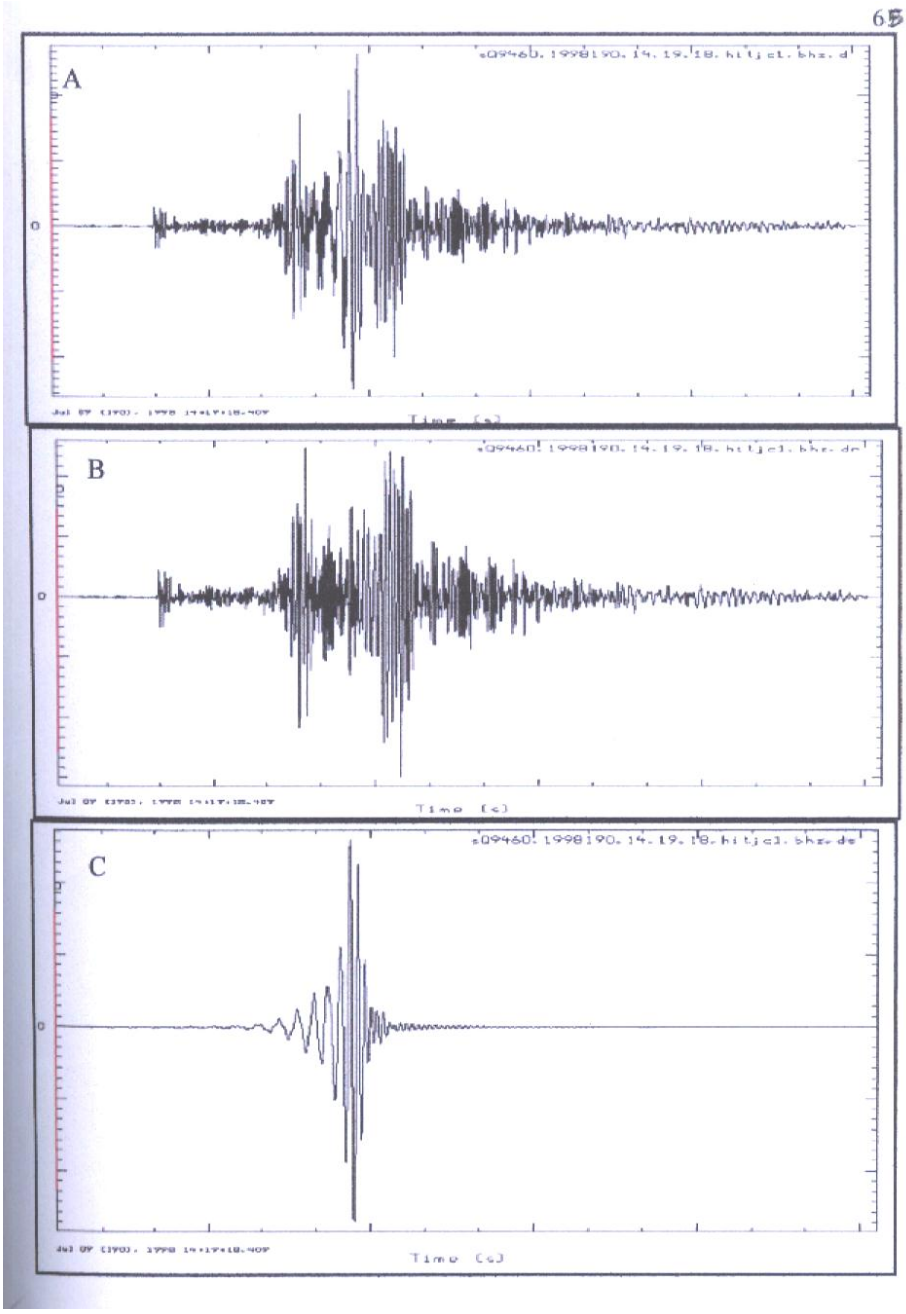


**Fig. 3 wave forms for the path of the event show the original (A), the. residual (B) and isolated fundamental mode signal (C)**

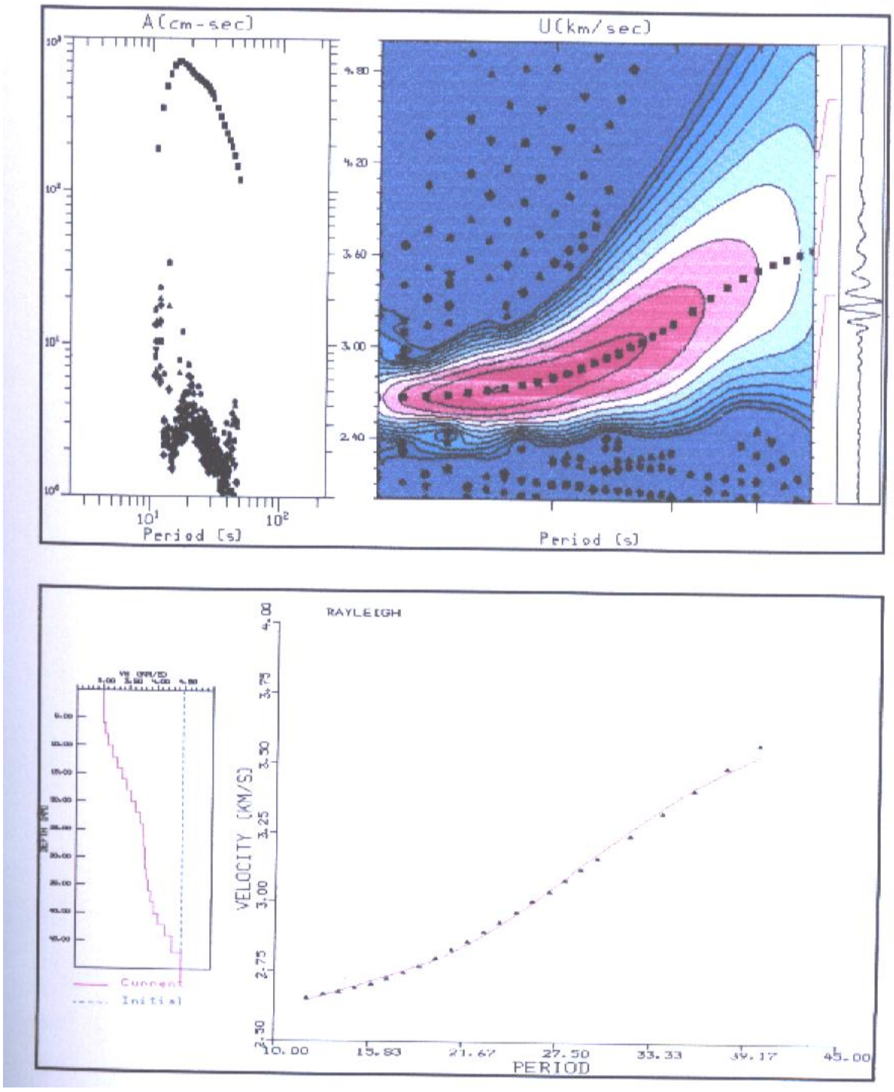


**Fig.4 Shows the starting model, current model and the dispersion data. Points are observed dispersion and the red line is the synthetic (predicted) dispersion**

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# دراسة تركيب القشرة الارضية والجزء العلوي من الجبة لشمال وشمال شرق العراق

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**( تاريخ الاستلام:** ١٦ / ٩ / ٢٠١١ ---- **تاريخ القبول:** ٢٦ / ١٠ / ٢٠١١ **)**

## الملخص:

استدل على تركيب القشرة والجبة العلوية لشمال وشمال شرق العراق من خلال تحليل وتحويل موجات الرايلي السطحية للهزات المسجلة خلال الفترة الممتدة من ١٩٩٨ الى ٢٠٠٠ في محطتين زلزاليتين ذواتي التردد الواسع والواقعتين في الاردن. استخدمت تقنية تحليل المرشح المتعدد ضمن التردد٠,٠٢ - ٠,٢٥ هرتز لتحديد الصيغة الاساسية لمجموع سرع رايلي المشتتة ، وانجزت عملية التحويل لايجاد معدل تركيب السرع الزلزالية بين كل هزة و المحطتين الزلزاليتين لسبعين مسار شعاعي و المسجلة لاكثر من خمسين هزة ارضية والتي تغطي بشكل جيد منطقة الدراسة الواقعة ضمن الصفيحة الايرانية – التركية.

تمثل النماذج الاحادية البعد الناتجة للسرع تركيب القشرة الارضية بين مسار الهزة والمحطة والتي اظهرت التطابق والتوافق بين منحنيات التشتت النظرية لمجموع السرع والتشتت التجريبية. واظهرت تركيب القشرة الارضية المستخرجة عموما اختلافات عمودية وجانبية لسرعة موجات القص. تتراوح سرع الموجات الاولية في النطاق العلوي للقشرة بسمك ٦ الى ١٤ كم والمتكونة من طبقات ذات سرع زلزالية واطية بين حوالي ٥-٦ كم/ ثا . ويمتد النطاق الاوسط الى عمق ٢٨ كم بانحدار موجب لسرع الموجات الاولية بين ٦ الى ٦,٥ ويتميز النطاق السفلي للقشرة بانحدار سرع للموجات الاولية من ٦,٤ الى ٧,٥ كم/ثا واعطت الموديلات الارضية معدلا لسرع الموجات الثانوية والتي تتراوح بين ٣ الى ٤ كم/ثا في طبقات القشر الارضية وقد تؤشر السرع العالية للموجات الاولية اكثر من ٧,٨ كم /ثا وحوالي ٤,٥ كم/ثا للسرع الثانوية الى بداية الجبة العليا.

لوحظ وجود ازدياد في سمك القشرة نحو سلسلة حزام زاكروس مع تواجد للنشاط الزلزالي بين الصفائح نسبة الى حدوثه داخل الصفائح وان تكون الزيادة في سمك القشرة الارضية والنشاط الزلزالي نتيجة لعملية الاصطدام بين الصفيحتين العربية واليوراسية.