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CRUSTAL STRUCTURE AND MOHO DEPTH BENEATH SEVEN REGIONS IN EGYPT USING THOMSON-HASKELL (TF) AND AMMON-HERRMANN METHODS (RF)

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التركيب البنائى للقشرة الأرضية وعمق طبقة الموهو أسفل سبع مناطق فى مصر باستخدام طريقتى طومسون-هاسكل وامون-هيرمان

الخلاصة: فى هذا العمل تم حساب نماذج السرعة المحلية مفصلة للموجات الزلزالية أسفل كل مواقع محطات رصد الزلازل التابعة للشبكة القومية المصرية لرصد الزلازل وقد قسمت إلى سبع مناطق طبقا للنشاط الزلزالى المحلى لمصر. لتحقيق هذا الغرض تم إستخدام طريقتى طومسون-هاسكل وامون-هيرمان. أظهرت النتائج أن تركيب القشرة الأرضية فى مصر يتكون من ثلاث وحدات رئيسية : الوحدة الأولى هى الجزء العلوى للقشرة الارضية ويتكون من طبقتين : رسوبيات هشة وتتميز بسرعة الموجات الزلزالية الأولية ٣,٥ كم /ث وسمك ٢,٣٩ كم، ورسوبيات صلبة تتميز بسرعة الموجات الزلزالية الاولية ٥,٠١ كم /ث وسمك ٦,٣ كم. الوحدة الثانية هى الجزء الاوسط من القشرة الأرضية وسمكه ٧,٥ كم وسرعة الموجات الأولية به ٥,٩٧ كم/ث. الوحدة الثالثة هى الجزء الأسفل من القشرة الأرضية بسمك ١٦ كم وسرعة الموجات الأولية به ٦,٨٦ كم/ث. عمق الموهو أسفل السبع مناطق هى على التوالى ٣٤,٨ كم، ٣٦,٨ كم، ٣٢,٣ كم، ٣١,٥ كم، ٣٢,٧ كم، ٣٣,١٣ كم، ٣٢,١ كم، متوسط عمق الموهو ٣٣,٣ كم.

ABSTRACT: *Since the establishment of the Egyptian National Seismological Network (ENSN, 1997), we propose to have detailed local velocity models beneath all the recording station- sites, which are grouped into 7 regions according to the local seismicity of Egypt. The Transfer Function (TF) and Receiver Function (RF) techniques are applied to reveal the crustal and upper mantle crustal structure beneath all used station sites. The results have shown crustal structure models. We realized that Egypt has three main units.*

First Unit; Upper Crustal part: it is composed of two layers; soft sediments with mean P- wave velocity 3.5 km/s and mean thickness is 2.39 km, the P- wave velocity of the second layer (Hard Deposits) is 5.01 km/sec and thickness is 6.3 km. Second Unit (middle Crustal part): It shows a mean thickness of 7.5 km and a mean P-wave velocity of 5.97 km/sec. This part is followed by Conrad discontinuity which separates the lower crustal part from above, Third unit; lower crustal part: it exhibits a p-wave velocity of 6.86 km/sec and a thickness of 16 km. The Moho depths under the seven recognized regions are as follows: 34.8 km, 36.8 km, 32.3km, 31.50 km, 32.7 km, 33.13 km and 32.1 km, respectively with a mean Moho depth of 33.3 km.

1- INTRODUCTION

Our problem is to extract reasonable crustal structure models beneath seismic stations for the all regions of Egypt. Several scientists studied several regions in Egypt e.g. Makris et al (1979), Marzouk (PH.D., 1988), Gharib (PH.D, 1991), Kebeasy et al (1991), Gharib (2006), Gharib, et al (2016), Hejazi (2007) and Abdelwahed et al. (2013). Obtaining 3-D velocity models using this work for the study areas will help enhancing the accuracy of the earthquake location, this will reflect in more precise determination for the earthquake Hazard Analysis. This study covers almost all Egypt.

These results will be useful for the urban planning and the other related activities. This is, actually, achieved through the accomplishment of the crustal and upper mantle structure beneath the assigned seven regions as will be presented in the next section. This work will be a good opportunity for our technical staff to do practice and to be aware of the modelling seismology using the spectral techniques. The results from the two applied techniques are compared with the existing model already obtained before, for some localities in Egypt using the Deep Seismic Sounding (DSS) through different areas in Egypt (Marzouk, 1988, Gharib, 1991). The obtained results through this project are more detailed, widely covering the Egyptian territories and give more information than the previous works.

2- METHODOLOGY

2.1-Transfer Function technique (TF):

Details Procedures of this method are given in Haskell (1953, 1962), Al-Amri and Gharib (2000) and Tealab et al. (2003).

2.2-Receiver Function technique (RF):

Details Procedures of this method are given by Al-Amri and Gharib (2000) and Hejazi (2007).

It is clear from this study that general crustal structure of Egypt is given by Makris et al. (1979)and Marzouk (1988) it consisted of three parts(upper crust, middle crust, and lower crust)

The basic mathematical background of these tools are given in detail by Al-Amri and Gharib (2000) , Gharib (2006) and Hejazi (2007) which is based upon Thomson-Haskell matrix formulation (Thomson 1950 and Haskell 1953, 1962, Phinney, 1964 and Fernandez, 1965). This technique depends on the assumptions that, the layered media have to be horizontal, homogeneous and isotropic (Fig. 1). Velocity and density are linearly changed with depth, while the Poisson's ratio is supposed to be equal to 0.25. The spectral ratios method is based on this technique, which requires only 3-components seismograms of the single station to constrain the crustal model beneath the seismic station. However, the obtained solution is not unique due to the theoretical assumption in Thomson–Haskell formulation and the complexity of the earth's crust. The physical characteristics of the crustal and upper mantle structure were obtained on the basis of P-wave spectra. In order to obtain the energy of the source, the observed spectra of the vertical components of motion are divided by the spectra of the two rotated horizontal components (Radial and Transverse). The ratios of the P-wave spectra provide the observed crustal transfer function, which depends on the system of layers under the recording seismic station. Figure (2) shows the flowchart of this method.

3- DATA ANALYSIS FOR STUDY REGIONS

We used tele and regional recorded events with magnitude ≥5 by wide band seismic stations of Egyptian National Seismic Network (ENSN) velocity and acceleration seismic data within the Egyptian seven regions as shown in Figure (3). Most of used events are presented in Figure (4) where it was recorded clearly by (ENSN) stations and strong motions Accelerographs (SMA) seismic stations in the period from 2012 to 2015.

The Transfer Function (TF) and Receiver Function (RF) techniques are applied to reveal the crustal and upper mantle structure beneath all used station sites. The obtained results show that; Egyptian model has three main units;

- First part called Upper Crustal part composed of two layers; soft sediments with mean P- wave velocity of 3.6 km/s and thickness of 2.55 km. The P- wave velocity of the underlined by the second layer (Hard Deposits) with P-velocity of 5.03 km/sec and thickness of 6.48 km.
- Second part called Middle Crustal part' shows a mean thickness of 7.75 km and a mean P-wave velocity of 5.98 km/sec.
- We expect that this part is followed by Conrad discontinuity with lower P-velocity zone which separates the lower crustal part from above.
- Third part is named Lower Crustal part. It exhibits a P-wave velocity of 6.86 km/sec with thickness of 16.55 km. where Moho depths are: 34.8 km, 36.8 km, 32.3 km, 31.5 km, 32.7 km, 33.13 km and 32.1 km, at regions from one to seven respectively with mean Moho depth of 33.3 km. The upper mantle part has a P-wave velocity of 8.2 km/sec.

The results of (RF) show that, there are 5 low zones occurrences at depths of 1 km, 3 km, 6.5 km, 18 km and 37.5 km. Moho is distinct Discontuity along the base of the crust shows clear change in the rock types (Abdelwahed et al., 2013). These are interpreted as the

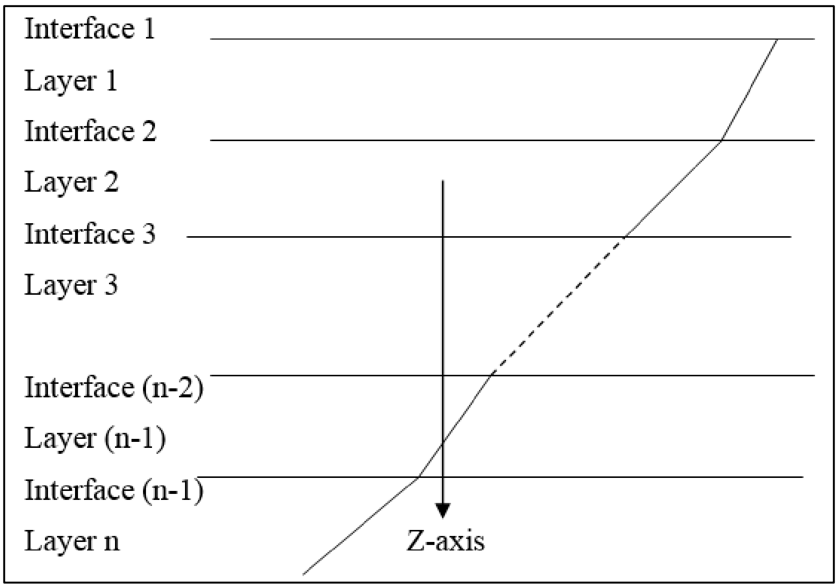

Figure (1): Layered earth model used to develop the Thomson-Haskell matrix formulation (Thomson 1950 and Haskell 1953).

interfaces between the crustal zones of 0.7, 5.5, 10.5, 15.5, 20.5, 30.5, 40.5, 45.5 and 50.5 km depths, obtained from (RF) respectively. Upper Crustal unit, composed of two layers; soft sediments with mean P- wave velocity of 3.73 km/s and mean thickness of 3.73 km, and the P-wave velocity for the second layer (Hard Deposits) is 5.53 km/sec and thickness of 6.7 km together represent the Upper crustal part followed by The middle Crustal part. It shows a mean thickness of 14 km and a mean P-wave velocity of 5.9 km/sec. Third Unit; Lower Crustal part: It exhibits a P-wave velocity of 7.14 km/sec and a thickness of 16 km. This part is followed by Conrad discontinuity is thin (Moho), low velocity thin layer with ≈5 km which separates the lower crustal part from above. Moho depths under the seven recognized regions are at following depths: 32.5KM, 32.3KM, 33.25KM,

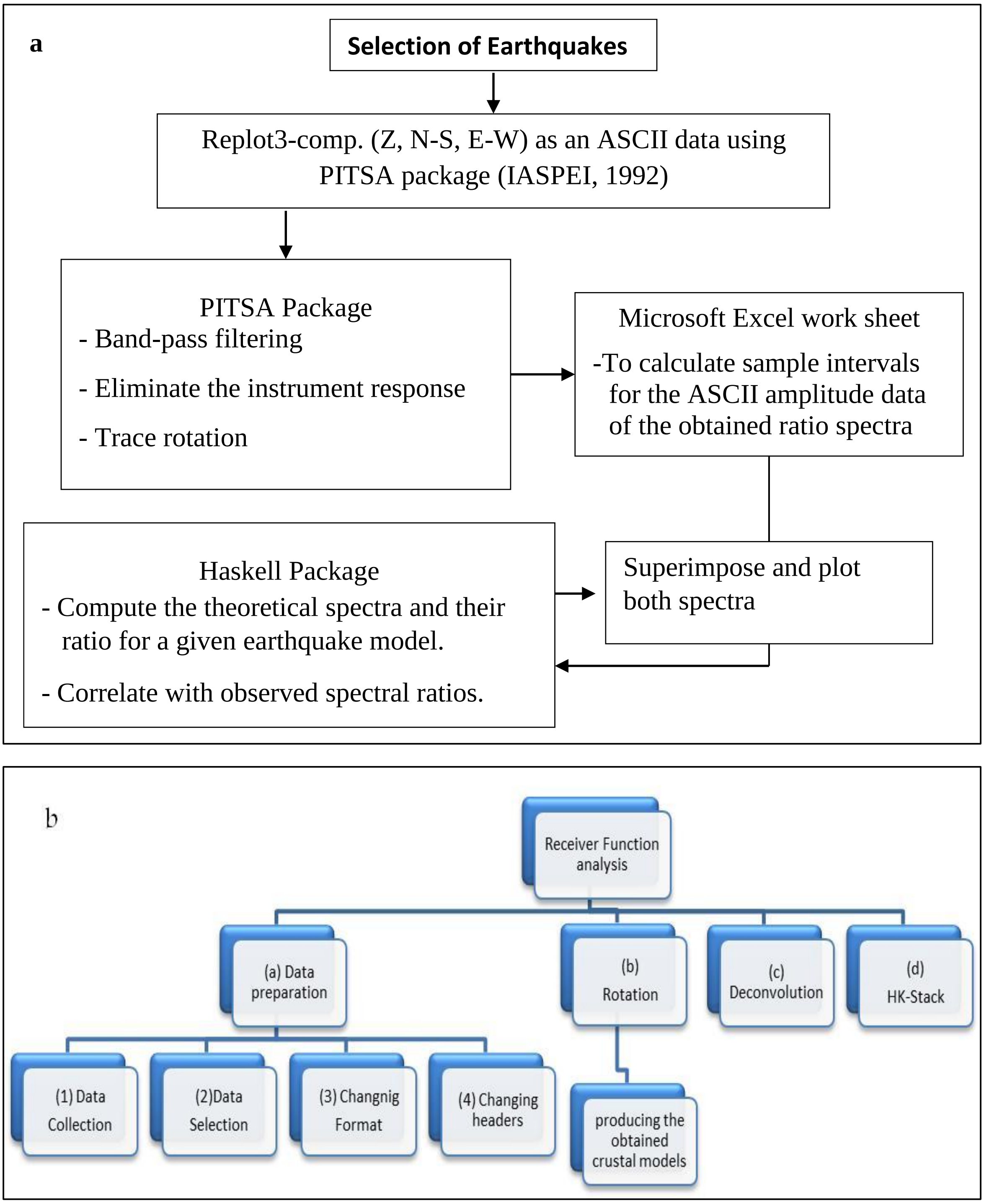

Figure (2): Flow chart of the analysing steps of both transfer function (TF) figure (a) and receiver function (RF) figure (b).

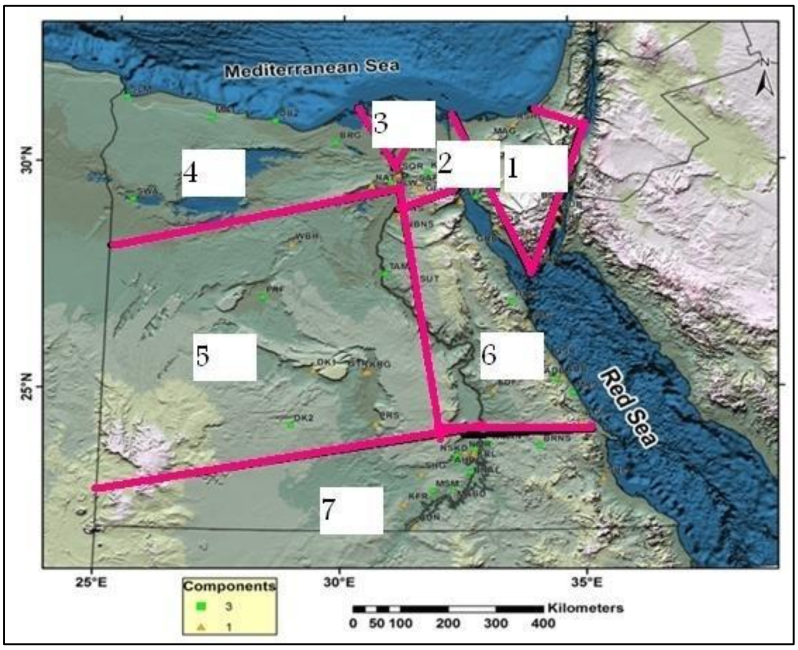

Figure (3): Location of the seismic stations for the seven study regions.

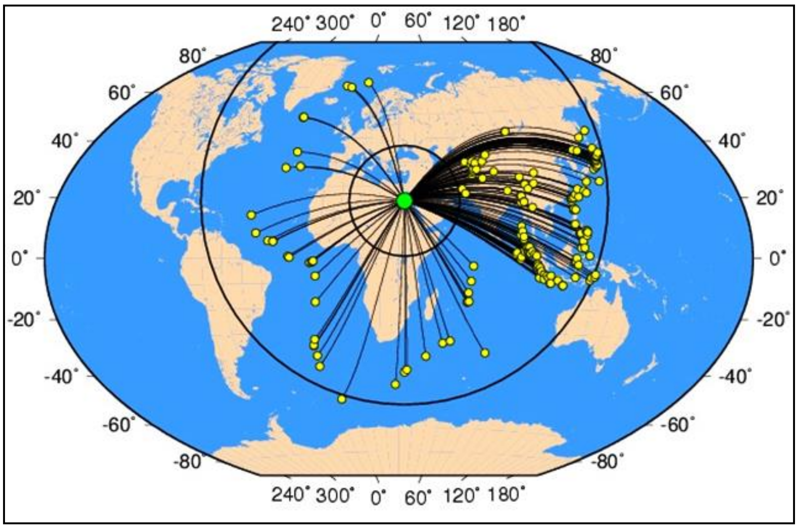

Figure (4): Epicenter location of the earthquakes selected for the RF (30°< Δ >90°) and (TF) (Δ >30°) analysis. Green closed-circle shows the location of NRIAG Institute network stations, while the smaller yellow circles show the location of the selected events (30°< Δ >90°).

31.66KM, 32.99KM, 31.7KM and 30.86 KM, respectively. The upper mantle part showed a P-wave velocity of 8.2 km/sec and a depth ranging from 32 to 50 km. The results show also that, 5 low velocity occurrences at depths of 1 km, 3 km, 6.5 km, 18 km and 37.5 km. These are interpreted as the interfaces between the crustal zones at depths of 0.7, 5.5, 10.5, 15.5, 20.5, 30.5, 40.5, 45.5 and 50.5 km respectively.These results will be available for the urban planning and the other related activities. The results from the two applied techniques are compared with the existed model already obtained before for some localities in Egypt using the Deep Seismic Sounding (DSS) through different areas in Egypt (Marzouk, 1988, Gharib, 1991).

We believe the obtained results through this project are more detailed, widely covering the Egyptian territories and give more information than the previous works.

3.1- Crustal structure of the seven Egyptian regions:

Sinai region (1), North Eastern Desert region (2), Nile Delta region (3), Qattara Depression region (4), Central Western Desert (5), Central Eastern Desert region (6), Aswan and Toshka region (7) as shown in Table (1).

Table (1): Integrated results table shows detail crustal structure of Egypt.

No.	St. site name	ST. Code	LAT. Nº	Long. Eº	Upper Crust		Middle crust	Lower Crust	Upper Crust Thick.		Middle crust Thick.	Lower Crust Thick	Moho Depth	Region
					VP1	VP2	VP3	VP4	D1	D2	D3	D4.		
1	Basata	BST	29.216	34.73	4.0	5.5	6.3	6.9	2.5	6	9	17.6	35.1	1
2	Katren	KAT	28.52	33.99	1.71	2.67	6	6.8	3	4.6	9	16.6	33.٢	1
3	Zenima	ZNM	29.37	32.87	4.0	4.78	5.6	7.03	2	6	8	17	33	1
4	Nekhel	NKL	29.92	33.98	3.9	5.1	5.6	6.2	3	9	10	16	38	1
5	Sharm	SHR	27.88	34.08	3.5	5.3	5.62	6.73	2	6	8	19	35	I
General model of region (1) Sinai					3.4	4.67	5.9	6.76	2.5	6.26	8.83	17.28	**34.8**	i
6	New Benisuef	NBNS	28.62	31.29	3.88	5.1	5.6	6.2	3	9	10	16	38	2
7	Hagoul	HAG	29.95	32.09	3.86	5.7	6.23	7.3	4	5.5	10.5	13	33	2
8	NRIAG	HLW	29.85	31.34	4.45	5.15	6.07	6.78	2.4	7.4	9	14.7	33.5	2
9	Kottamia	KOT	29.92	31.82	3.95	5.6	6,4	6.8	4	8	10.5	18	40.5	2
10	Fayed	FYD	30.29	32.23	3.81	5.6	5.8	7.03	4.5	6.5	11	13	35	2
11	Anshas	ANS	30.29	31.40	3.95	5.6	6.3	6.9	4	8.5	10.5	18	41	2
General model of region (2) N. E. Desert					3.98	5.45	6.06	6.8	3.65	7.48	10.25	15.45	**36.8**	ii

Table (1): continues

No.	St. site name	ST. Code	LAT. N°	Long. E°	Upper Crust		Middle crust	Lower Crust	Upper Crust Thick.		Middle crust Thick.	Lower Crust Thick.	Moho Depth	Upper Crust
					VP1	VP2	VP3	VP4	D1	D2	D3	D4		
12	Banha Univ.	BNHA	30.47	31.18	3.67	5	6.5	6.9	2.11	6.2	9.5	14	31.81	3
13	Mansora Univ.	MANS	31.04	31.35	3.3	5.05	5.95	6.7	3.46	6.9	5.5	14.38	30.24	3
14	Zagazig Univ.	ZAGZ	30.58	31.48	4.4	4.9	5.25	6.8	3.46	6.8	5.6	18	33.86	3
15	NRIAG	HLW	29.58	31.34	3.8	5	6.3	6.83	3	8.5	7.5	19	33.5	3
16	Alexandria	ALX	31.19	29.9	3.67	5	6.5	6.9	3.52	5.5	6.5	17	32.52	3
17	Tanta Univ.	TANT	30.8	30.99	3.5	5.4	5.8	6.7	3	6	8	14	31	3
18	Adfina	ADFN	31.30	30.51	3.33	4.93	5.63	6.7	1.67	6.4	7.3	15.37	30.7	3
19	Ismailia Univ.	ISML	30.36	32.18	3.4	4.99	6.15	6.8	2.3	7	7.6	17.5	34.4	3
20	Damanhour	DMNR	31.04	30.46	2.64	5.1	5.9	6.91	1.6	5	7.5	17.5	31.6	3
21	Dammita	DMIT	31.44	31.68	3.2	4.8	5.8	6.8	1.5	8.5	7.5	16	33.5	3
General model of region (3) (Delta)					3.59	4.32	6	6.8	2.56	6.68	7.25	16.27	**32.3**	III
22	Borg Alarab	BRG	30.57	29.84	4.04	5	6.3	7.59	2.5	6	8.5	17	32.3	4
23	Matrouh	MATR	31.094	27.096	3.5	4.2	4.6	6.6	2.17	9.16	6.24	15.1	33.24	4
24	Elsalloum	SLM	31.49	25.21	3.5	4.6	5.6	6.7	2.07	6.14	7.5	15	30.57	4

Table (1): continues

No.	St. site name	ST. Code	LAT. Nº	Long. Eº	Upper Crust		Middle crust	Lower Crust	Upper Crust Thick.		Middle crust Thick.	Lower Crust Thick.	Moho Depth	Upper Crust
					VP1	VP2	VP3	VP4	D1	D2	D3	D4		
25	Elnatroun	NAT	29.63	30.62	3.4	4.78	6.7	7.1	2.54	7.23	6.77	16.23	32.72	4
26	Siwa	SWA	29.24	25.46	3.55	5	6.11	6.7	2	5	7.5	17.9	32.4	4
27	Dabaa	DB2	31.05	28.5	3.2	4.1	4.99	6.6	1.78	8.3	4.44	13.44	27.96	4
28	Fayoum	FYM	29.69	31.04	3.6	4.58	5.5	6.84	2.41	7.12	6.7	15.24	31.47	4
General model of region (4) (N. Western. Desert)					3.54	4.6	5.69	6.88	2.21	6.99	6.8	15.7	**31.50**	iv
29	Dakhla	DK2	24.32	28.95	3	4.8	5.9	6.7	3	6	9	14	32	5
30	Farafra	FRF	27.15	28.31	3	4.8	6.2	6.9	1	6	10	16	33	5
31	Tal Elamarna	TAMR	27.68	30.92	3.8	4.8	5.8	6.9	1	7	9	14	31	5
General model of region (5) Central Western Desert					3.26	4.8	5.97	6.8	1.66	6.33	9.33	15	**32.7**	V
32	Hurghada	HRG	27.05	33.61	3.86	5.7	6.23	7.3	4	5.5	10.5	13	33	6
33	Abu Dabbab	NADB	25.34	34.5	2.7	5.3	6.3	6.9	3	7	6	15	31	6
34	Mersa Alam	MRS	25.01	34.83	3.2	4.5	6.3	6.9	2.5	5	8	18	33.5	6
35	Baranees	BRNS	23.86	34.11	3	5.4	6	6.9	2	6	6	21	35	6
General model of region (6) Central Eastern Desert					3.19	3.23	6.2	7	2.88	5.88	7.63	16.75	**33.13**	vi

Table (1): continues

No.	St. site name	ST. Code	LAT. Nº	Long. Eº	Upper Crust		Middle crust	Lower Crust	Upper Crust Thick.		Middle crust Thick.	Lower Crust Thick.	Moho Depth	Upper Crust
					VP1	VP2	VP3	VP4	D1	D2	D3	D4		
36	Abu Hadid	AHD	23.80	32.78	3.4	4.6	6.2	6.9	1	6	5	20	32	7
37	Gebal Marawa	GMR	23.52	32.40	3.5	4.8	6.3	6.9	3	4	4	19	30	7
38	Senkadab	NSKD	23.66	32.39	3.6	5	5.8	6.8	3	4	5	22	34	7
39	Wadi Manama	NMAN	23.92	33.07	4.1	5.2	6.4	7.1	2.8	6	8	16	32.8	7
40	Kurkur	KUR	24.00	32.65	3.5	5.3	6.1	7.1	1.7	7	9	19	36.8	7
41	Masmas	MSM	22.88	31.89	3.5	5.3	6.2	6.9	1.5	5	6	16	28.5	7
42	Maabed	MABD	22.97	32.33	3.4	4.7	6	6.8	3	4	4	19	30	7
43	Gharamol	GRW	23.67	32.79	4.5	5.5	6.4	7.3	1.6	8	8	18	32.6	7
General model of region (7) Aswan					3.25	5.05	6.17	6.97	2.2	5.5	6.12	18.6	**32.1**	vi
Egypt general crustal model From all seven regions model					3.6	5.03	5.98	6.86	2.55	6.48	7.75	16.55	**33.3**	Egypt model

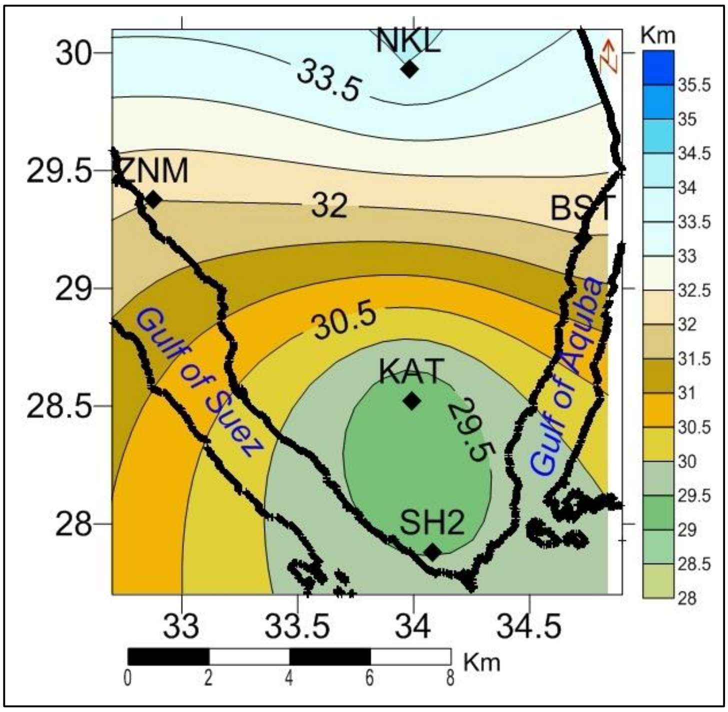

Figure (5): Contour map represents the Moho depths beneath the stations in Region 1 (Sinai).

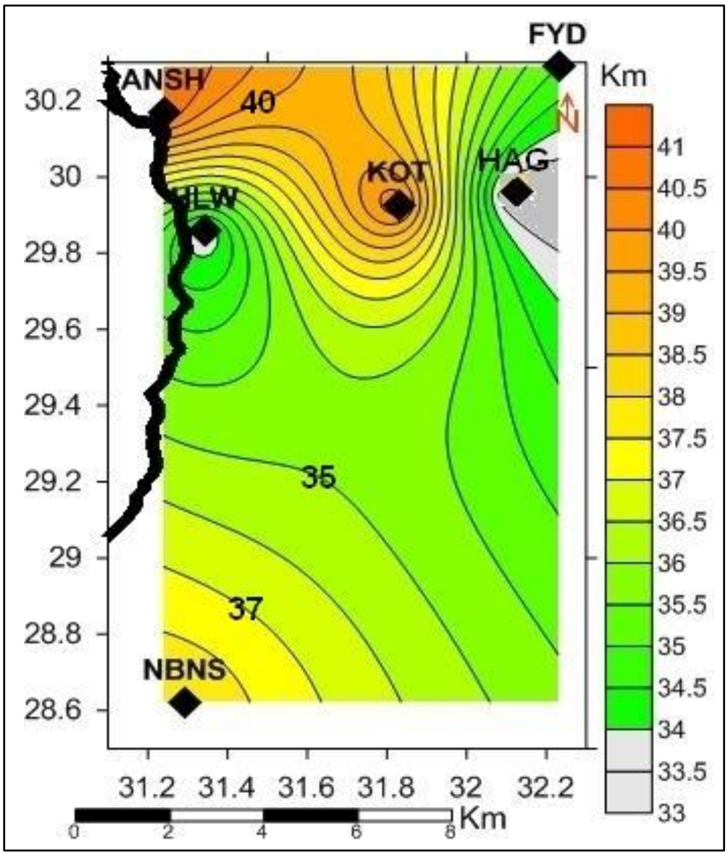

Figure (6): Contour map represents the Moho depths beneath the stations in Region 2.

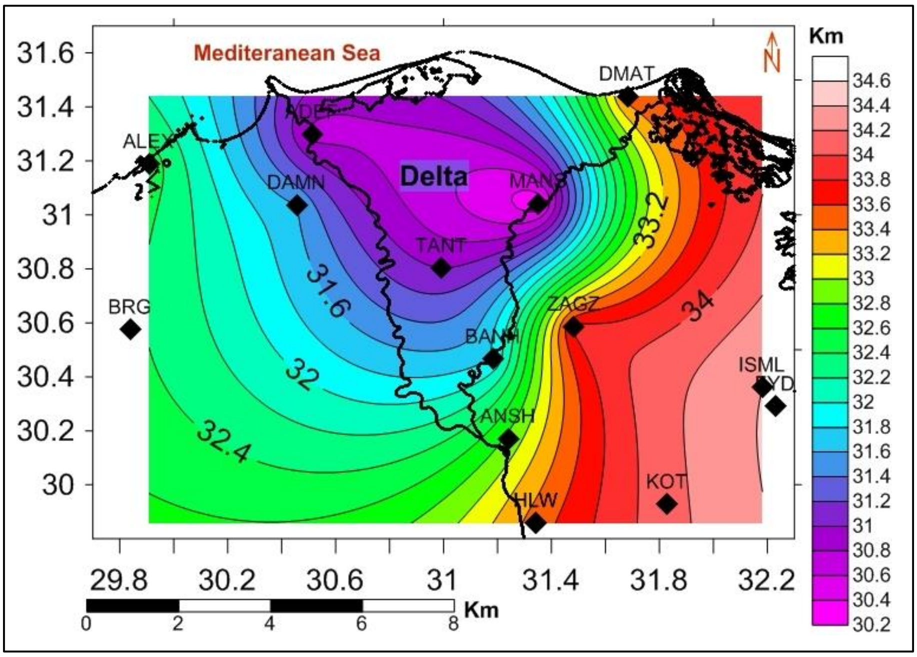

Figure (7): Contour map represents the Moho depths beneath the stations in Region 3 (Nile delta region).

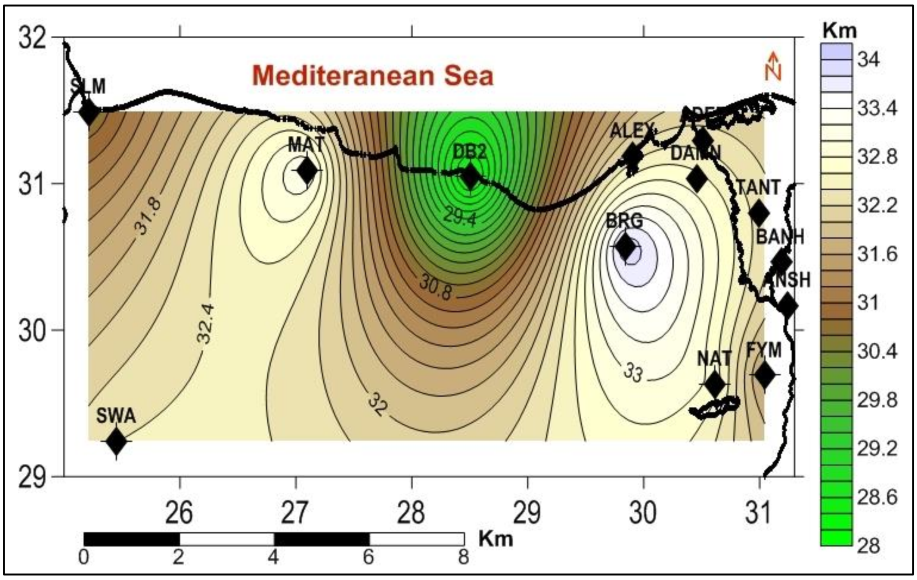

Figure (8): Contour map represents the Moho depths beneath the stations in Region 4 (Qattara Depression).

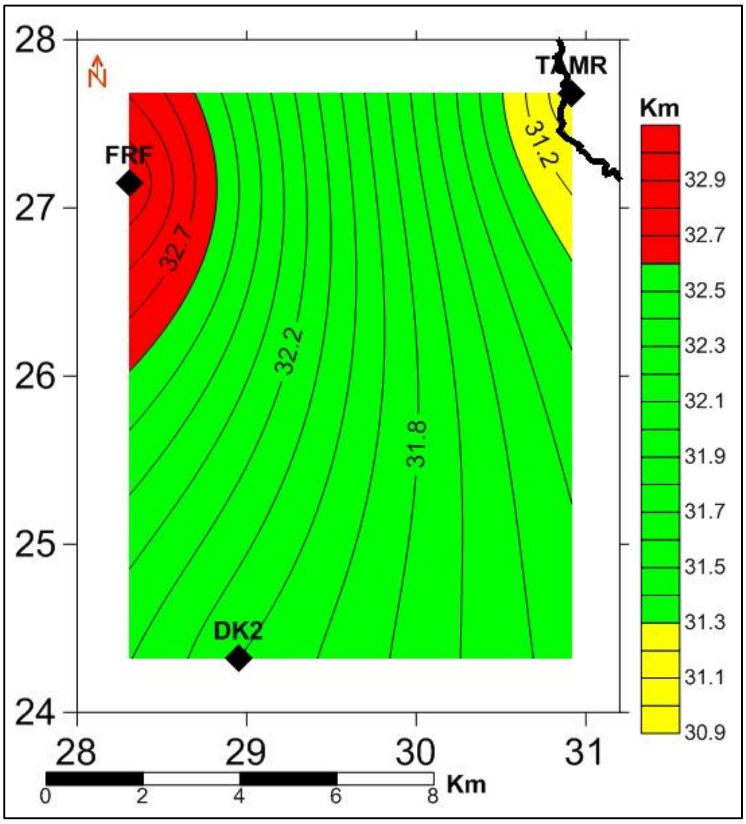

Figure (9): Contour map represents the Moho depths beneath the stations in Region 5.

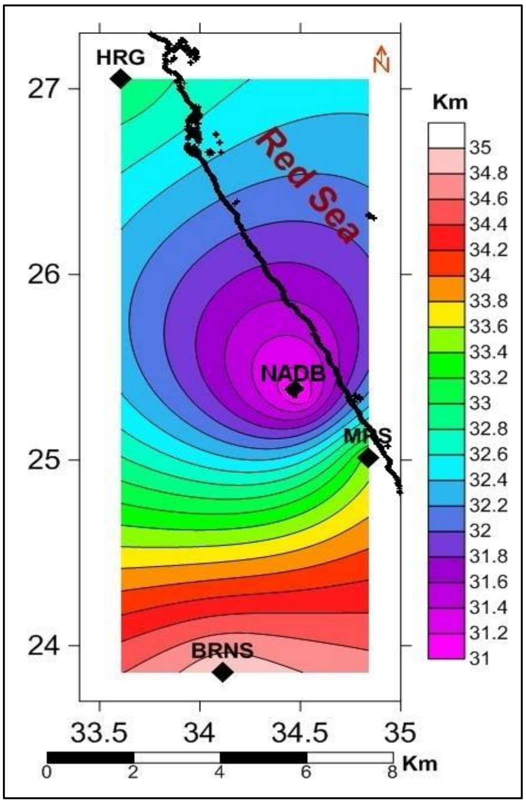

Figure (10): Contour map represents the Moho depths beneath the stations in Region 6.

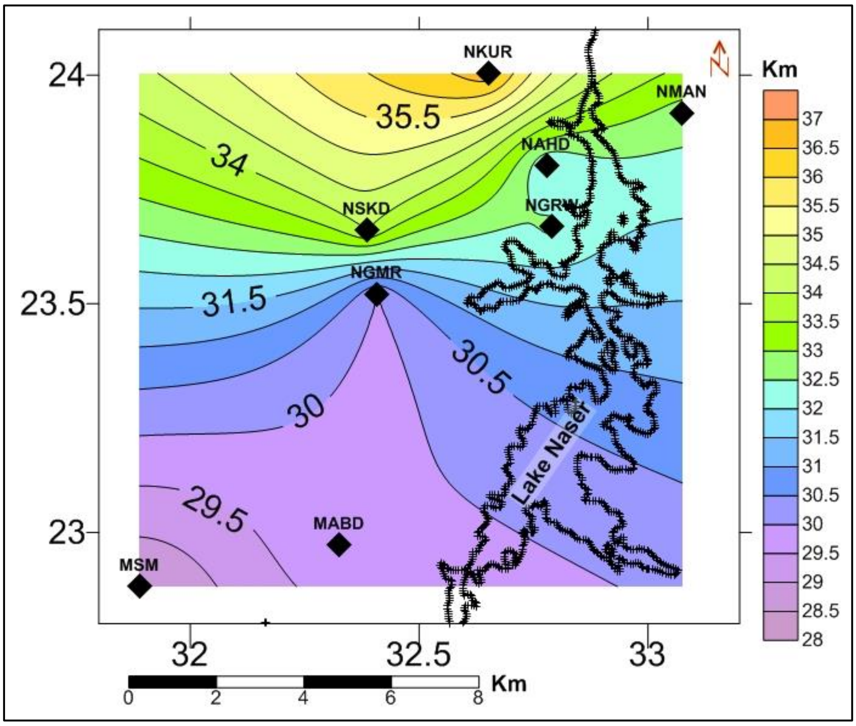

Figure (11): Contour map for the Moho depths beneath the stations in Region 7.

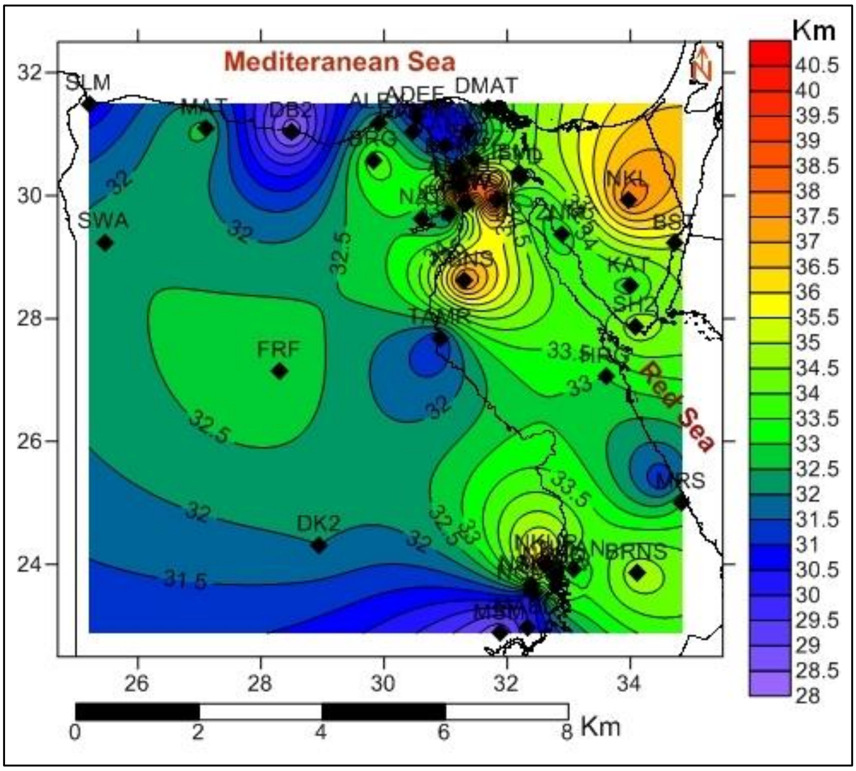

Figure (12): The average depths to the Moho throughout Egypt.

By applying two techniques Transfer Function (TF) and Receiver Function (RF) Techniques for the recorded regional and local data to estimate crustal structure beneath each seismic station sites together to obtain general regional models.

Results given in Table (1) show that the net results of the work where : D1= thickness of surface layer, D2 = thickness of basement layer, D3= thickness of middle crustal part, d4= thickness of the lower crustal part, Moho depth= Mohorovici depths beneath the network stations and VP1 = body wave velocity of the surface layer (cover layer of the upper crust),VP2=Body wave (longitudinal wave) velocity of basement layer (the bottom layer of upper crust),VP3= Body wave (longitudinal wave) velocity of the middle crustal unit, VP4= Body wave velocity of the lower crustal unit, Lat. and Long are seismic station site coordinates and Moho-depths are presented in most right column of Table (1). Also general region models are shown in Table (1).

4- MOHO DEPTHS FOR THE SEVEN REGIONS

Figures from (5) to (12) show the contour maps for Moho Depth at the seven regions of Egypt.

5- CONCLUSION

General regional structure models were estimated. The obtained results show that the Egyptian model has three main units (Gharib et al 2016). This indicates that the Upper crustal unit which contains two thin layers superficial layer followed by hard deposits layer. The second is the middle Crustal part and it is followed by Conrad discontinuity which separates the lower crustal part from above. Lower Crustal part exhibits a P-wave velocity of 7.14 km/sec and a thickness of 16 km as depths under the seven selected regions (1 up to 7), where Moho depths are for seven regions: 34.8, 36.8, 32.3, 31.5, 32.7, 33.13 and 32.1 km, respectively. The of (RF) shows that, there are 5 low zones occurrences at depths of 1 km, 3 km, 6.5 km, 18 km and 37.5 km. These are interpreted as the interfaces between the crustal zones of 0.7, 5.5, 10.5, 15.5, 20.5, 30.5, 40.5, 45.5 and 50.5 km depths. Upper Crustal unit is composed of two layers; soft sediments with mean P- wave velocity of 3.73 km/s and mean thickness of 2.5 km, the P- wave velocity of the second layer (Hard Deposits) is 5.53 km/sec and thickness of 6.7 km. The middle Crustal part shows a mean thickness of 14 km and a mean P-wave velocity of 5.9 km/sec. Third Unit; Lower Crustal part exhibits a P-wave velocity of 7.14 km/sec and a thickness of 16 km. This part is followed by Conrad discontinuity, low velocity thin layer with ≈5 km which separates the lower crustal part from above. Moho depths under the seven recognized regions are: 32.5 km, 32.3 km, 33.25 km, 31.66 km, 32.99 km, 31.7 km and 30.86 km, respectively. The upper mantle part showed a P-wave velocity of 8.2 km/sec and a depth ranging from 32 to 50 km. The results show also the existence of 5 low velocity occurrences at depths of 1 km, 3 km, 6.5 km, 18 km and 37.5 km. These are interpreted as the interfaces between the crustal zones at depths of 0.7, 5.5, 10.5, 15.5, 20.5, 30.5, 40.5, 45.5 and 50.5 km respectively.These results are available for the urban planning and the other related activities. The results from the two applied techniques are compared with the existed model already obtained before (Abdelwahed, for some localities in Egypt using the Deep Seismic Sounding (DSS) through different areas in Egypt (Marzouk, 1988, Gharib, 1991). The obtained results through this project are more detailed, and widely covering the Egyptian territories and give more information than the previous works done by other researchers.

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