Receiver function studies of crustal structure, composition, and evolution beneath the Afar Depression, Ethiopia

PhD Dissertation

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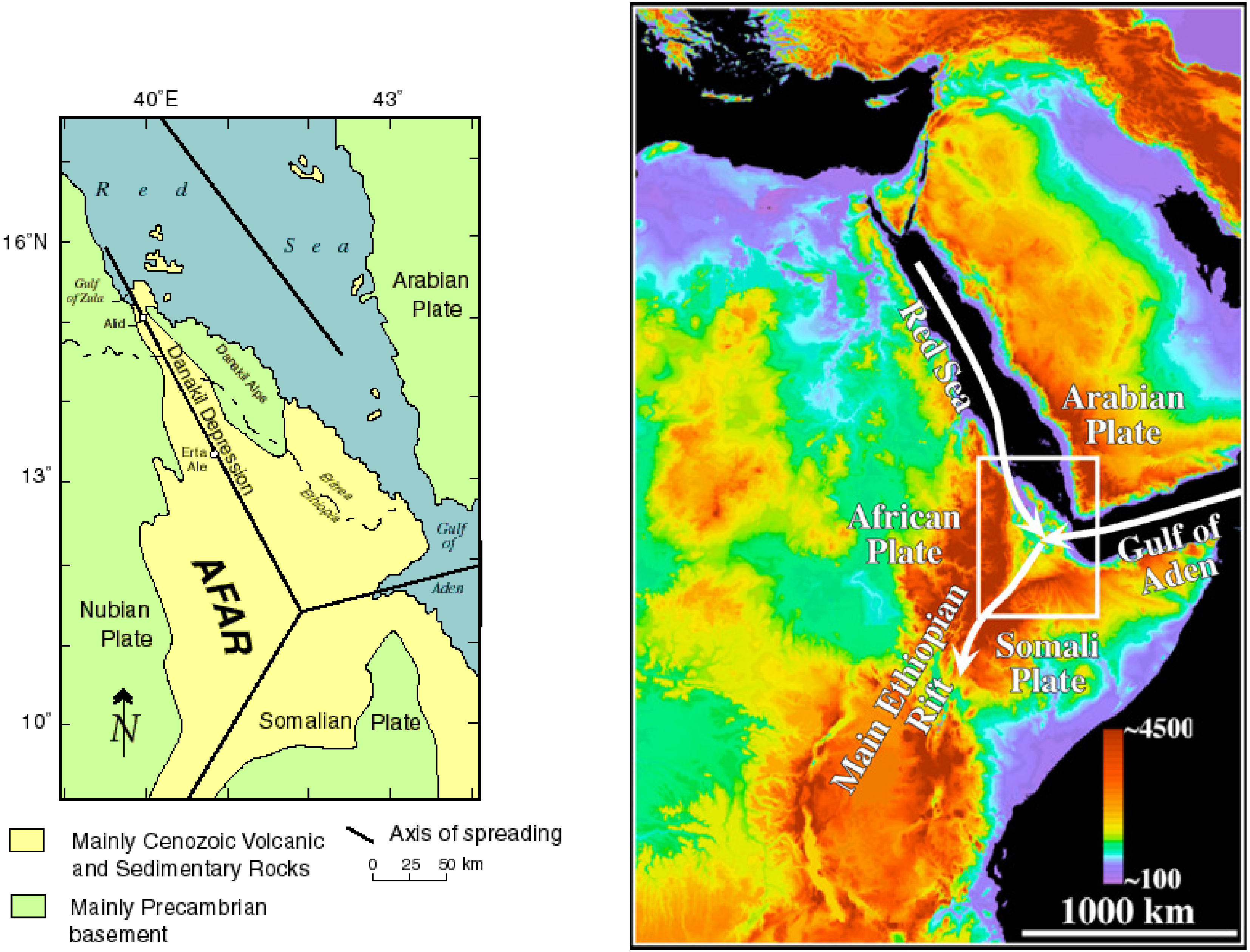
Outline:

- Aims of the study.
- Importance of the Afar Depression.
- Receiver function analysis.
- Data.
- Results.
- Implications of the observed results.
- Conclusions.

Aims of the study:

The study aimed at charactering crustal properties beneath the Afar Depression by measuring the following parameters:

- Crustal thickness (H).
- The composition of the crust by measuring the crustal mean of V_p/V_s (Φ), which is related to Poisson's ratio (σ), where: $\sigma = 0.5\,[1-1/(\Phi^2-1)]$.
- The sharpness of Moho by measuring R, where R is the amplitude of the converted phases from the Moho.



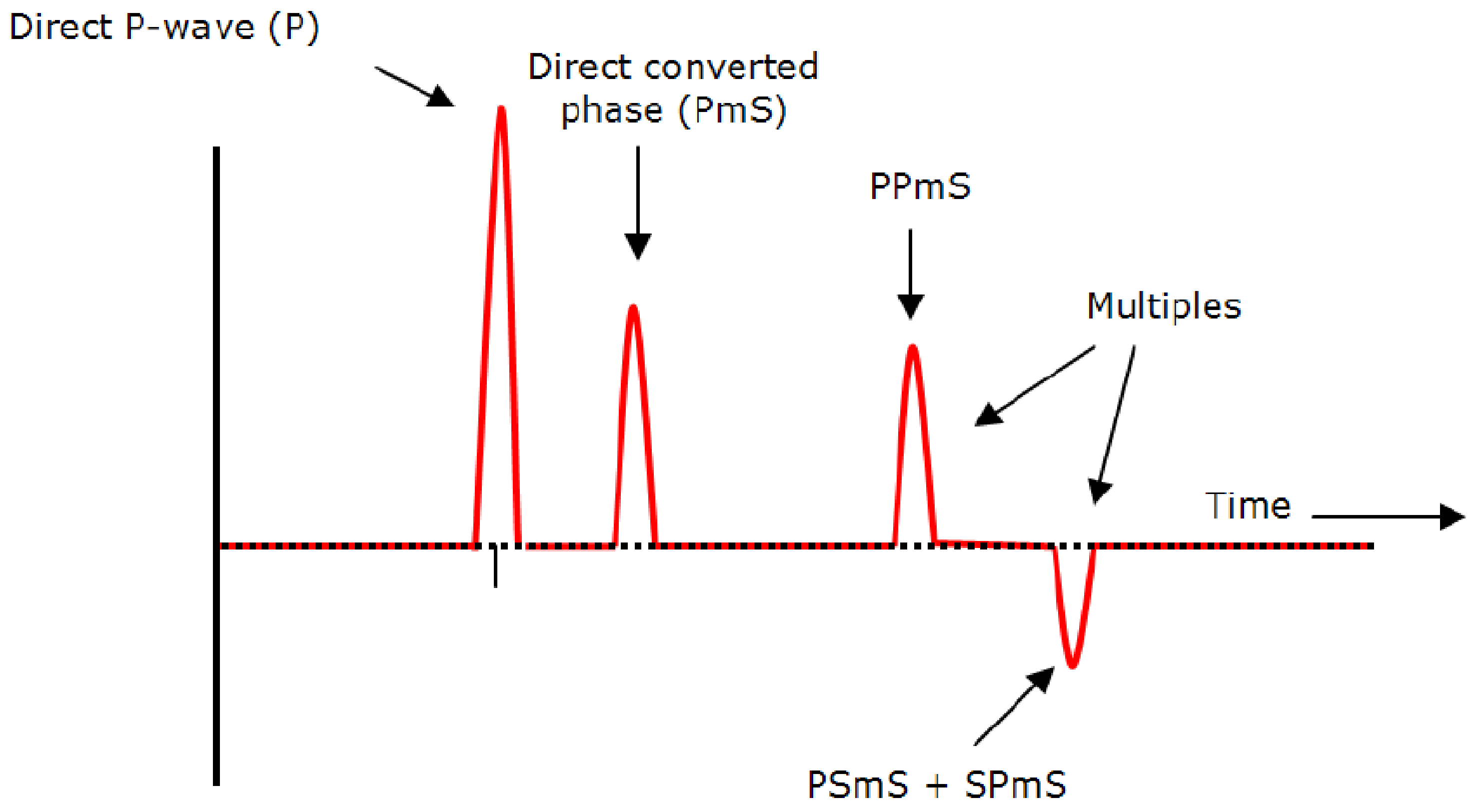
Maps of the Afar Depression [Beyene and Abdelsalam, 2005]

Importance of the Afar Depression:

- The unique geological history and tectonic setting.
- It represents the only emerged R-R-R triple junction in the world, beside Iceland.
- Characteristics of the crust beneath Afar have been a subject of controversy among scientists.
- Afar is an example of a transitional stage from continental rifting to seafloor spreading.
- High teleseismic data sets that are available from 18 broadband seismic station that we deployed.

Receiver function analysis:

- Receiver function analysis is a well-established technique to estimate crustal and upper mantle structure using three-component seismic data.
- The analysis detects the crustal boundary by identifying the P-to-S converted waves (PmS) and their multiples (PPmS and PSmS) [Ammon, 1991; Langston, 1977].



The P-to-S converted waves (PmS) and their multiples (PPmS and PSmS)

Data:

- 18 Gűralp CMG-3T broad-band seismometers we deployed along a profile of 250 km long with a station spacing of 10 km.

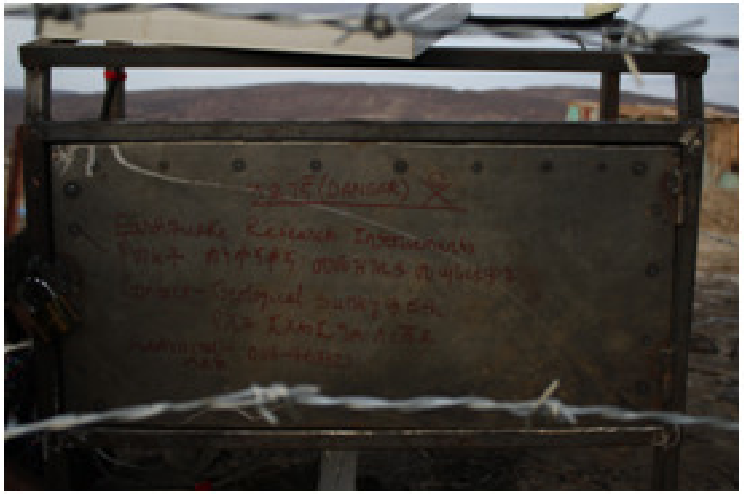
- The instruments recorded data at 100 samples per second for 12-months period (December 2009 until December 2010).

- The stations have been visited and services twice in June 2010 and December 2010.

The equipments used for the installation:

- Sensor
- Q330
- Baler
- Clie
- Battery
- Power box
- Solar panel
- GPS


QUANTERRA PACKET BALER
Model PB14F
STATUS
ATTN
QUANTERRA
Q330
SENSOR A
SENSOR B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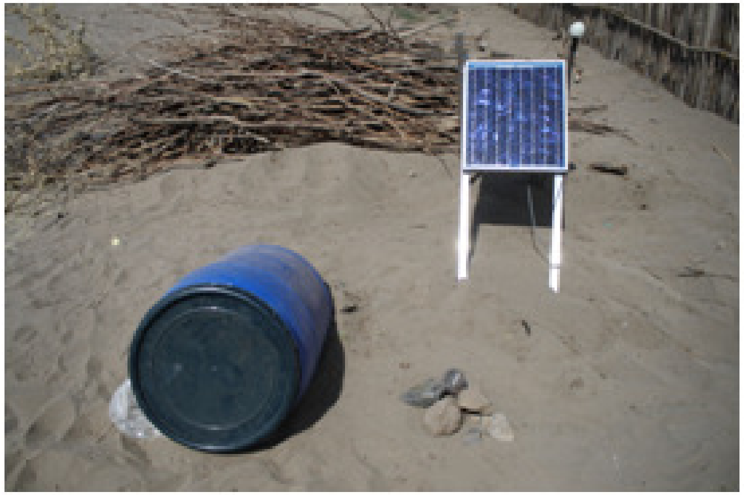
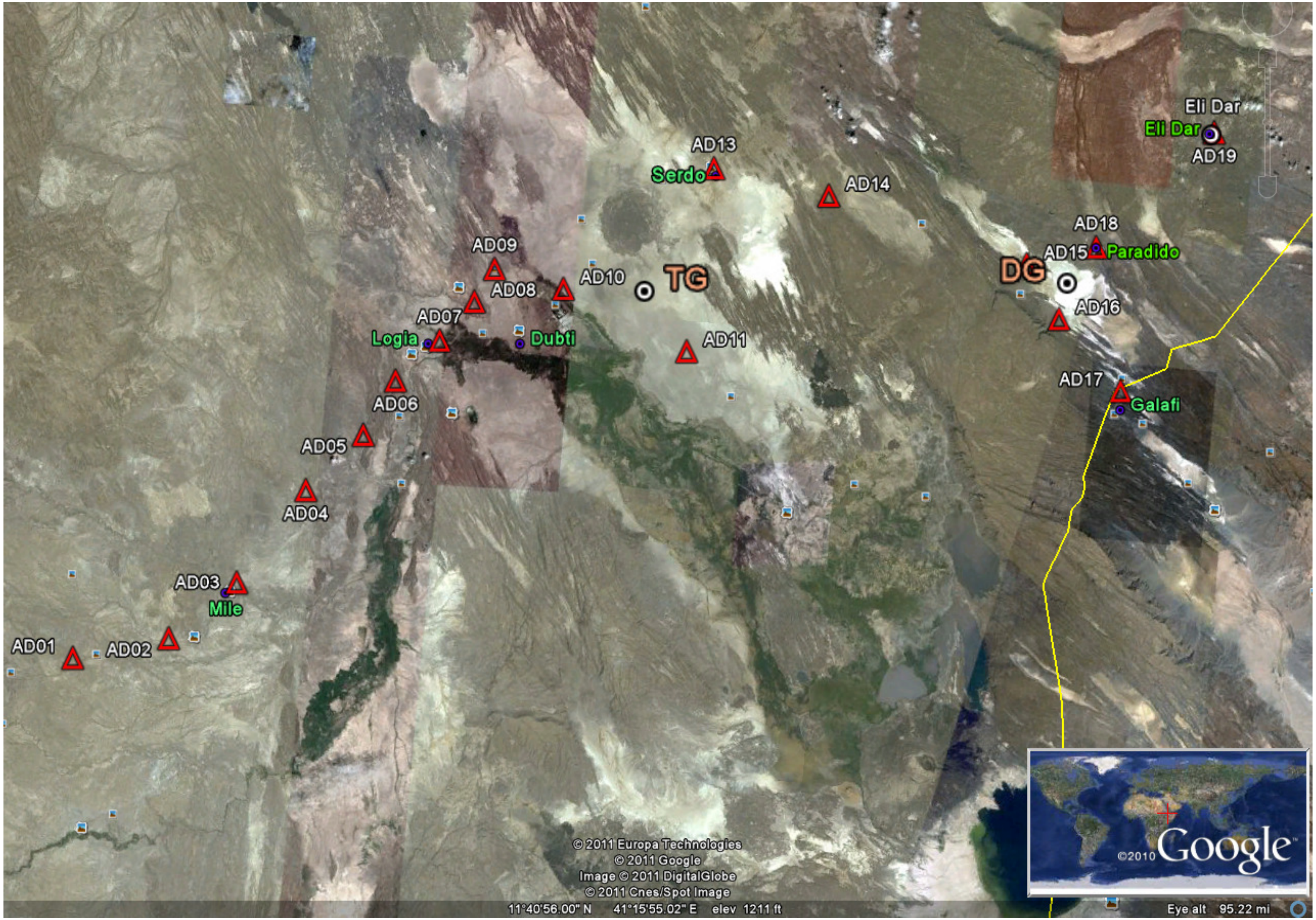




The distribution of the seismic satiations in the AD showing
the Tendaho Graben (TG) and the Dobi Graben (DG) by using Google Earth

Results:

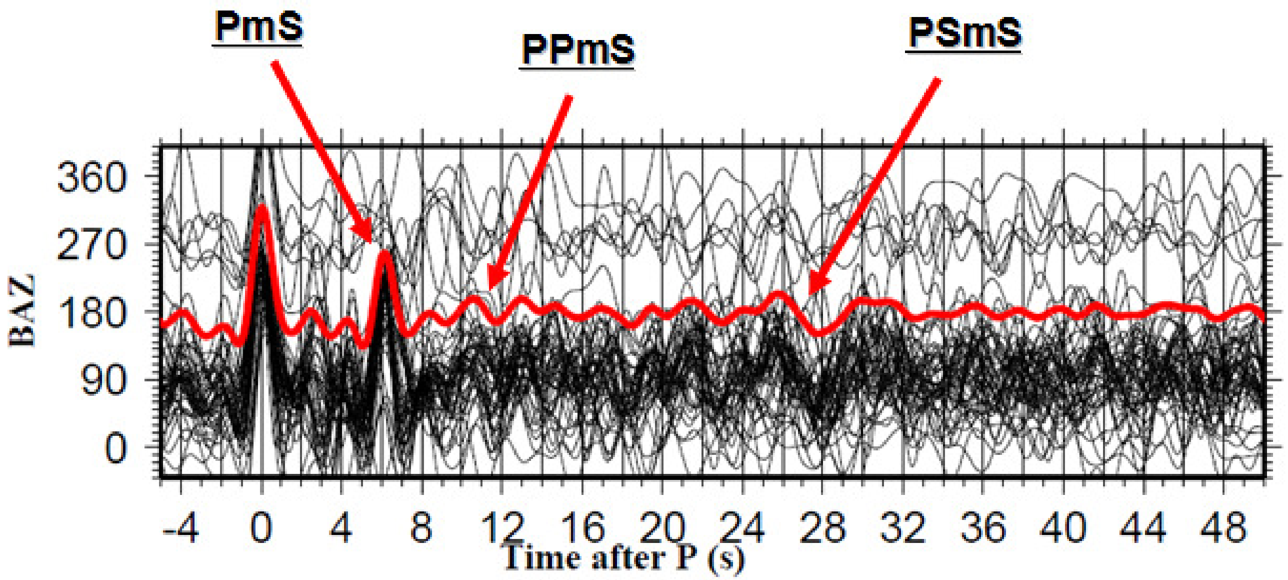
- The results were organized into two categories (A and B) based on the quality of the H-Φ plots.

- Category A stations display a clear defined single peak in the H-Φ plots (H and Φ can be determined)

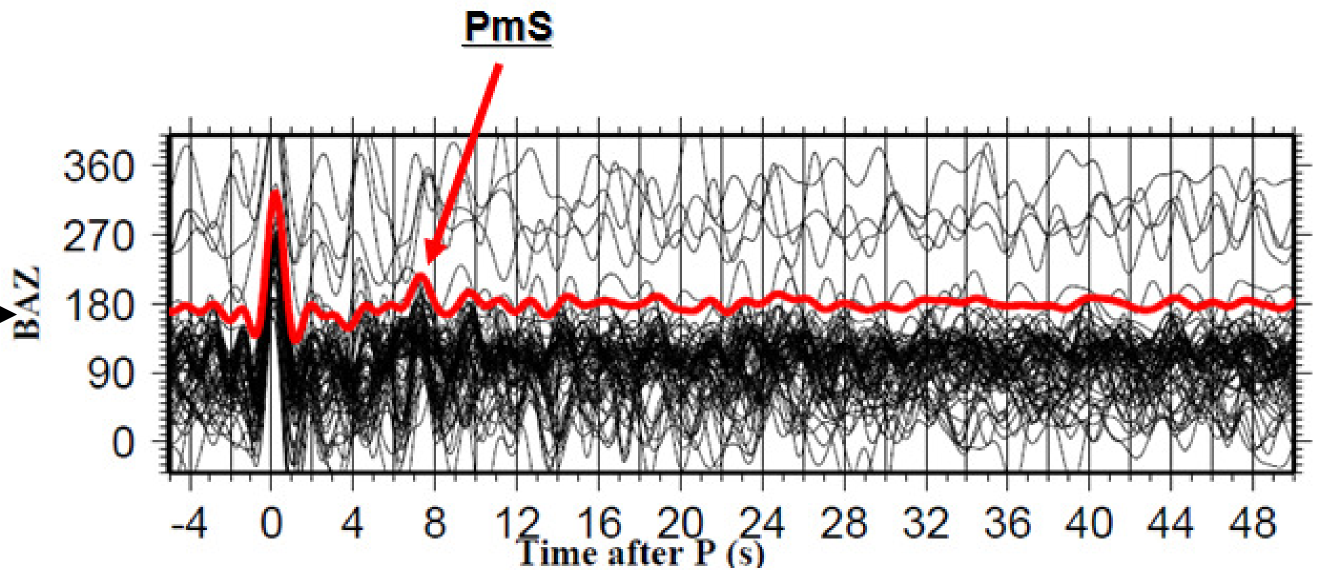
- Category B stations show clear PmS but not PPmS or PSmS (H and Φ can not be determined)

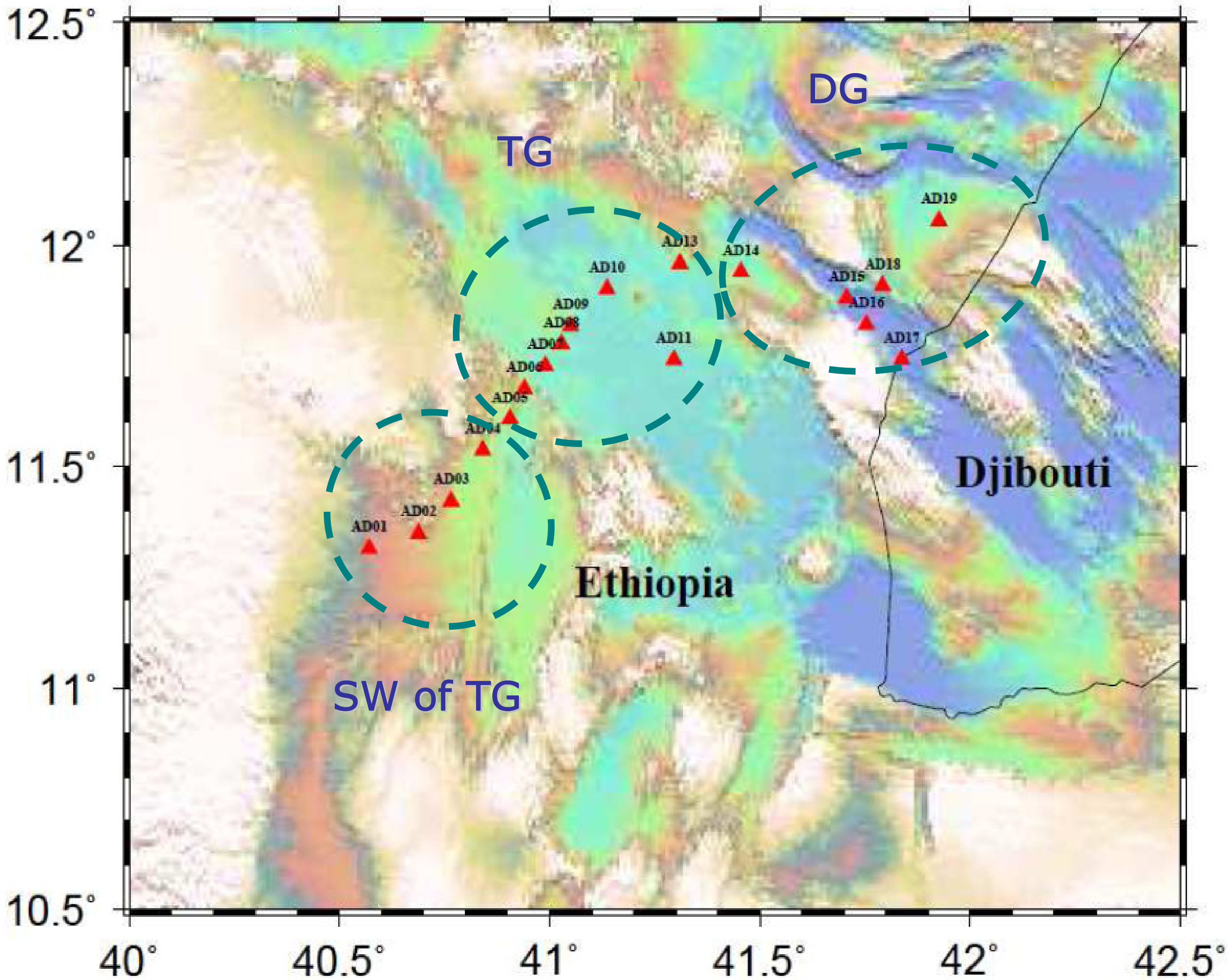
Category A	Category B
AD01	
AD02	
AD03	AD06
AD04	AD07
AD05	AD09
AD08	AD10
AD13	AD11
AD15	AD14
AD16	AD19
AD17	
AD18	

Category A



Category B

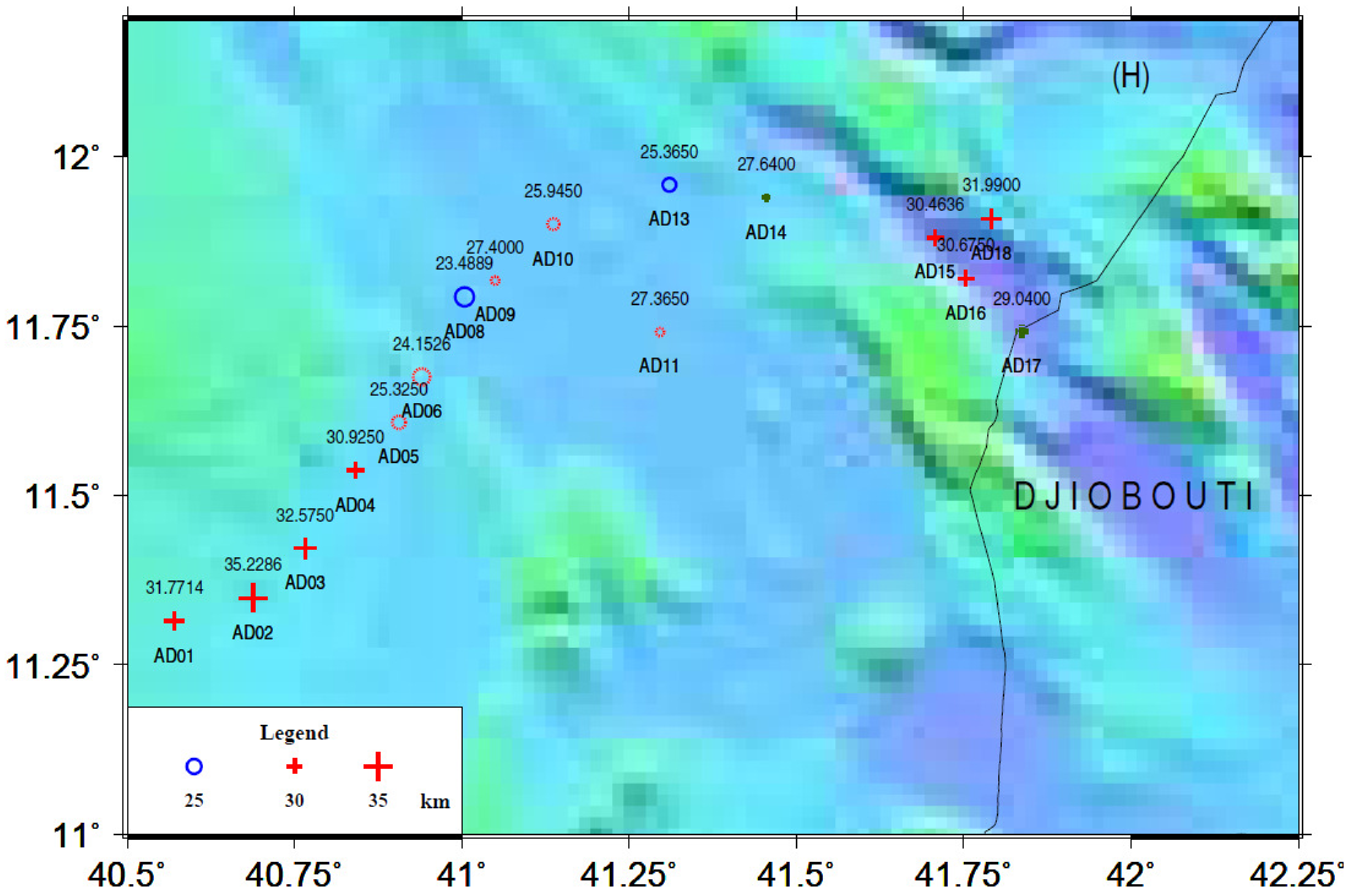




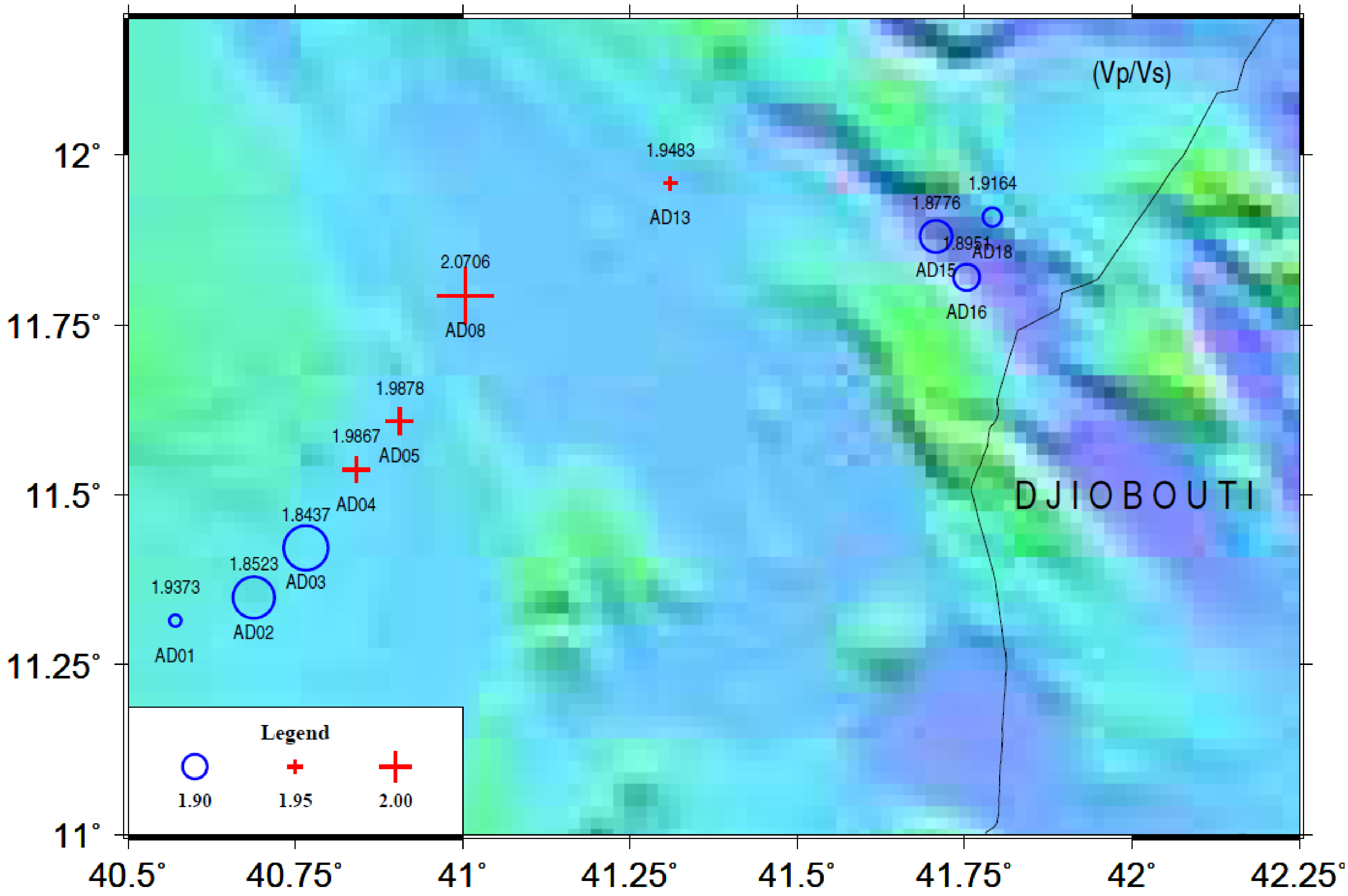
Locations of the three divisions

	Station	Lat. North	Long. East	Elev. (m)	H (km)	H STD	Φ	Φ STD	R	R STD	Poisson's ratio	Quality
SW of TG	AD01	11.32	40.571	580	31.77	0.19	1.937	0.013	0.181	0.019	0.318389	A
	AD02	11.35	40.688	523	35.23	0.29	1.852	0.007	0.089	0.006	0.294325	A
	AD03	11.42	40.766	488	32.58	0.33	1.844	0.024	0.078	0.013	0.2916	A
	AD04	11.54	40.841	483	30.93	0.15	1.987	0.005	0.069	0.009	0.330335	A
	AD05	11.61	40.906	451	25.33	0.11	1.988	0.004	0.128	0.01	0.330586	A
	Mean				31.17	0.214	1.922	0.0106	0.109	0.0114	0.313047	
TG	AD06	11.68	40.94	460	24.15	0.33	1.921	0.041	0.066	0.015	0.314037	B
	AD07	11.73	40.99	395	24.29	0.21	1.93	0.01	0.32	0.021	0.316507	B
	AD08	11.78	41.028	391	23.49	0.17	2.071	0.009	0.2	0.005	0.347903	A
	AD09	11.82	41.05	385	27.4	0.47	1.945	0.042	0.017	0.009	0.320364	B
	AD10	11.8	41.137	370	25.95	0.37	1.866	0.015	0.302	0.015	0.298425	B
	AD11	11.74	41.296	370	27.37	0.15	1.964	0.01	0.257	0.023	0.324985	B
	AD13	11.96	41.31	352	25.37	0.68	1.948	0.027	0.127	0.011	0.321165	A
	Mean				25.43	0.34	1.949	0.022	0.184	0.0141	0.320484	
DG	AD14	11.94	41.455	422	27.64	0.25	1.984	0.009	0.13	0.011	0.329623	B
	AD15	11.88	41.707	88	30.46	0.4	1.878	0.033	0.12	0.021	0.30201	A
	AD16	11.82	41.753	118	30.68	0.28	1.895	0.018	0.146	0.013	0.307054	A
	AD17	11.74	41.837	150	29.04	0.12	1.981	0.006	0.265	0.026	0.329092	A
	AD18	11.91	41.791	452	31.99	0.26	1.916	0.019	0.103	0.011	0.312915	A
	AD19	12.05	41.926	435	30.52	0.36	1.87	0.016	0.068	0.014	0.299752	B
	Mean				30.05	0.278	1.921	0.0168	0.139	0.016	0.313408	

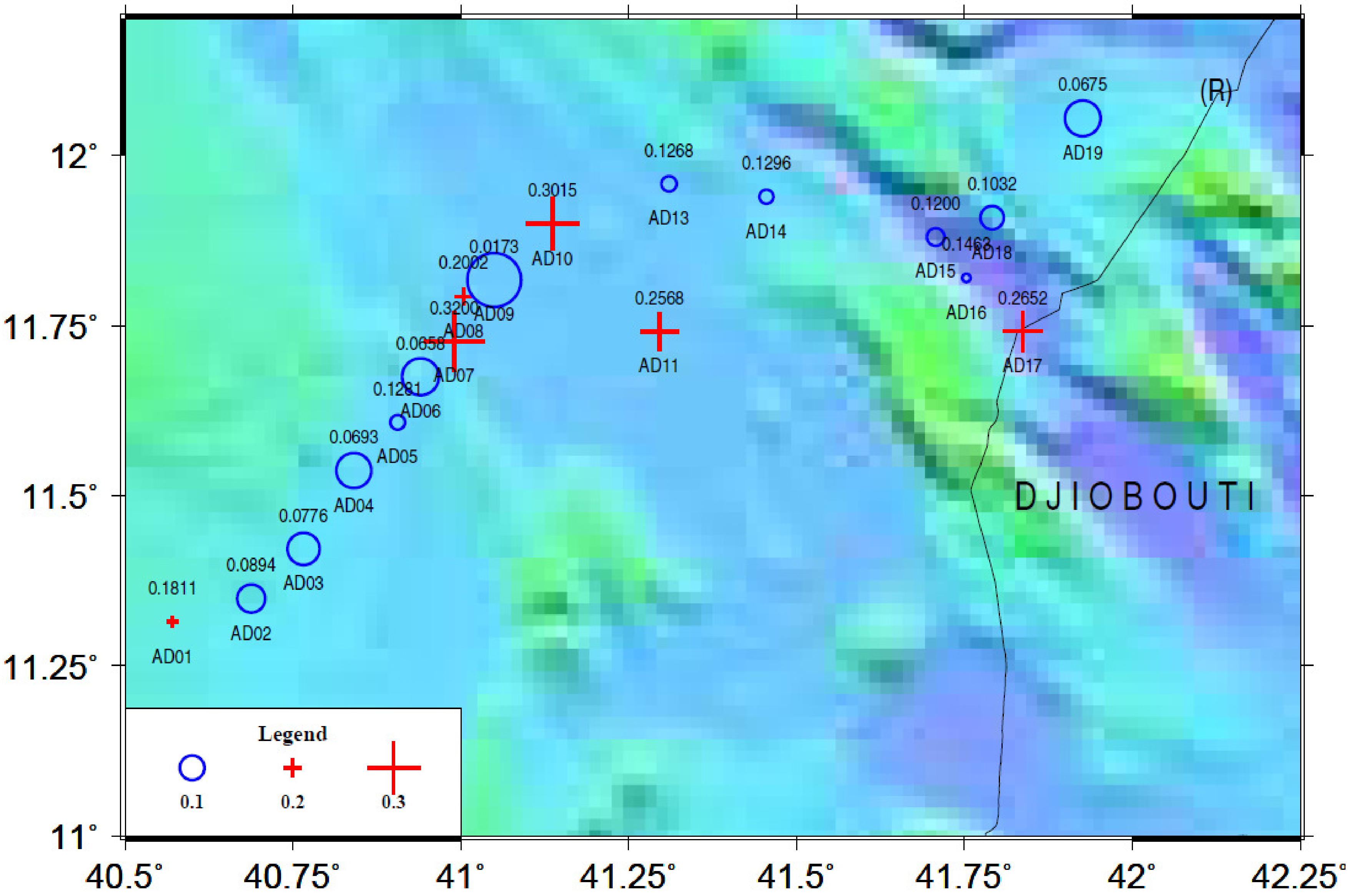
The resulted H, Φ, and σ for the three divisions



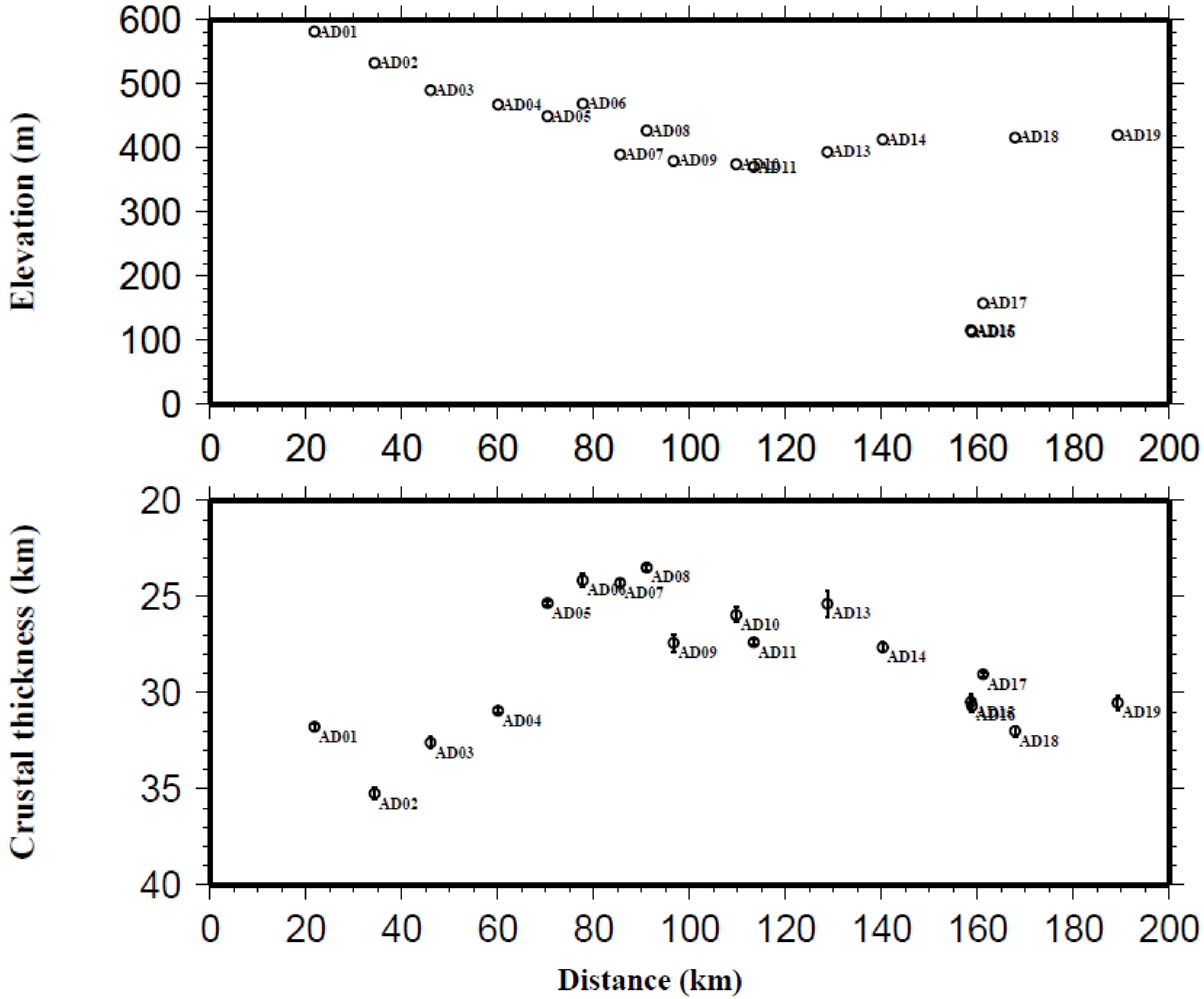
Resulting crustal thickness (H). Circles represent stations with a smaller thickness and pluses represent station with larger thickness



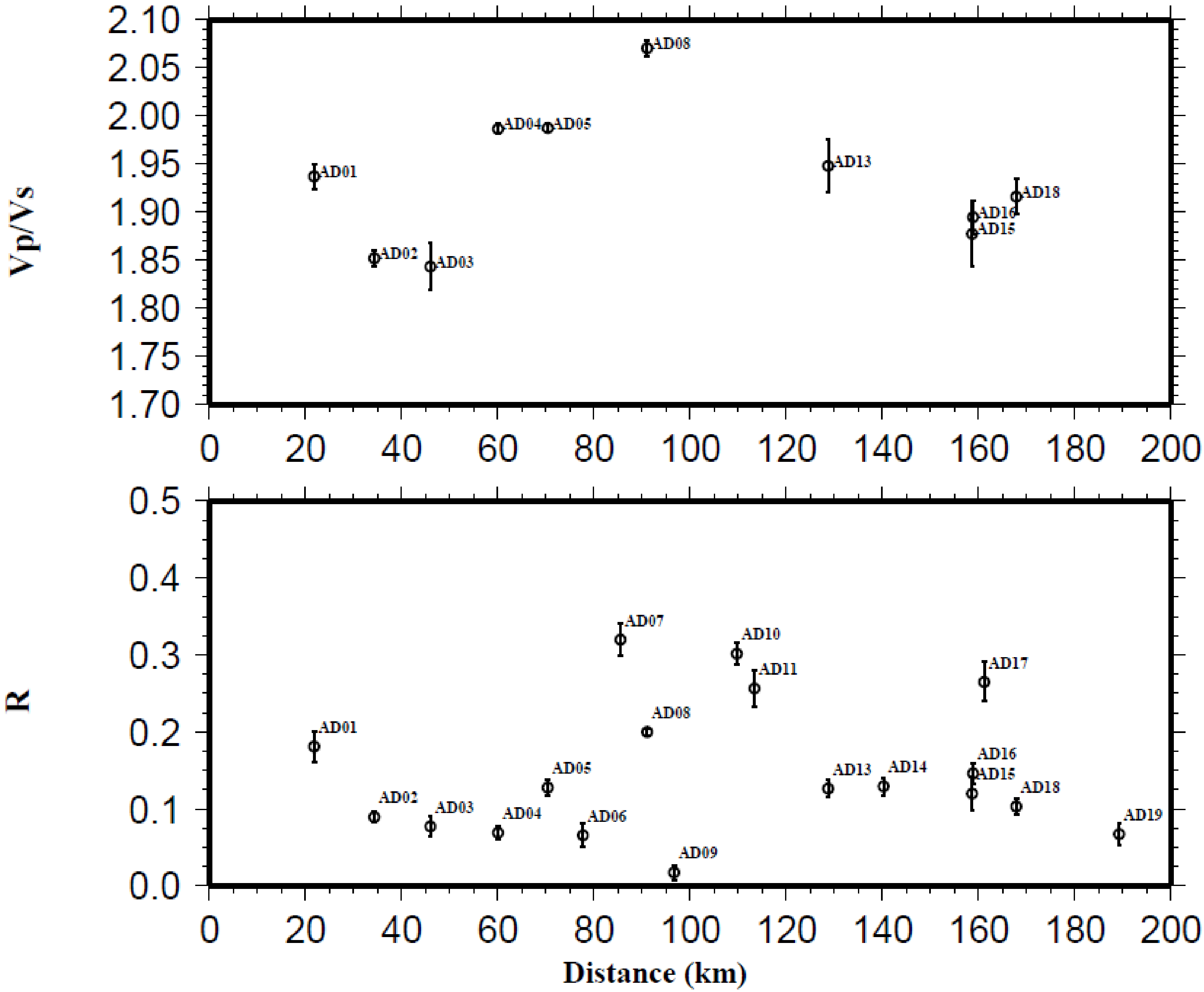
Resulting crustal Vp/Vs (Φ) for category A stations



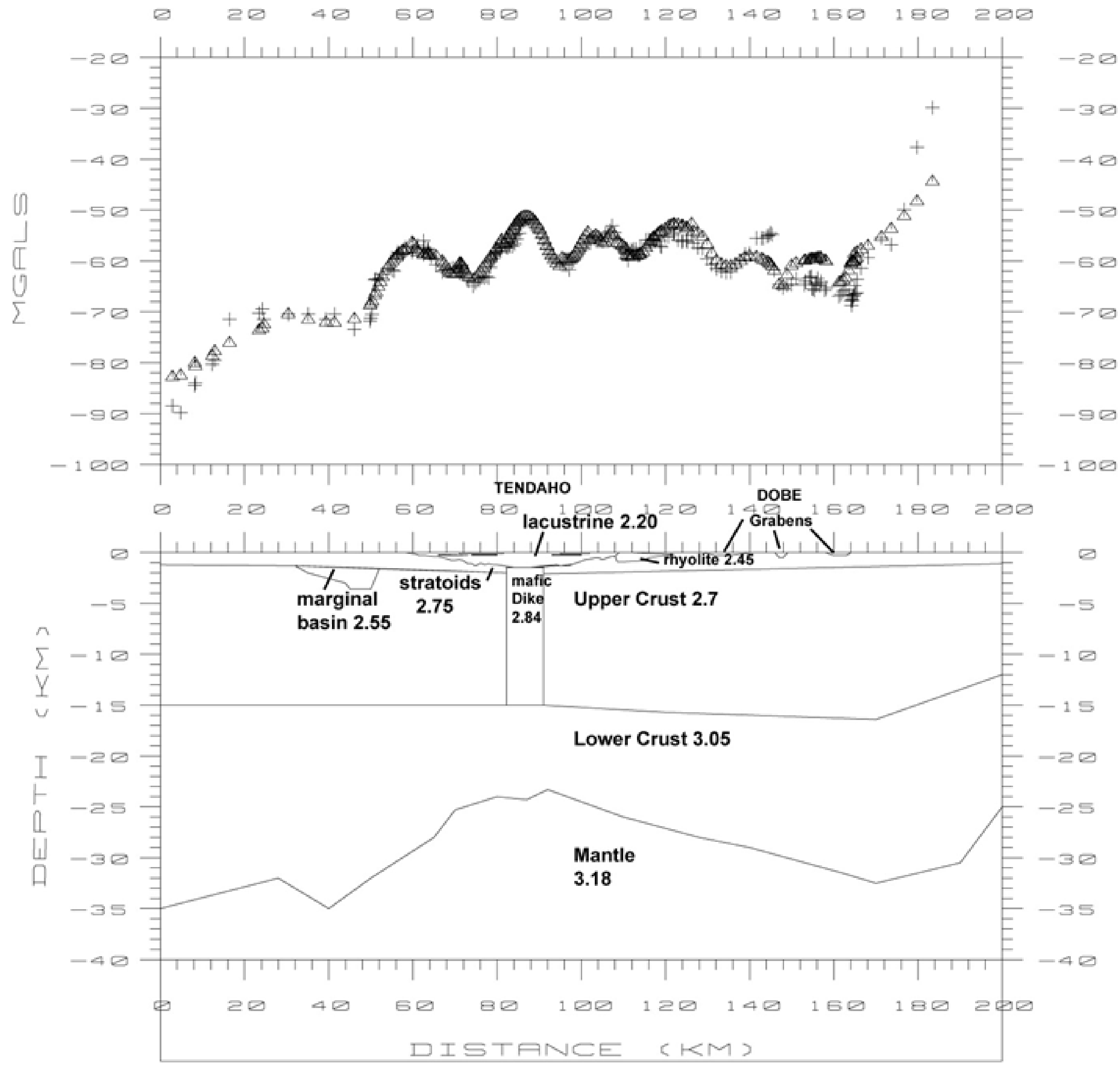
Resulting ratio (R) of the stacking amplitude corresponding to the optimal pair of (H,Φ) over that of direct P-wave on the radial component



Cross-section plots for elevation and H



Cross-section plots for Vp/Vs and R



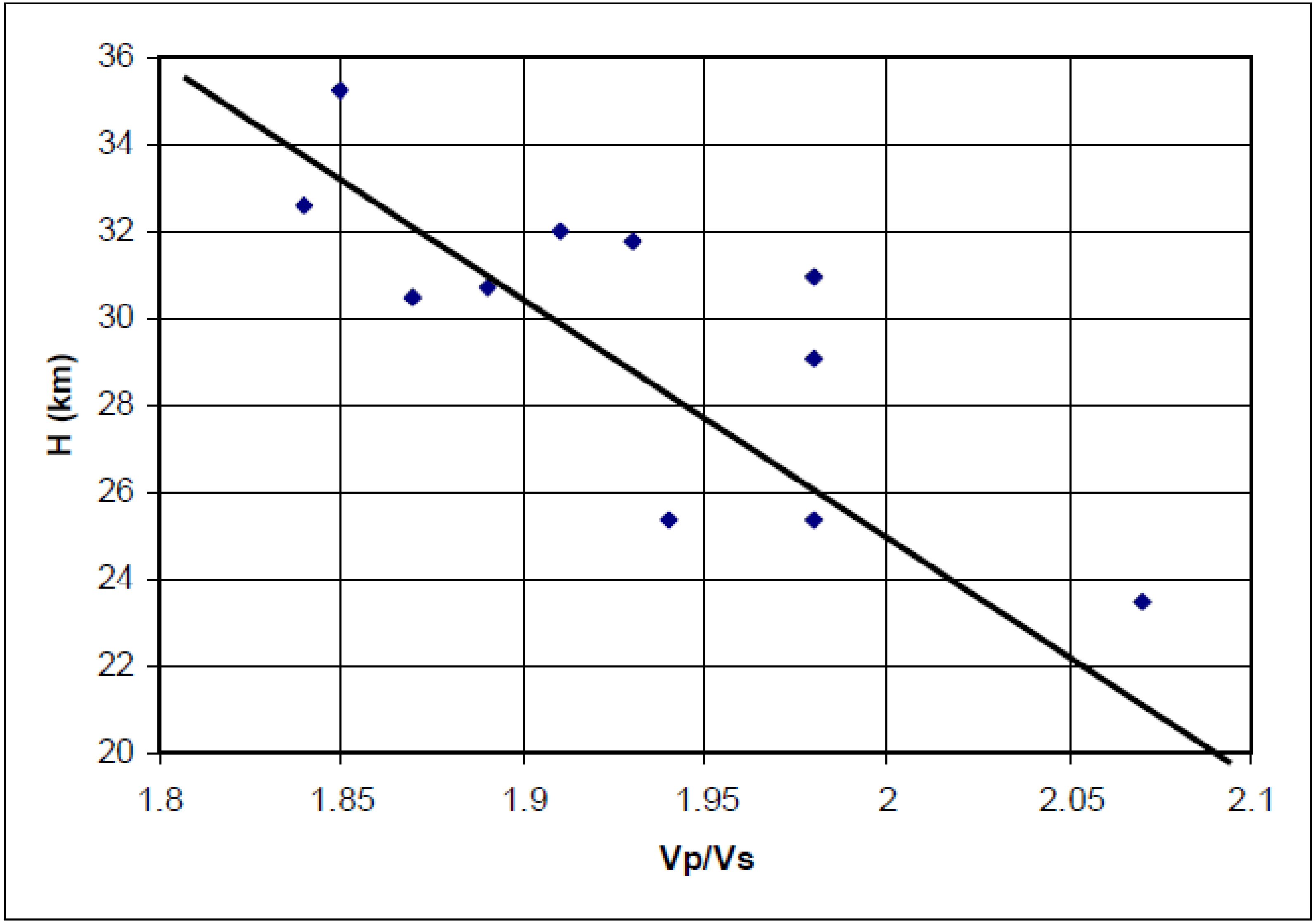
Resulting Bouguer Anomalies Model [Mickus, 2011]

Summary of the results:

- The average crustal thickness is 28.56 km, Φ values ranging from 1.84 to 2.07 with an average of 1.94 and Poisson's ratio ranging from 0.29 to 0.34.
- The resulted Poisson's ratio obtained in this study is consistent with the estimation of Ruegg (1975) of 0.28 to 0.33, Zandt and Ammon (1995) of 0.29 and Dugda and Nyblade (2006) of 0.30.
- The gravity minimum occurs over the area of high elevation (negative), while the values increase towards the TG.
- The gravity modeling results are consistent with the distribution of the crustal thickness and the observations of Vp/Vs using receiver function analysis.

Implications of the observed results:

- The study indicates that the crust layer beneath the study area in the Afar Depression is composed mainly of more mafic material and contains a small amount of partial melt.
- The Φ distribution is remarkably large throughout the area and seem to have a clear relationship with the crustal thickness (i.e. smaller H corresponds to large Vp/Vs and vice versa). The more mafic component occur in the crust, the thinner the crust will be.
- The mean values of Vp/Vs for the stations located SW of TG and in the TG are considerably larger than those in the DG. It is likely that magma source exist in the crust that led to rise the values of σ.



The relationship between the resulted Φ and H

- The TG has thinner crust comparing with those SW of TG and DG.
- The distribution of crustal thickness go together with reasonable rational with high elevation areas.
- The AD has smaller-than-normal stacking amplitude of the P-to-S converted phases beneath most stations.
- The study assume that diking is more likely the cause that rise the observed high values of Vp/Vs.

Conclusions:

- The average crustal thickness beneath the Afar Depression is about 28.56±0.28 km.
- The crust is characterized by large Vp/Vs of 1.93±0.017.
- Smaller-than-normal overall stacking amplitude of the P-to-S converted phases beneath most stations.
- The crust beneath the entire study area is significantly thinned and extensively intruded by mafic dikes, representing a transitional stage between continental and ocean crust.

- The Tendaho Graben has the thinnest and most mafic crust. The crust beneath the center of the Tendaho Graben is likely to be oceanic-type, and becomes progressively more continental away from the center.
- Active magmatic areas (i.e. Tendaho Graben) are characterized by higher gravity anomalies while the thicker crusts have small and negative anomalies.
- The observed Φ values in this study seem to have a clear relationship with the crustal thickness (i.e. smaller H corresponds to large Vp/Vs).
- The study assumes that diking is more likely the source which causes the elevation of Φ values.

Thank you …