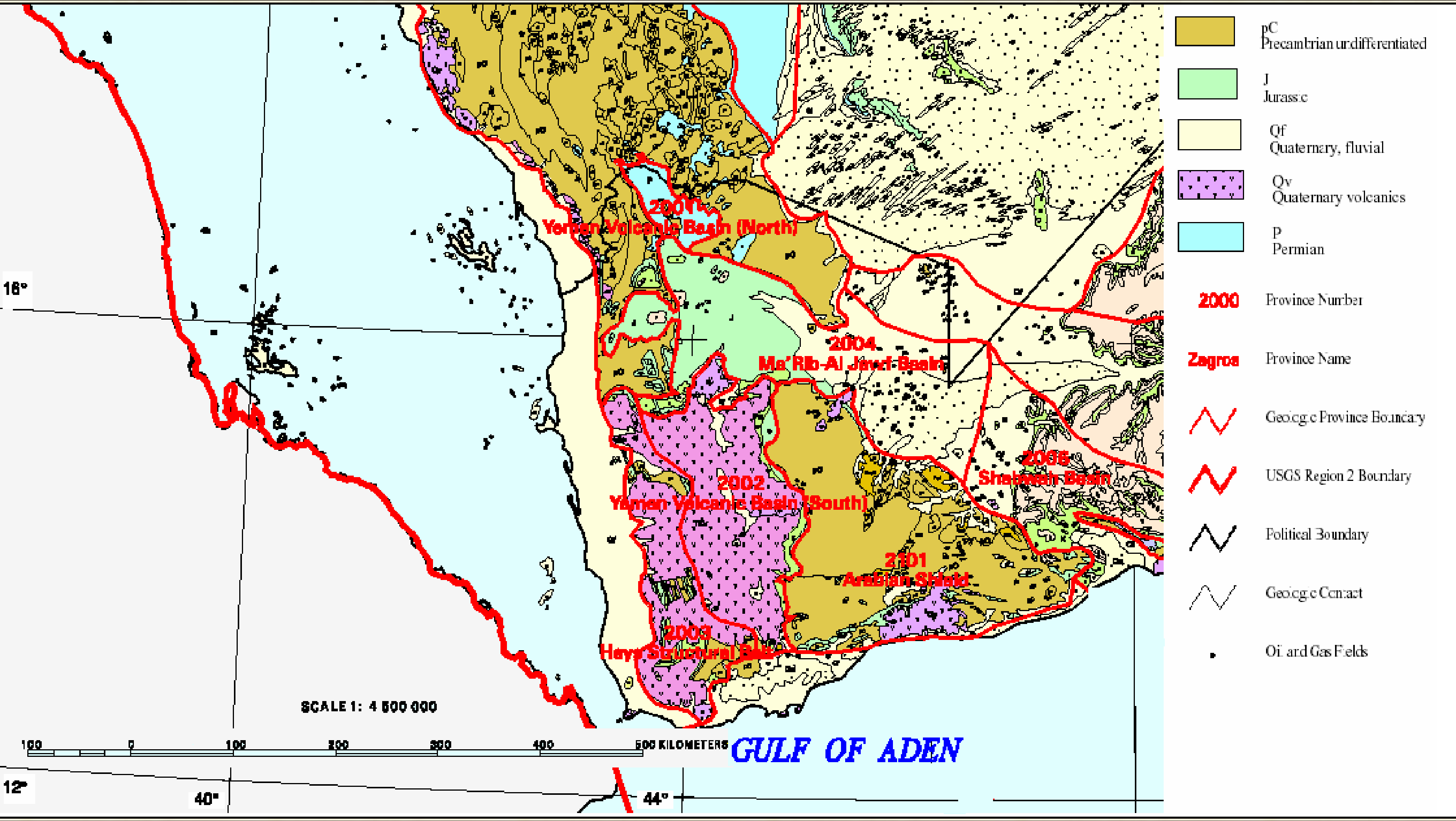
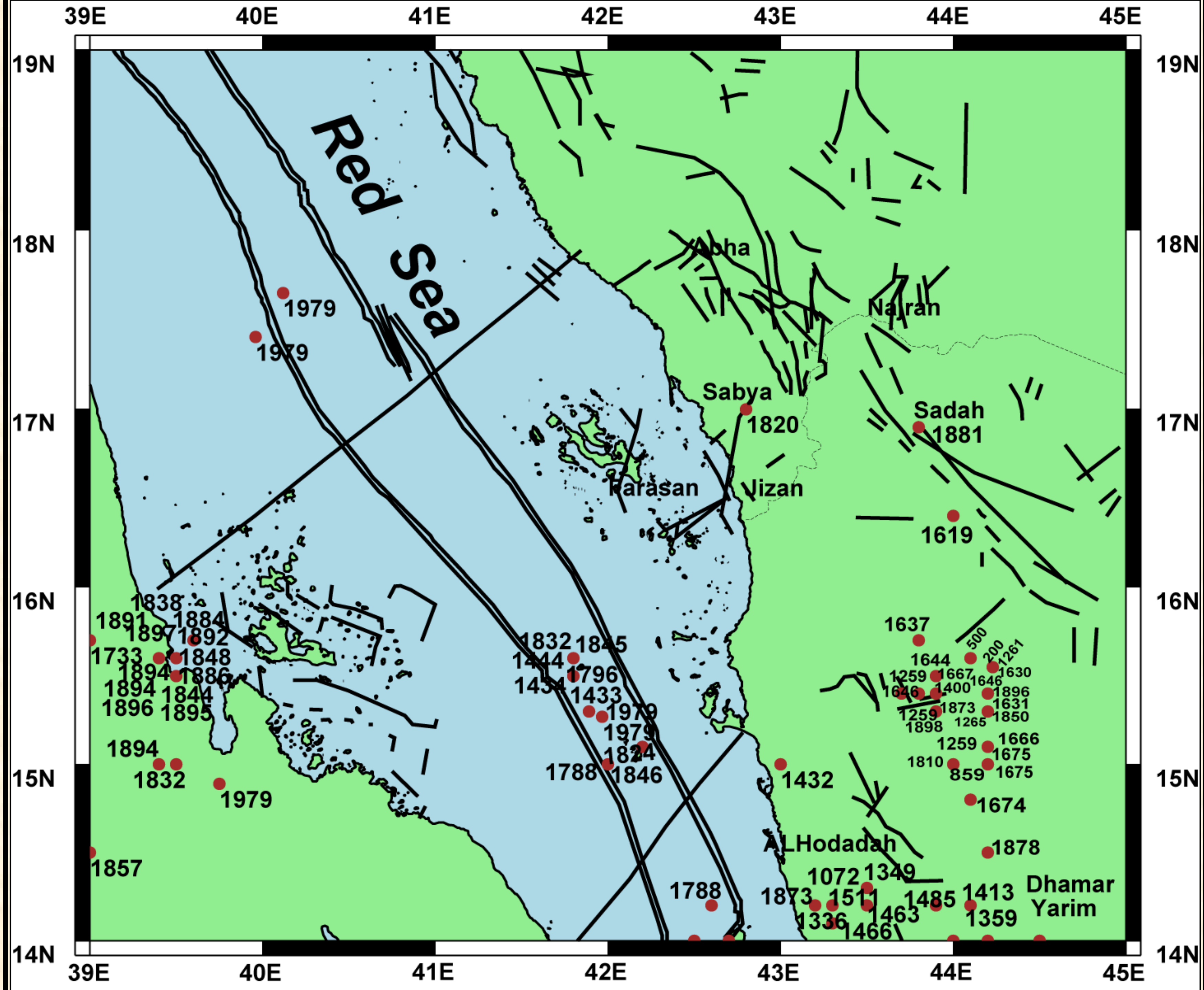
SEISMIC CHARACTERISTICS AND HAZARD ASSESSMENT OF SOUTHERN RED SEA REGION

Abdullah M. Al-Amri



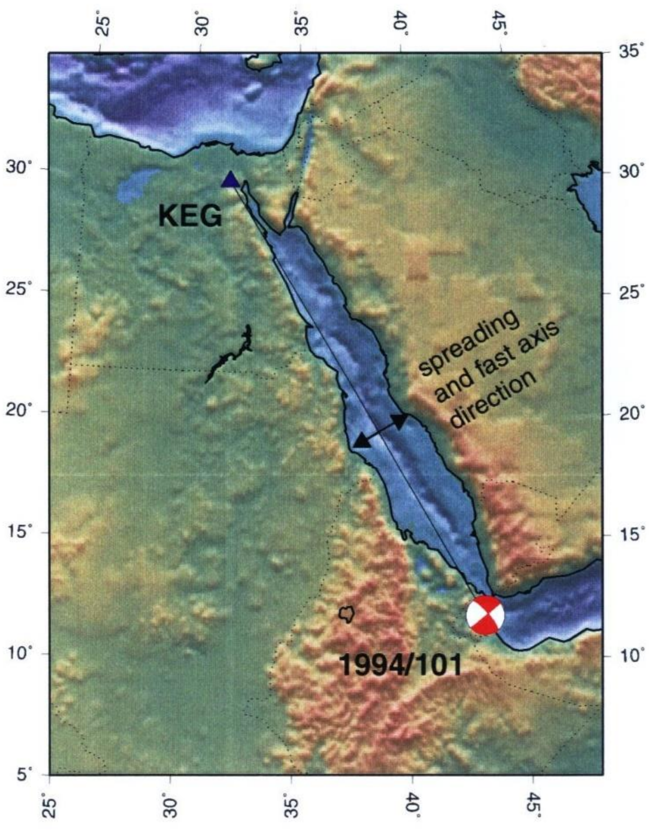
pC
Precambrian undifferentiated
J
Jurassic
Qf
Quaternary, fluvial
Qv
Quaternary volcanics
P
Permian
2000
Province Number
Zagros
Province Name
Geologic Province Boundary
USGS Region 2 Boundary
Political Boundary
Geologic Contact
Oil and Gas Fields
2001
Yemen Volcanic Basin (North)
2004
Ma'Rib-Al Jawf Basin
2005
Shabwah Basin
2002
Yemen Volcanic Basin (South)
2101
Arabian Shield
2003
Hays Structural Belt
SCALE 1: 4 500 000
100
0
100
200
300
400
500 KILOMETERS
GULF OF ADEN
16°
12°
40°
44°

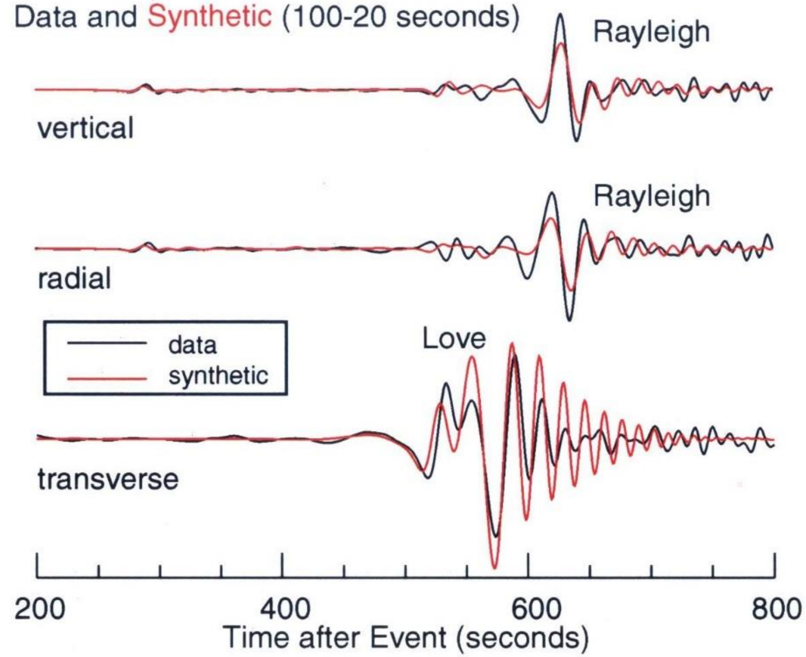


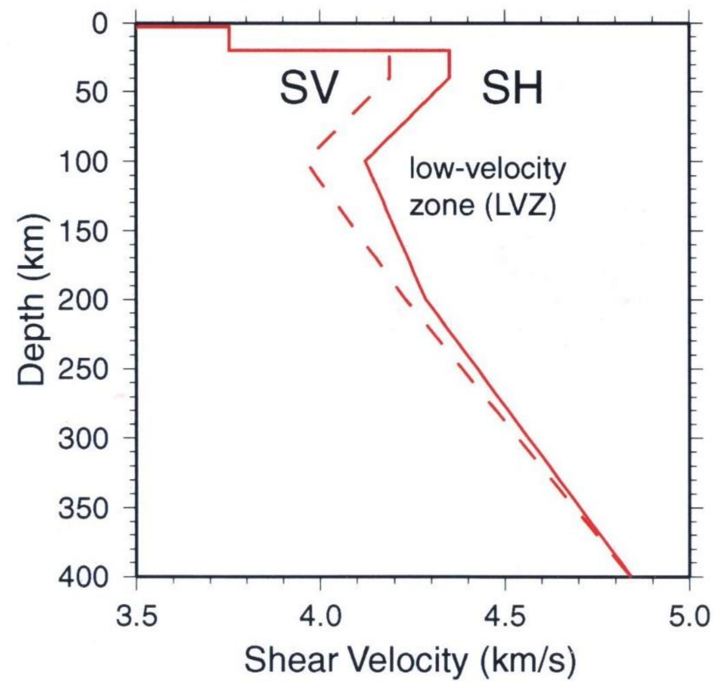
39E
40E
41E
42E
43E
44E
45E
19N
18N
17N
16N
15N
14N
Red Sea
Abha
Najran
Sabya
Sadah
Farasan
Jizan
ALHodadah
Dhamar
Yarim

Red Sea Paths Require Anisotropy

Waveforms for the April 11, 1994 Afar earthquake recorded at station KEG (Kottamya, Egypt, $\Delta = 20.8^{o}$) reveal anisotropy in the upper mantle. SH and SV cannot be fit with the same isotropic model. These data are fit (upper right) with an anisotropic model (lower right) with SH about 4% faster than SV. This is consistent with the fast axis of anisotropy aligned with the spreading direction.



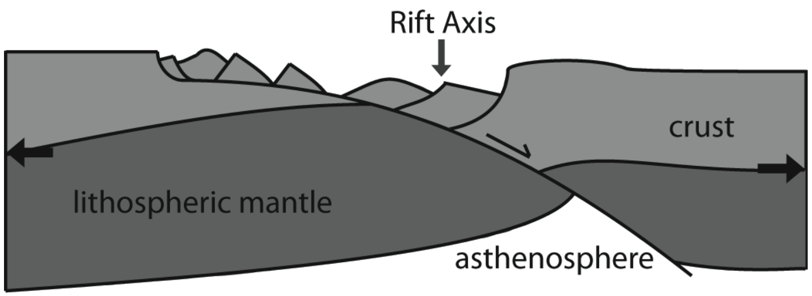




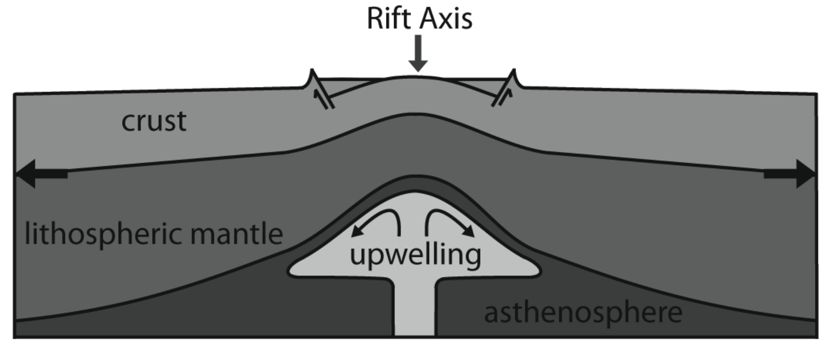
Courtesy of Sara Russell, UC Santa Cruz

Lithospheric Structure Supports Active Rifting Mechanism (Currently)

Passive Rifting



Active Rifting

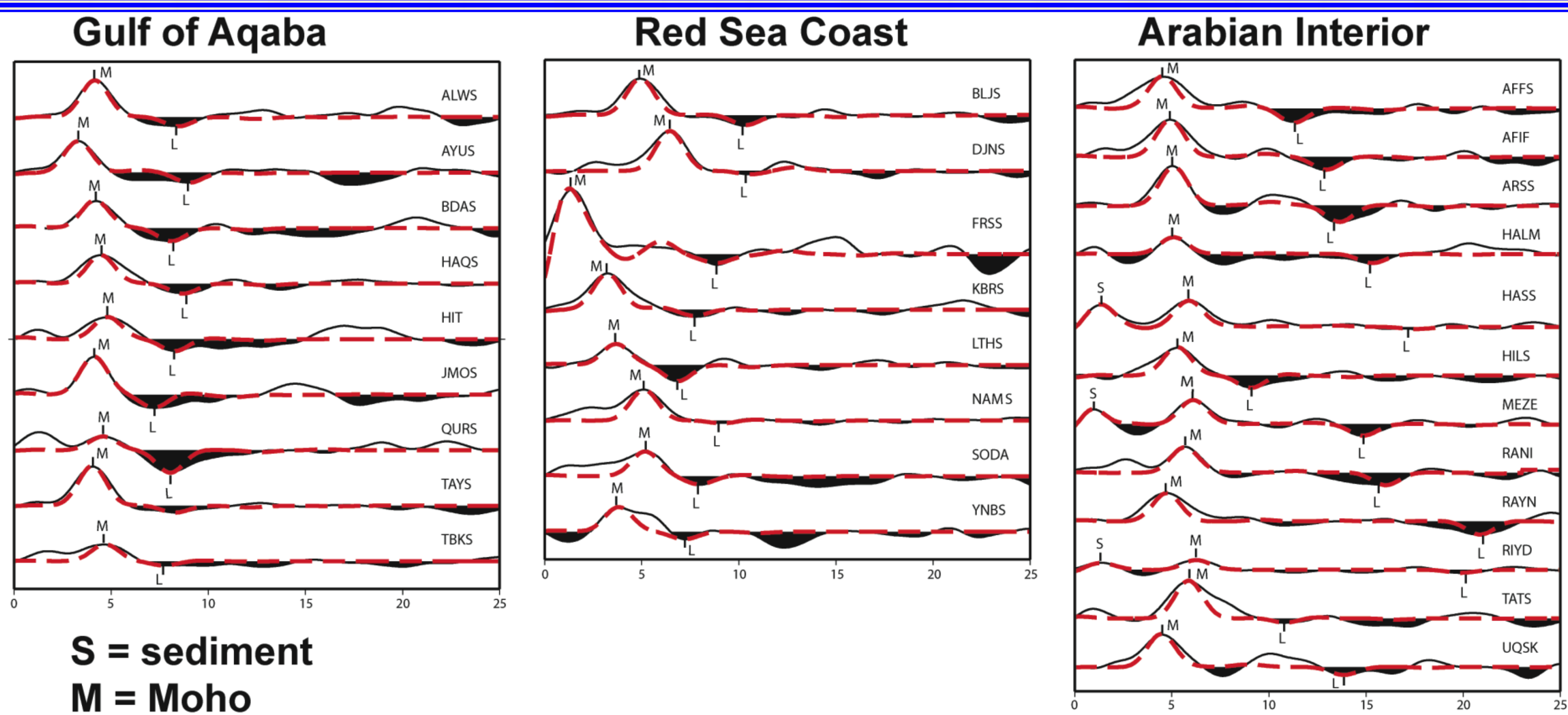


We observe lithospheric thickening that is symmetric about rift axis, consistent with active mechanism.

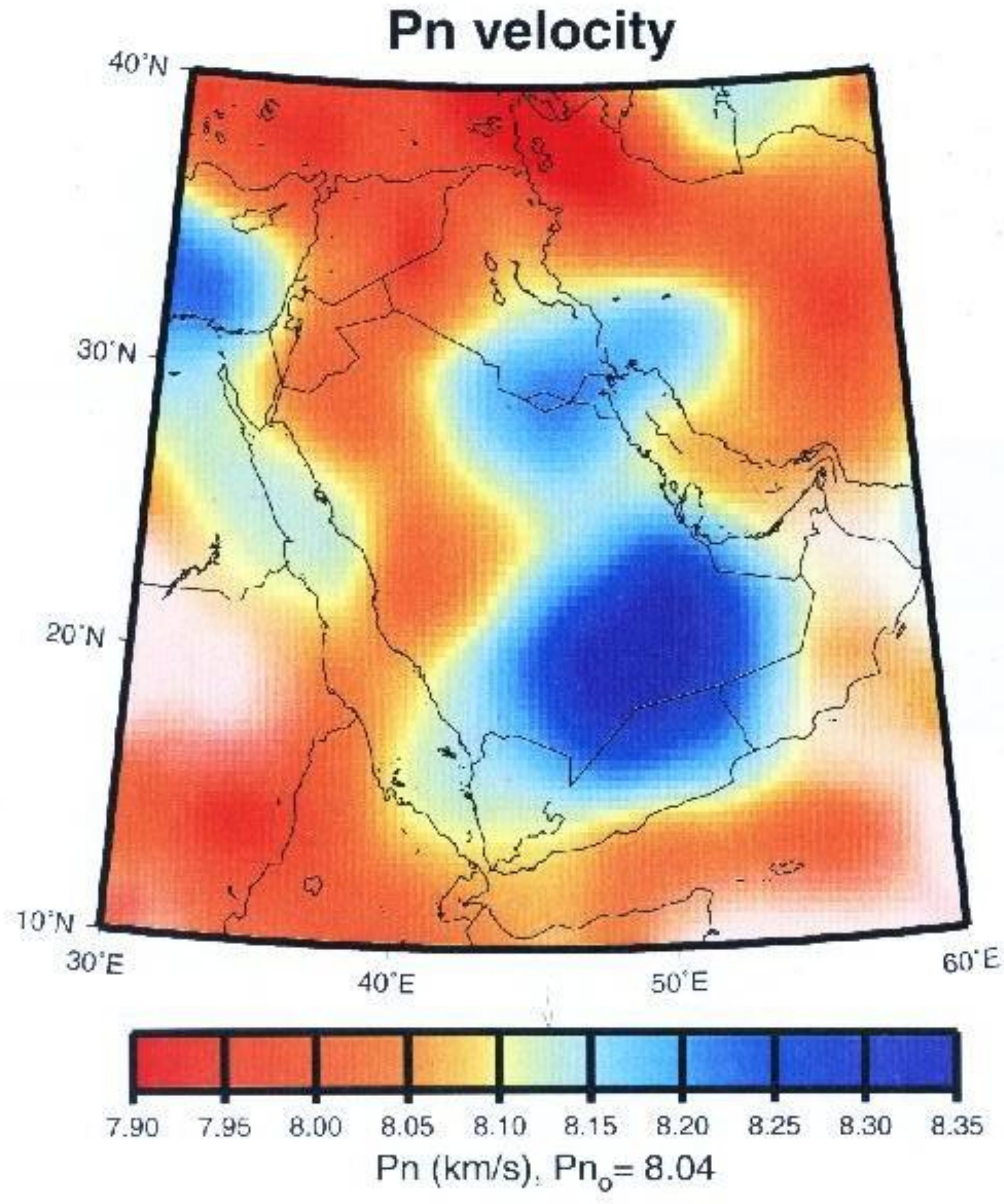
Geologic evidence indicates that rifting was initiated by passive mechanism.

We conclude Red Sea rifting has two-stages: initiated passively, then maintained actively.

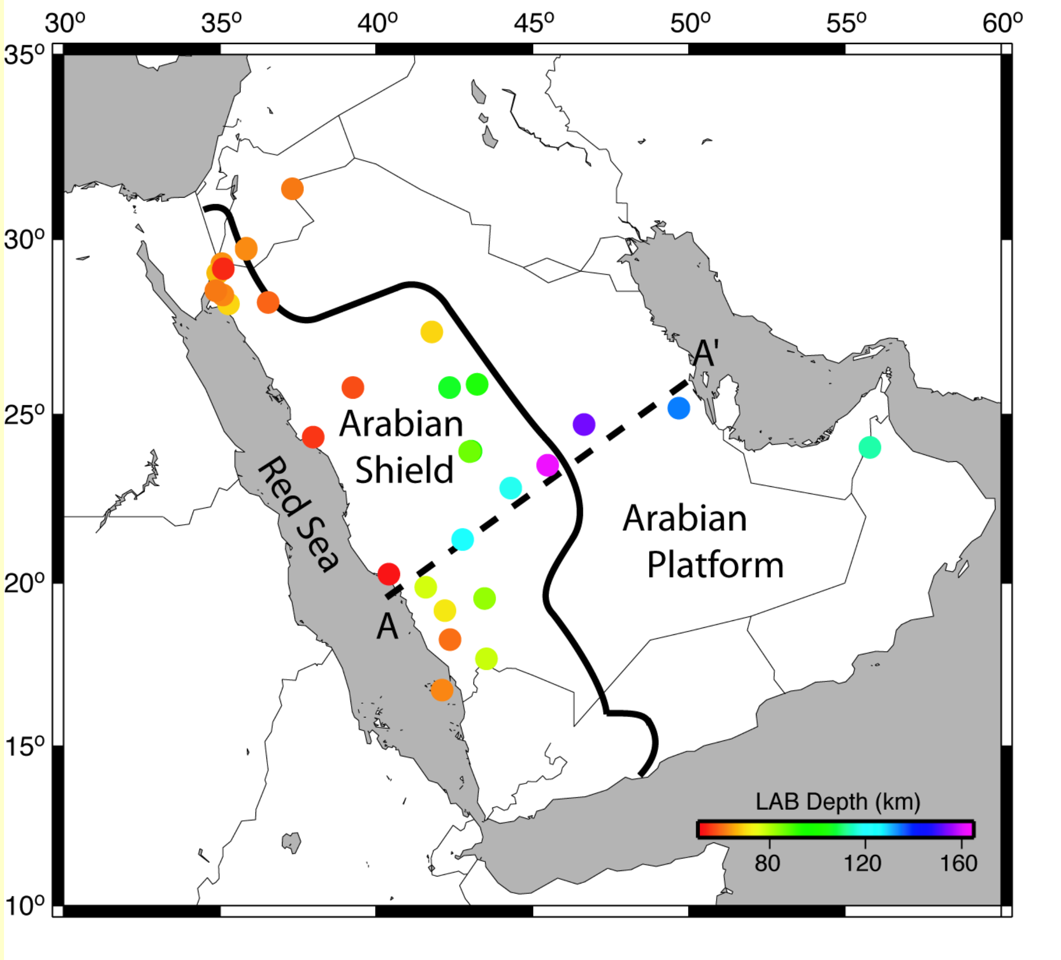
S-Wave RF's: Modeling Results



S = sediment
M = Moho
L = Lithosphere-Asthenosphere Boundary (LAB)


Pn velocity
40°N
30°N
20°N
10°N
30°E
40°E
50°E
60°E
7.90
7.95
8.00
8.05
8.10
8.15
8.20
8.25
8.30
8.35
Pn (km/s). Pn$_o$= 8.04

LAB Depth Results Across Arabia



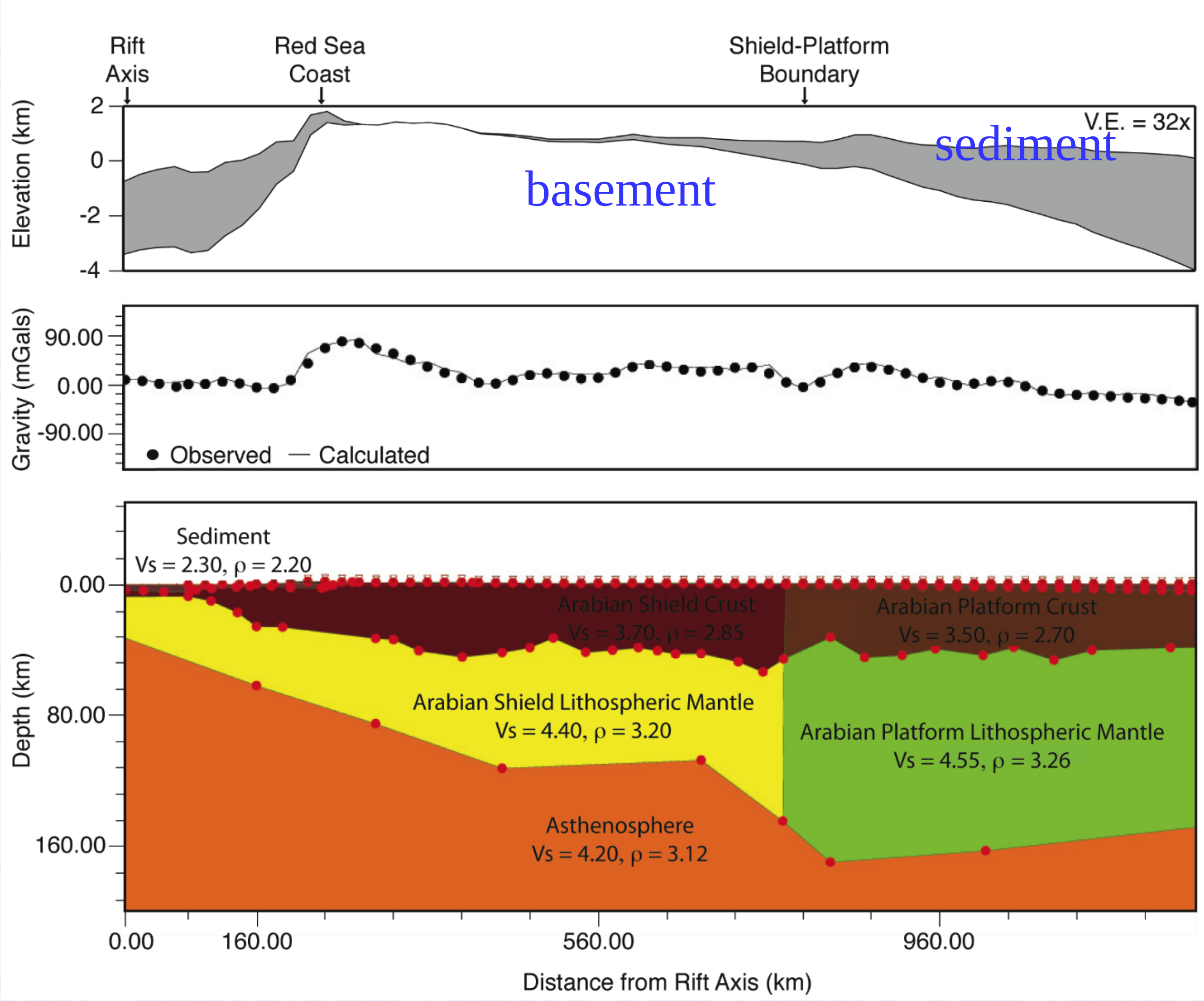
Shallow (40-60 km) LAB along Red Sea coast and Gulf of Aqaba
Thickens (80-120 km) toward interior of Shield
Step (20-40 km) across the Shield-Platform boundary

Our Inferred Lithospheric Cross-Section Predicts Gravity

Topography, sediment and basement

Observed (dots) and predicted (line) gravity anomaly

Lithospheric cross-section



Observed gravity data taken from GRACE satellite

MODELING OF SEISMIC ZONES

1. Correlation between seismic and tectonic data

(a) Earthquakes do not occur everywhere, but only in definite tectonically active areas and in strong accordance with movement and deformation of geological structures.

(b) Major earthquakes occur along tectonically active source zones having large faults.

(c) Geological structures move abruptly on faults along tectonically homogeneous active zone not simultaneously but alternatively in different places of the zones.

2. Correlation between Earthquake Frequency and Mechanics of Faulting

In the identification and delineation of the seismogenic source areas, some criteria were followed and utilized as guidelines. These are mainly the seismological and geological parameters, and to lesser extent is the consideration of the geophysical parameters when needed.

- **The seismological parameter** is chiefly composed of the planar spatio-temporal distribution of earthquakes that indicates both seismogenic provinces and seismo-active faults, and occurrences of large earthquakes, the level of which depends upon the seismic activity in the region.

- **The geological parameter is primarily a map of regional tectonics that shows the location of joints, faults, lineaments, and rift systems that are associated with the seismic activities in the area.**
- **Geophysical parameters- maps of heat flow and gravity anomaly distributions are useful in the interpretation on the nature of geologic structures**

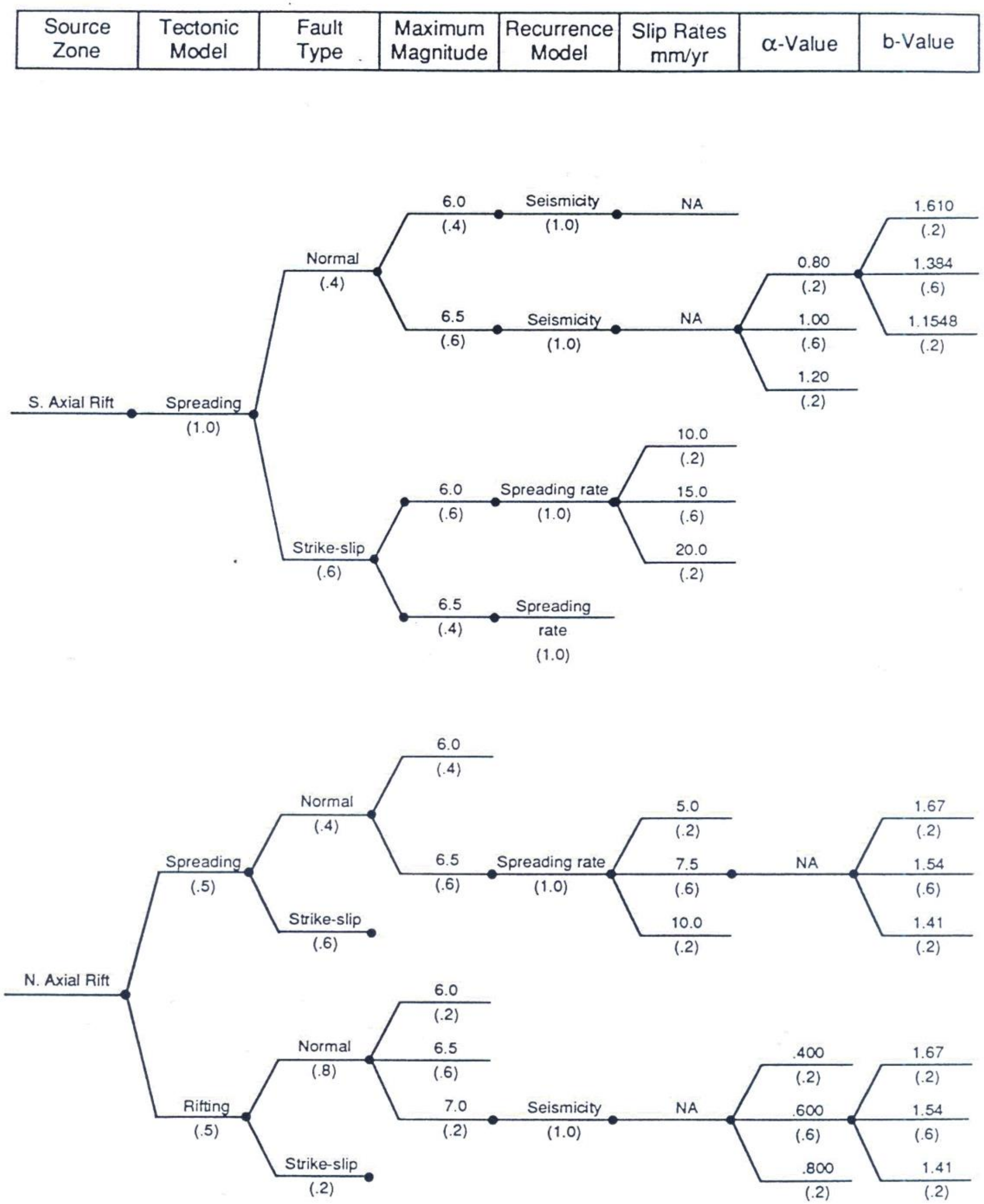
From these considerations, there were four identified and delineated seismogenic source zones.

Cont.

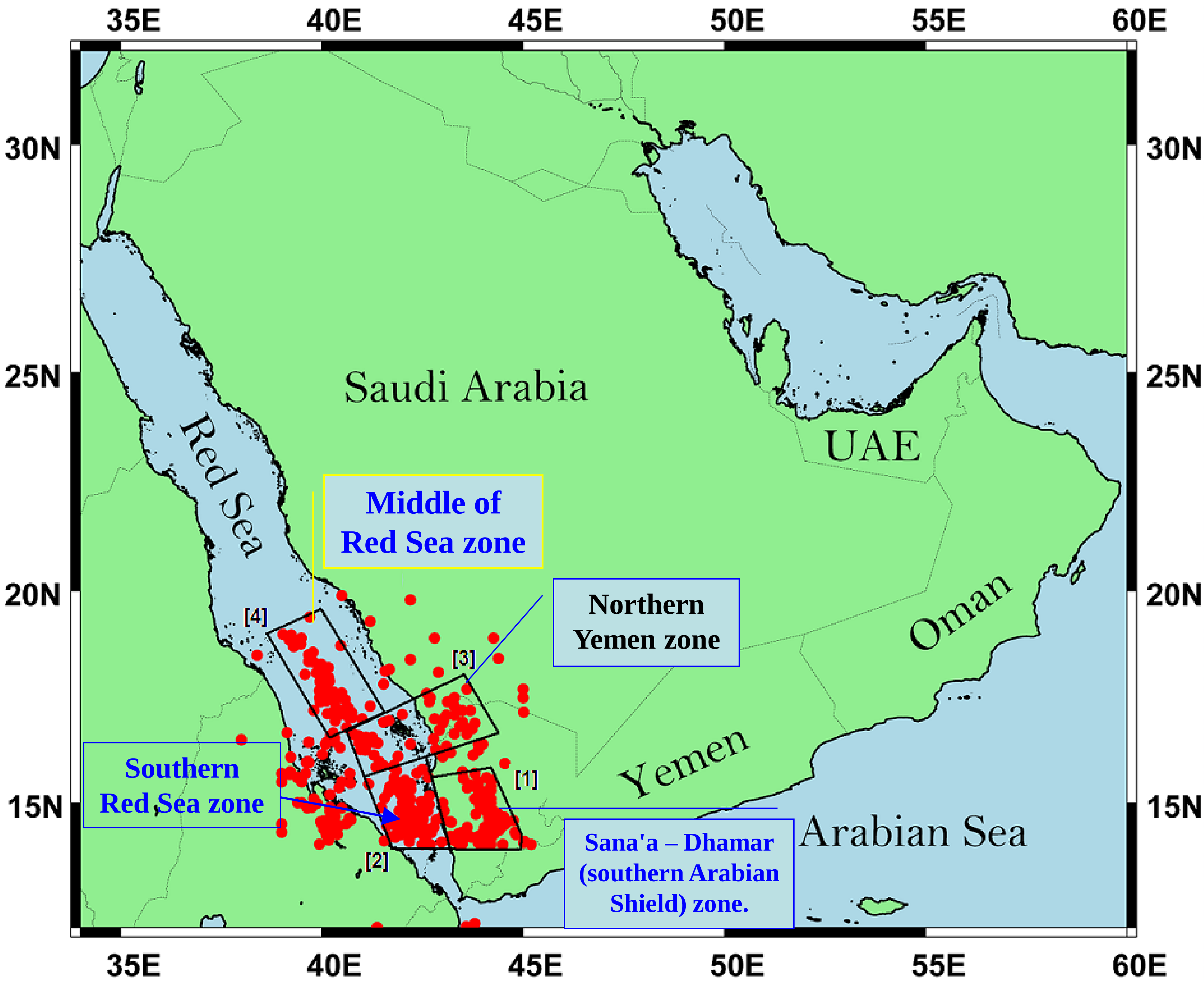
Source Zone	Style of Faulting	Rate of Deformation	Crustal Thickness
Yemen	Normal: N30W/60SW N70W/60S	NA	11-38 km
Aden Marginal Rifts	Normal: N70W/60S,N	NA	NA

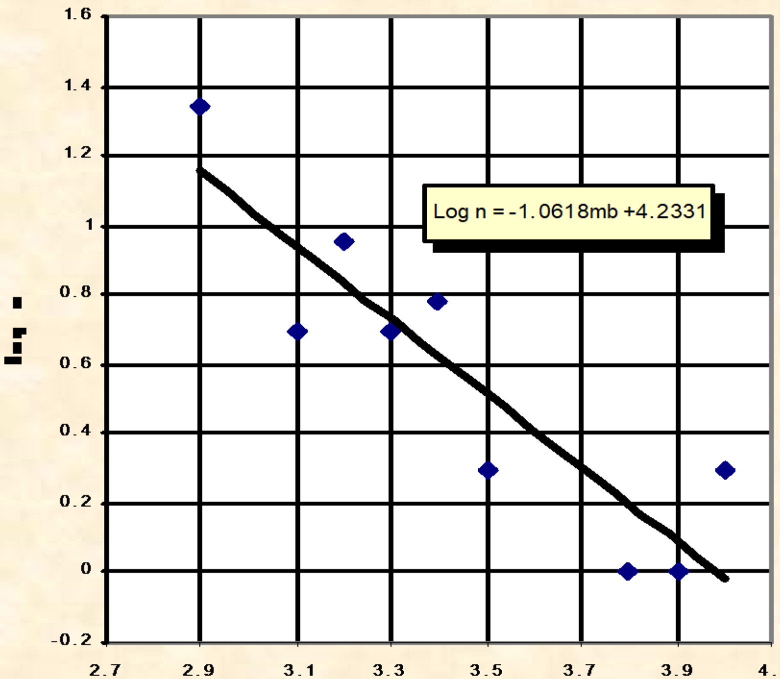
Red Sea and Gulf of Aden Axial Rifts

Red Sea Axial Rifts	**Normal: N30W/60SW,NE** **Strike-slip: N10E/90 (Transform)** **Volcanic: Geometry High Variable**	**Northern Red Sea** **Normal: NA** **Transform: 5.0 to 9.8 mm/yr** **Volcanic: NA** **Southern Red Sea** **Normal: NA** **Transform: 8 to 15.4 mm/yr** **Volcanic: NA**	**18 km** **5-8 km**
Aden Axial Rift	**Normal: N70W/60S,N** **Strike-slip: N30E/90 (Transform)** **Volcanic: Geometry Extremely Variable**	**Normal: NA** **Strike-slip: 17.2-30.2 mm/yr (Transform)** **Volcanic: NA**	**NA**

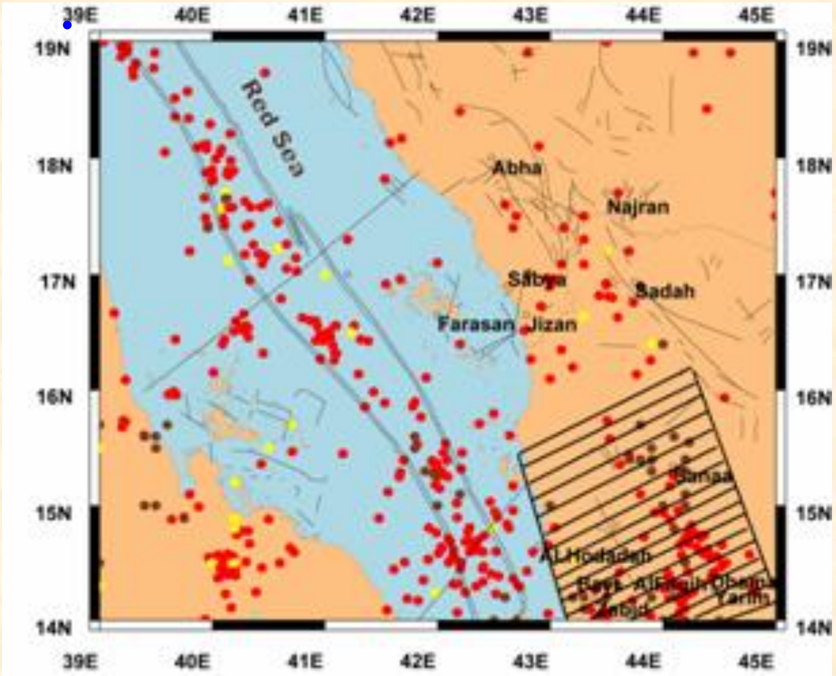


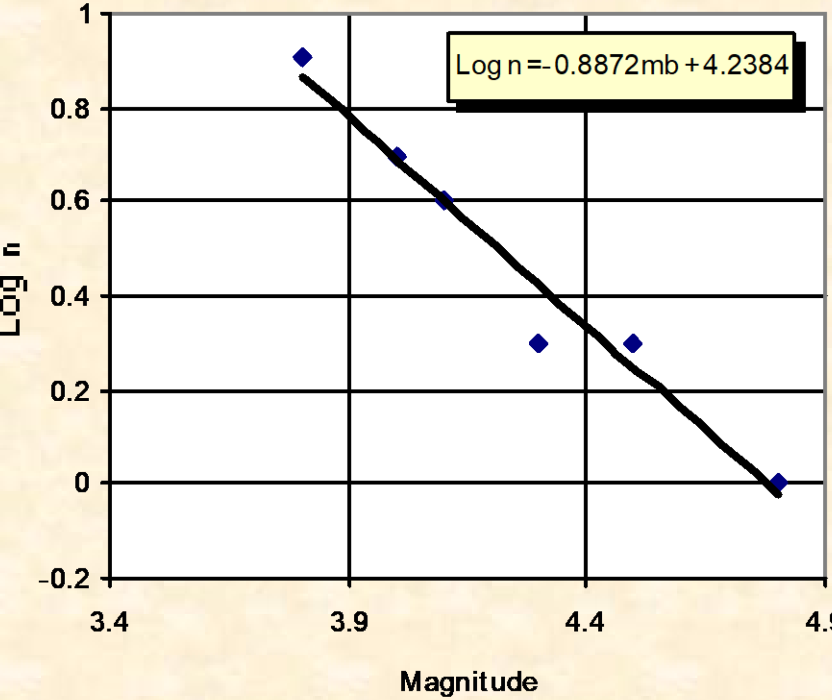
Source Zone of Red Sea Axial Rift

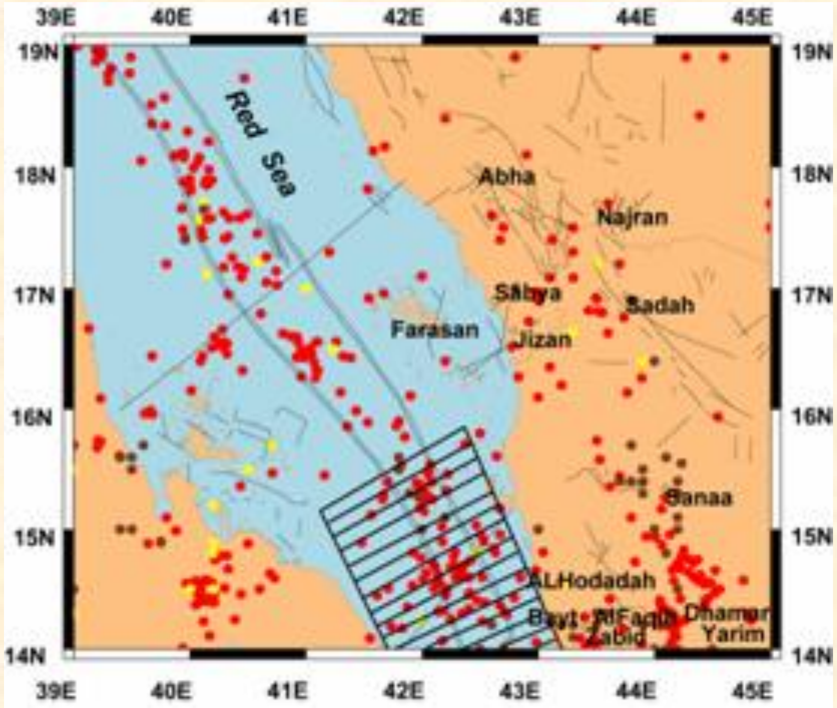

35E
40E
45E
50E
55E
60E
30N
25N
20N
15N
Saudi Arabia
UAE
Red Sea
Oman
Yemen
Arabian Sea
Middle of
Red Sea zone
Northern
Yemen zone
Southern
Red Sea zone
Sana'a – Dhamar
(southern Arabian
Shield) zone.
[1]
[2]
[3]
[4]


Log n = -1.0618mb +4.2331
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
-0.2
2.7
2.9
3.1
3.3
3.5
3.7
3.9
4.1

zone 1

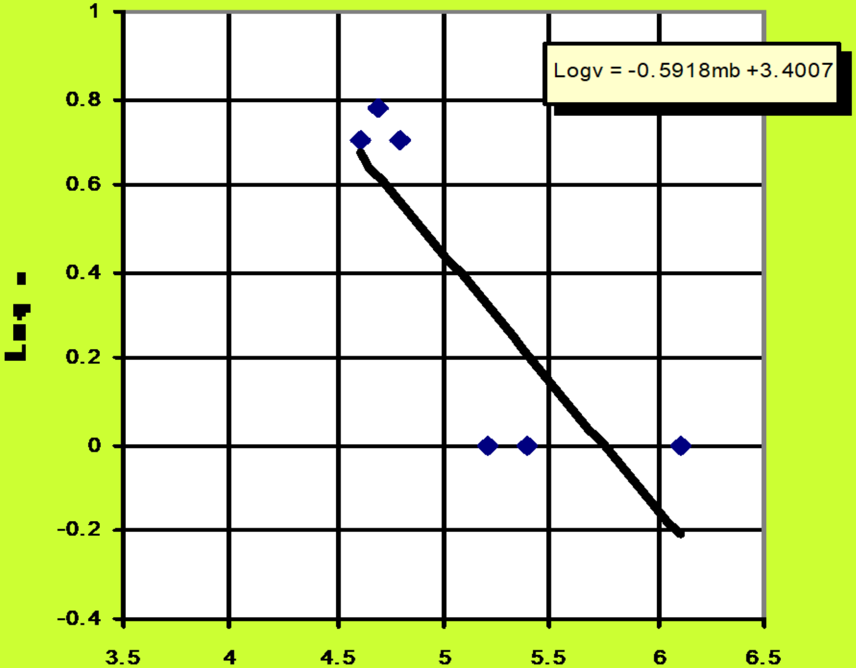

Red Sea
Abha
Najran
Sabya
Sadah
Farasan
Jizan
Sanaa
ALHodadah
39E
40E
41E
42E
43E
44E
45E
19N
18N
17N
16N
15N
14N


Log n =-0.8872mb +4.2384
Log n
Magnitude
1
0.8
0.6
0.4
0.2
0
-0.2
3.4
3.9
4.4
4.9

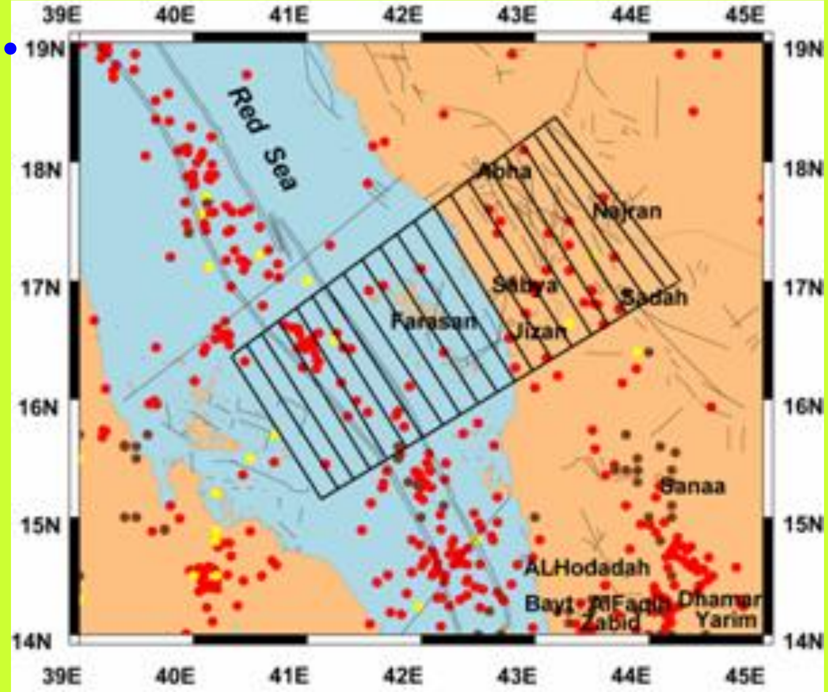

Red Sea
Abha
Najran
Sabya
Sadah
Farasan
Jizan
Sanaa
ALHodadah
Bayt AlFaqih
Dhamar
Zabid
Yarim
39E
40E
41E
42E
43E
44E
45E
19N
18N
17N
16N
15N
14N

zone 2.

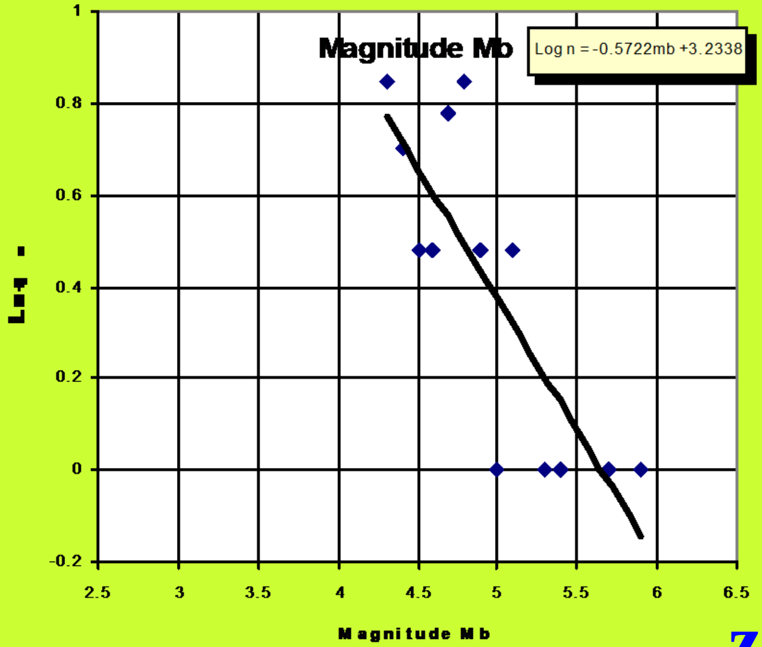
zone 3.



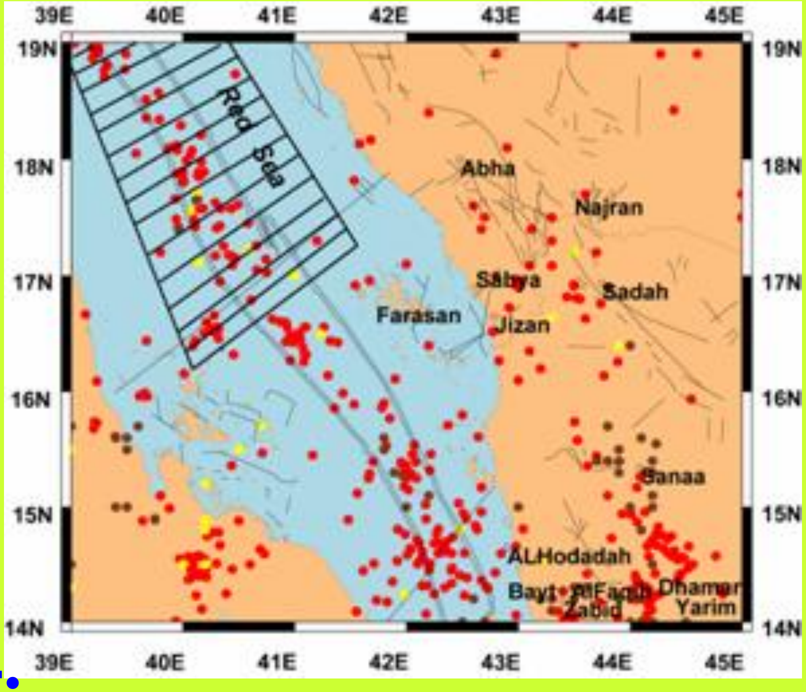
Logv = -0.5918mb +3.4007



Red Sea
Abha
Najran
Sabya
Sadah
Farasan
Jizan
Sanaa
ALHodadah
Bayt AlFaqih
Zabid
Dhamar
Yarim



Magnitude Mb
Log n = -0.5722mb +3.2338
Magnitude Mb



Red Sea
Abha
Najran
Sabya
Sadah
Farasan
Jizan
Sanaa
ALHodadah
Bayt AlFaqih
Zabid
Dhamar
Yarim

zone 4.

Parameters of seismic source zones.

Seismic zone	N	a-value	b-value
Z1	48	4.233	1.061
Z2	87	4.238	0.887
Z3	51	3.4	0.591
Z4	77	3.2	0.572

Maximum expected magnitude for each zone.

Zone	M_{max}	Lat(N)	Lon(E)
Z1	7.5	15.00	44.00
Z2	7.2	14.2	42.6
Z3	8.5	15.2	40.5
Z4	6.1	17.2	40.58

Source parameters of the effective earthquakes in each zone.

ZONE	$\Delta\sigma$	$M_{b\ (MAX)}$	Depth (km)	Density (ρ)	V_P	Shear wave (β)
Z1	30	7.5	9.7	2.85	6.8	3.95
Z2	30	7.2	45	3.2	7.9	4.59
Z3	30	8.5	41	3.2	7.9	4.59
Z4	30	6.1	32.1	3.2	7.9	4.59

Attenuation Relationship

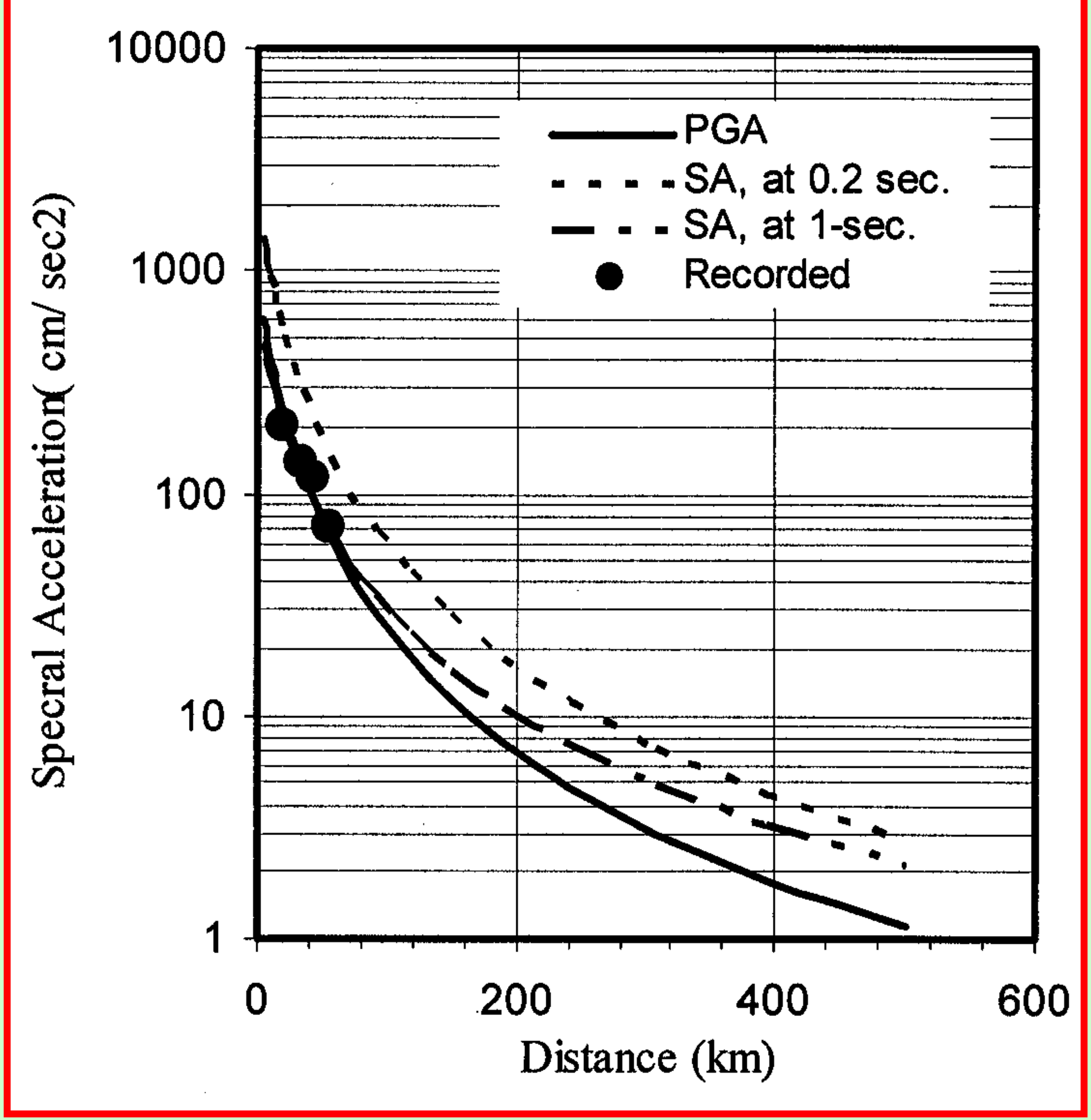
Information on the attenuation of ground motion from a source is required for prediction of potential ground shaking at a given site. Many attenuation relations or transfer functions are available in the literature. These relationships express a variable of the strong ground motion in terms of parametes that characterize the earthquake source, its size, propagation medium, and the local site geology. Presently, with the worldwide availability of region-specific strong motion data (for regions other than KSA), a relation of the following type:

$$\text{Ln } A = b_1 + b_2 M + b_3 \text{ Ln } [R + b_4 \exp(b_5 M)]$$

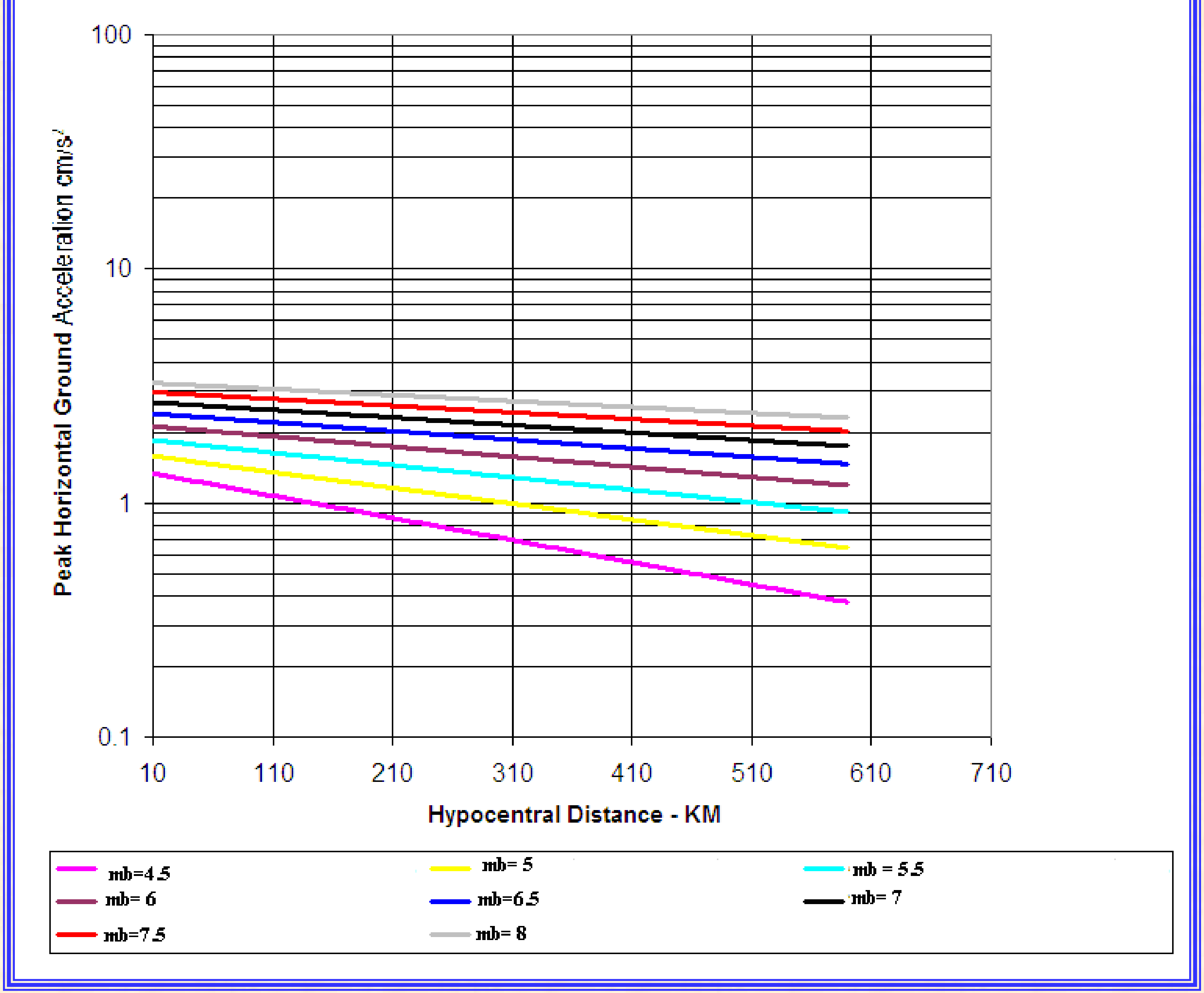
Where: R = the distance between the source and the site,

m = the earthquake magnitude,

b_1 thru b_5 = constants

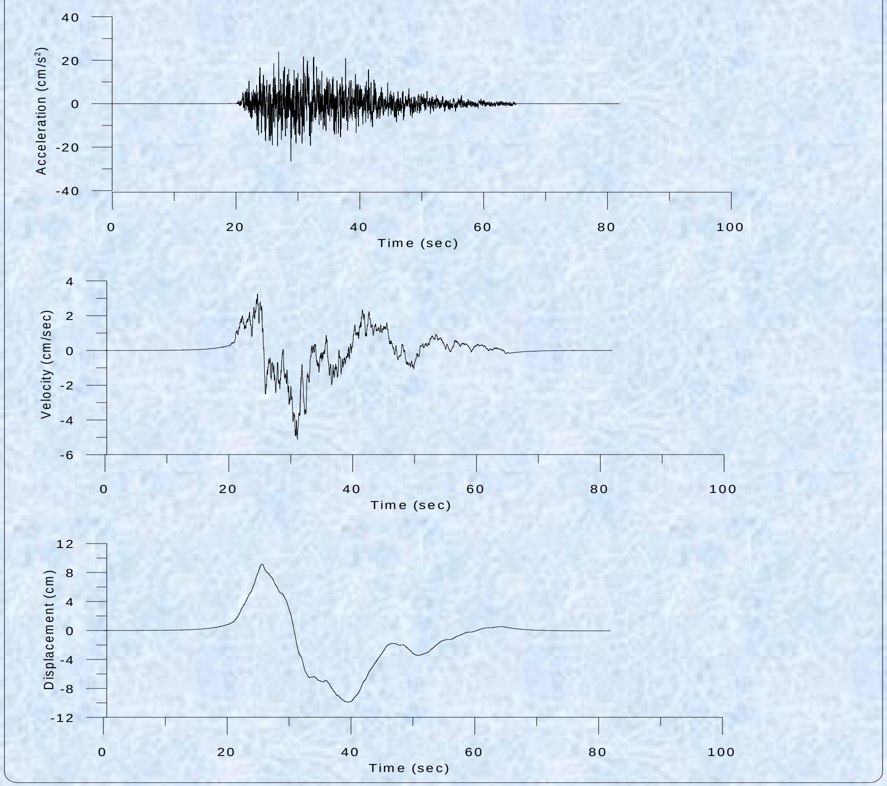


Ground motion attenuation relationship used in the Study (M=7.1)

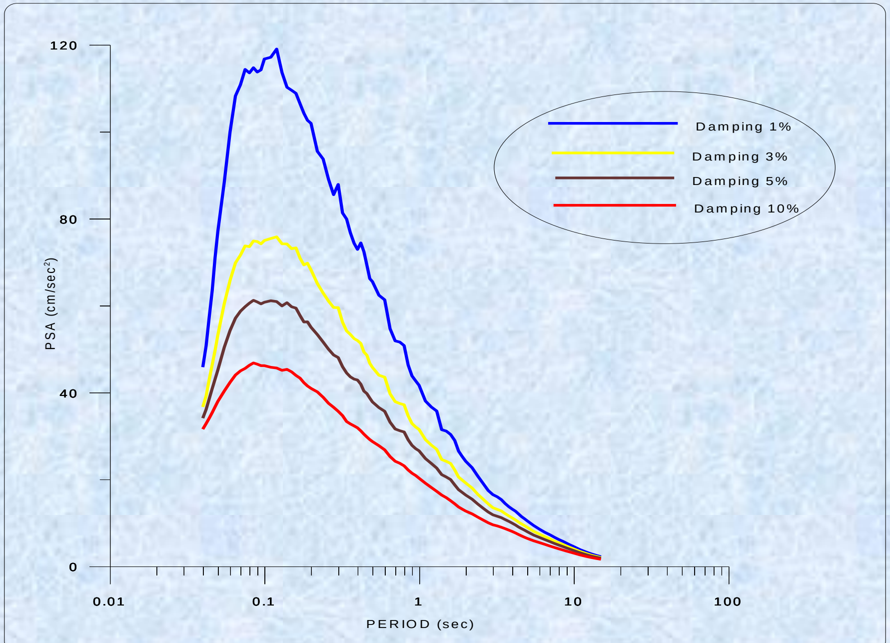


Attenuation curves for Peak Ground Acceleration within the area.

a)



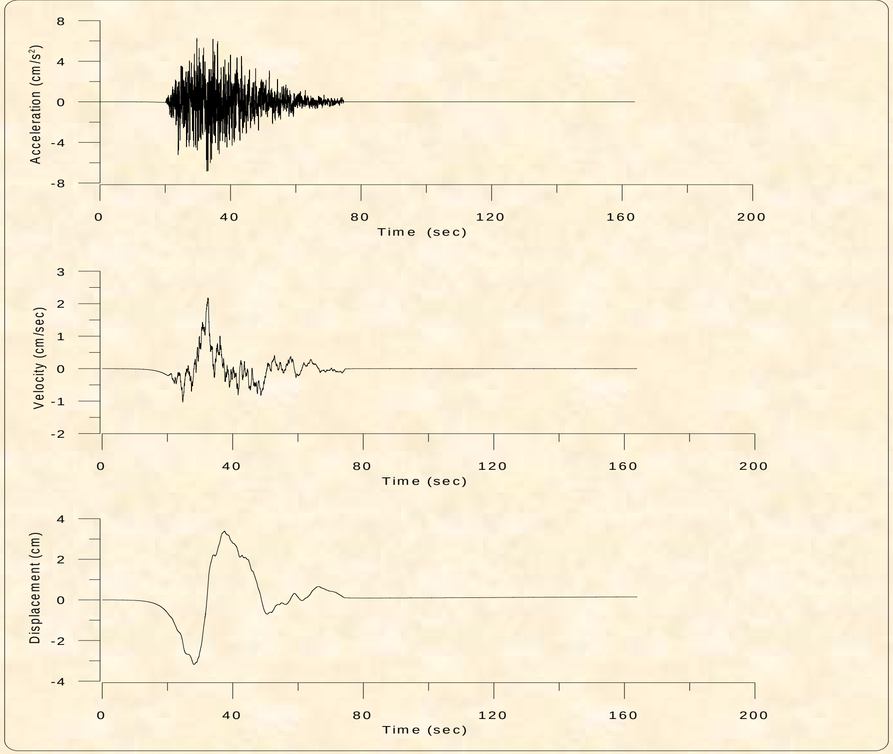
b)



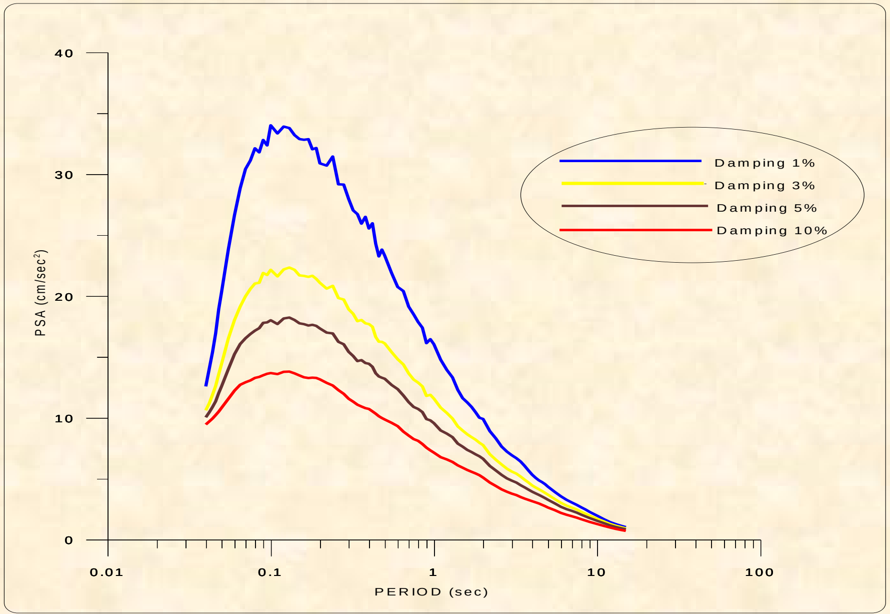
a) Simulated time history of PGA, velocity and displacement at Sanaa area in Quaternary rocks and

b) b) the response spectra at Sanaa with maximum PGA resulted in zone 1.

a)



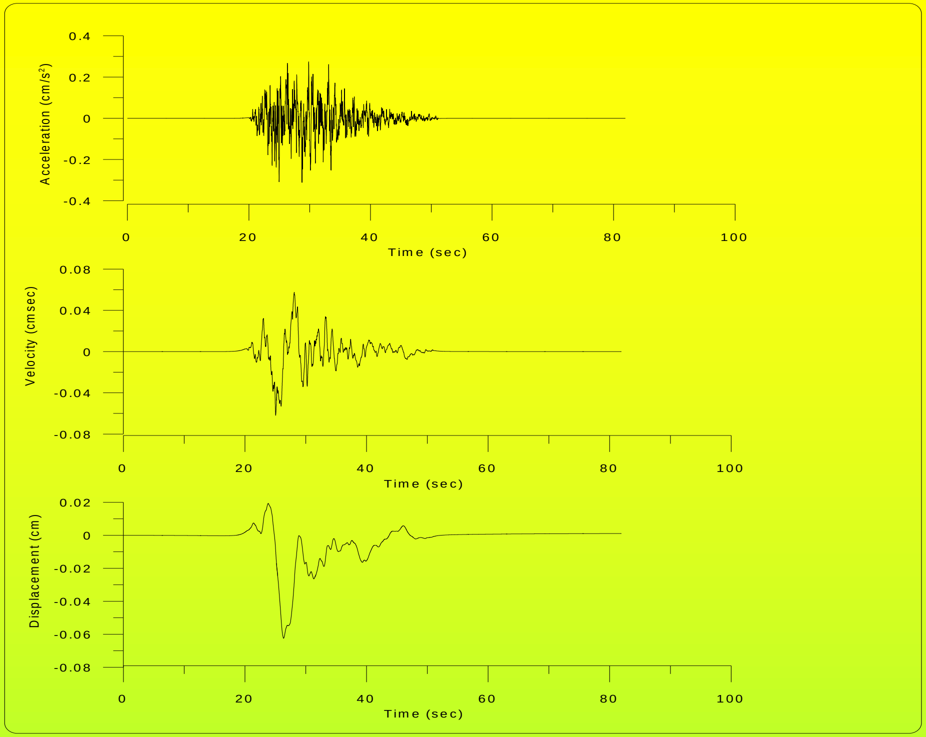
b)



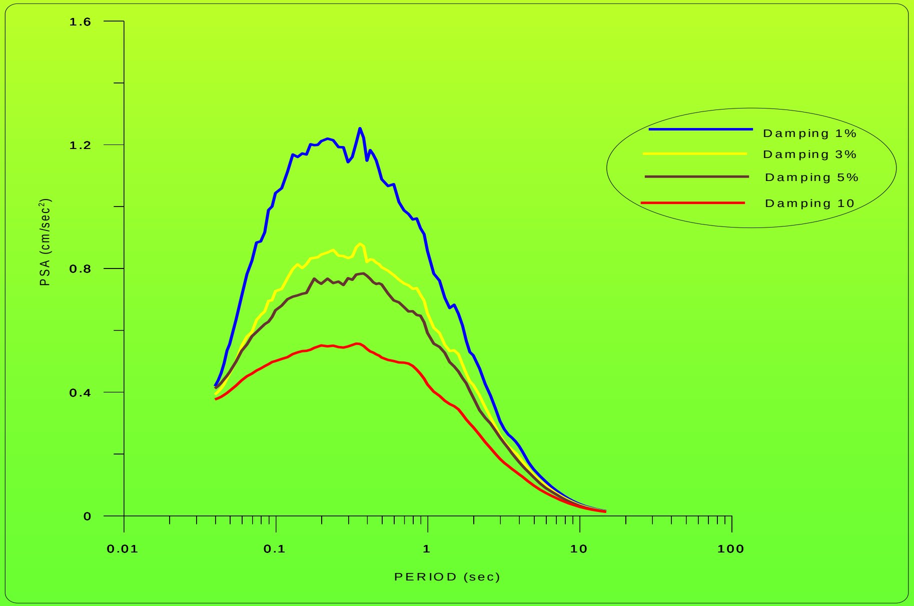
a) Simulated time history of PGA, velocity and displacement at Dhamar area in Permian rocks and

b) b) the response spectra at Dhamar with maximum PGA resulted in zone 1.

a)

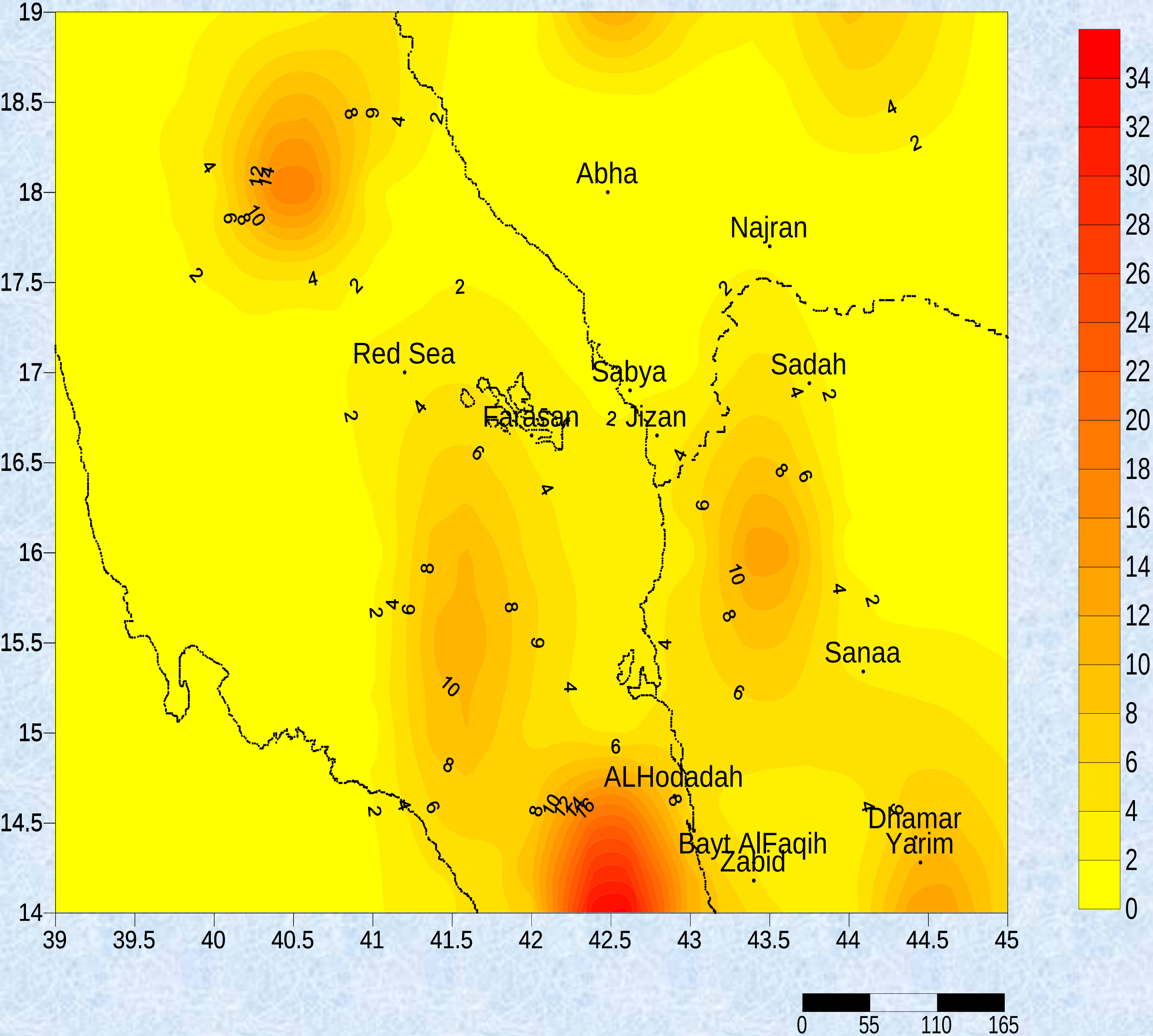


b)

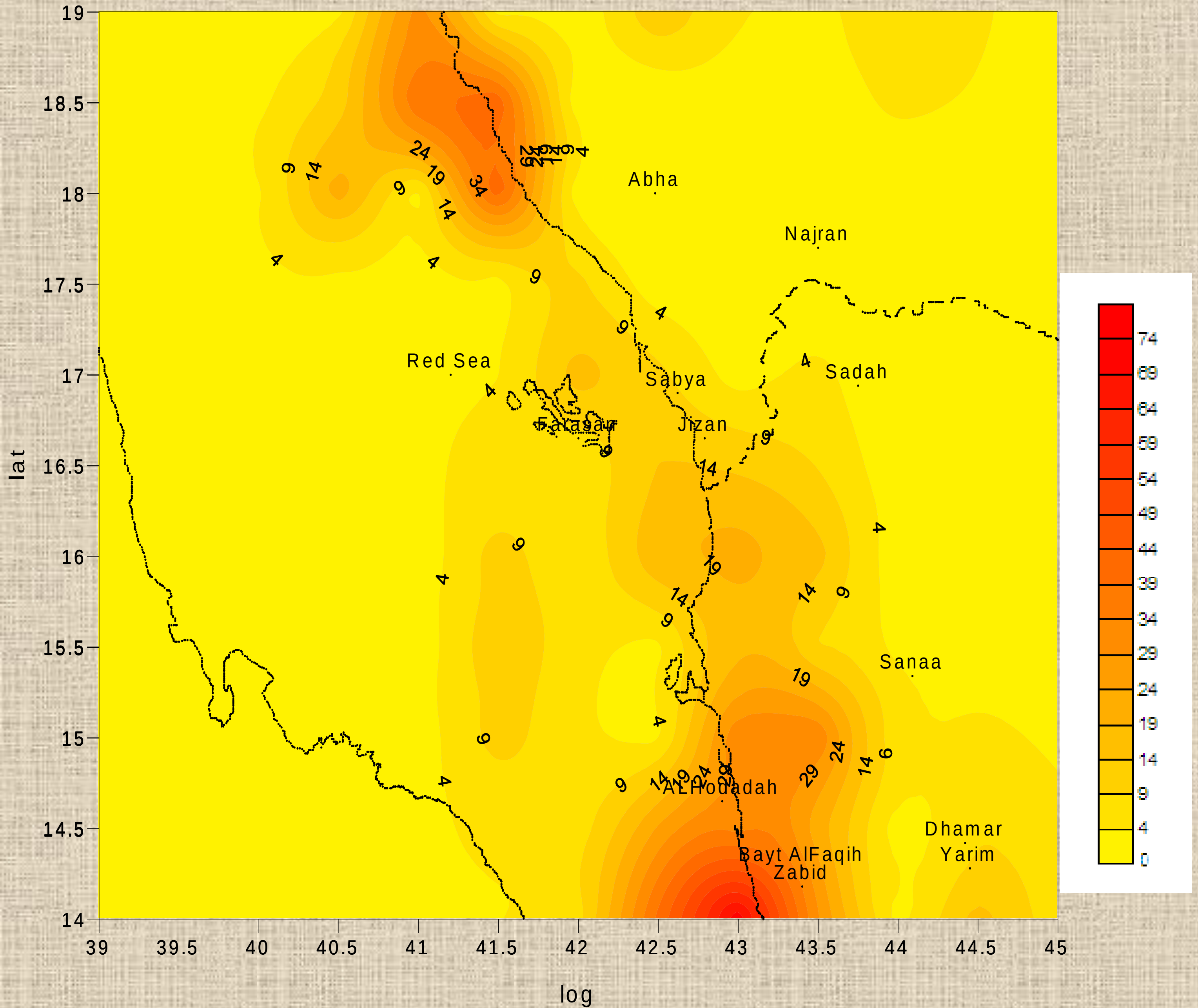


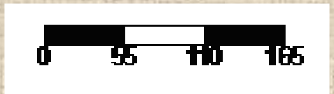
a) Simulated time history of PGA, velocity and displacement at Abha area in Pre-Cambrian rocks and

b) The response spectra at Abha with maximum PGA resulted in zone 4.



Contour map for values PGA (cm/sec2) on the bedrock.

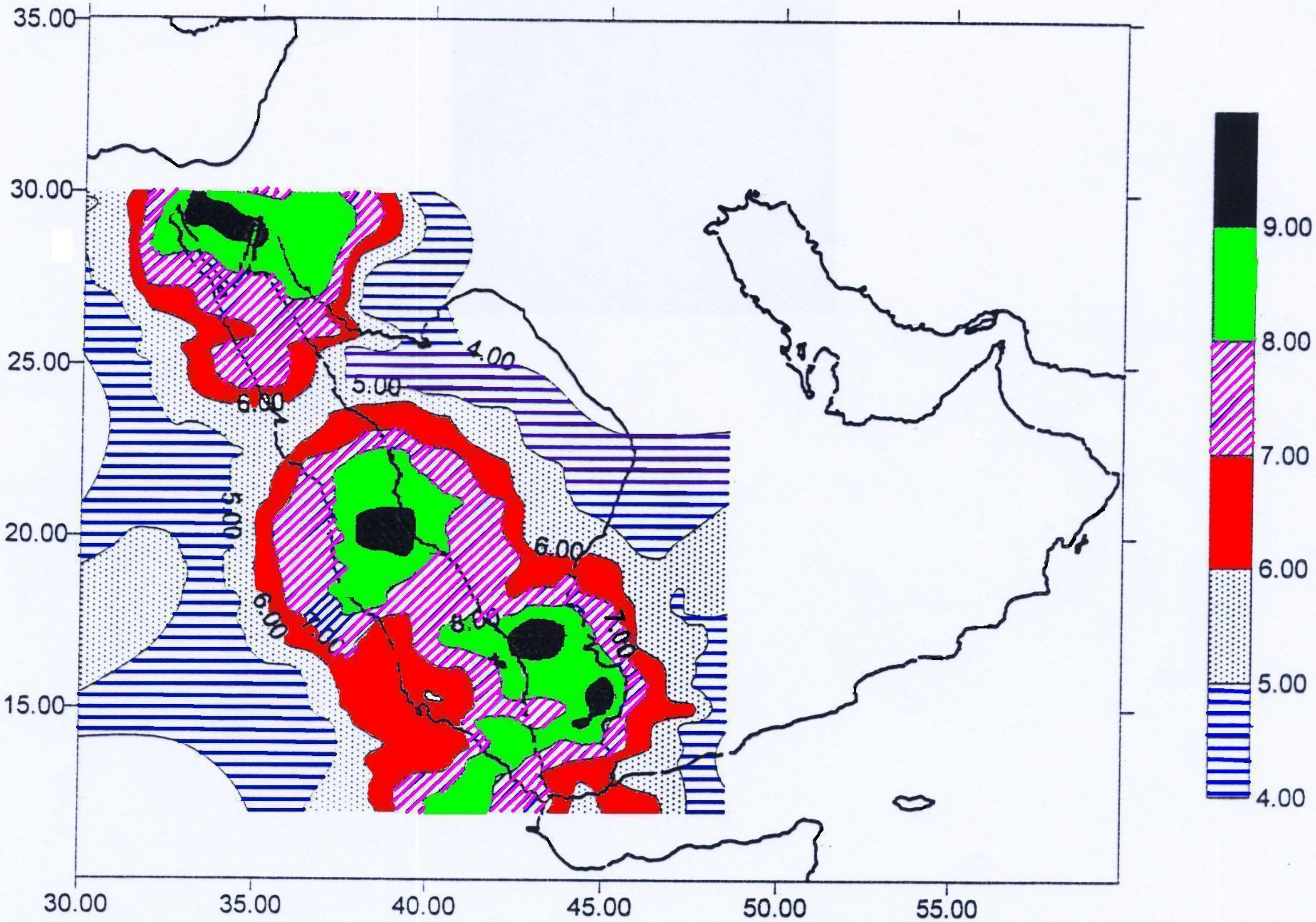




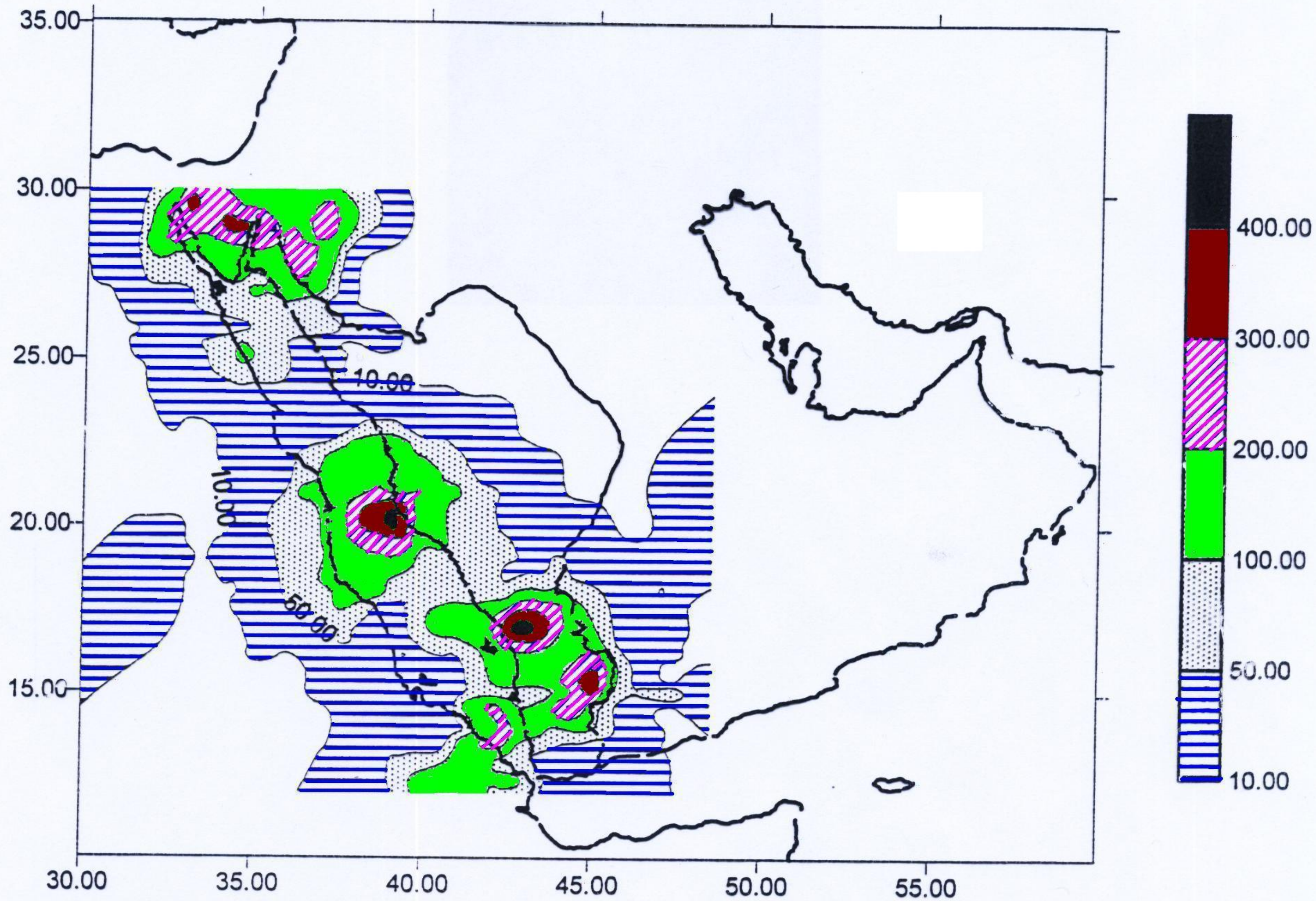
Contour map for values PGA (cm/sec2) on the ground surface.

Comparison of PGA values

City	Thenhaus et al., 1986 cm/sec^2	Al-Haddad et al., 1994 cm/sec^2	Al-Amri 1995 cm/sec^2	Al-Malki & Al-Amri 2007 cm/sec^2	
				Bed-rock	Ground surface
Abha	10	15	17	10	10
Jizan	20	20	20	2.16	11.07
Sadah	21	10	12	8	9
Southern Red Sea	40	20	20	41.1	72.12
Najran	10	10	12	1.5	3
Sanaa	23	17	20	10	20
AlHodadah	20	**	**	6	29
Dhamar	22	20	**	12	12
Farasan	15	20	20	3.9	14
Zabid	21.5	**	**	5	32



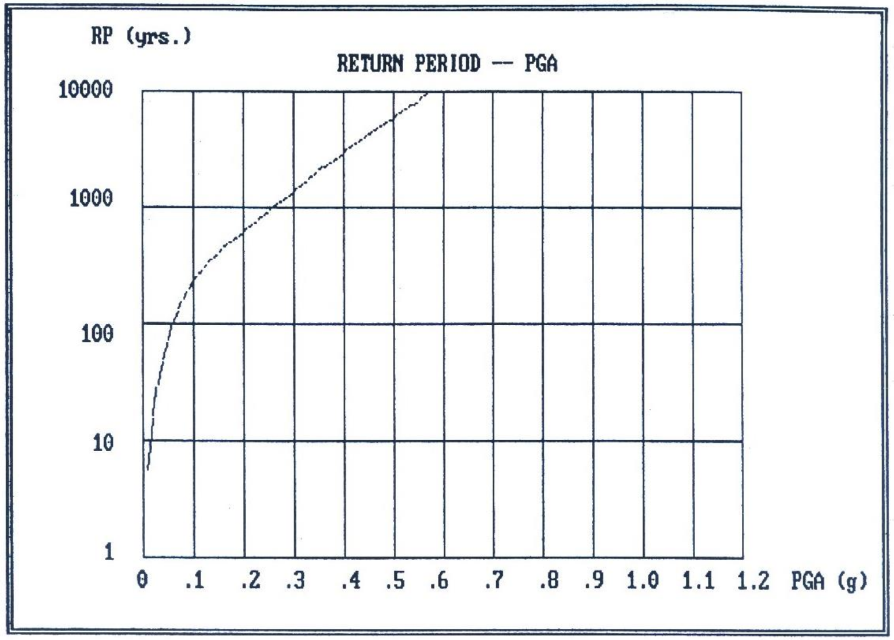
Map of expected maximum intensity at 10% probability of exceedance in 50 years when variability is considered (Iv). Areas of concern which are covered by the range of intensity from VII to IX are broader than those covered by the mean maximum intensity.

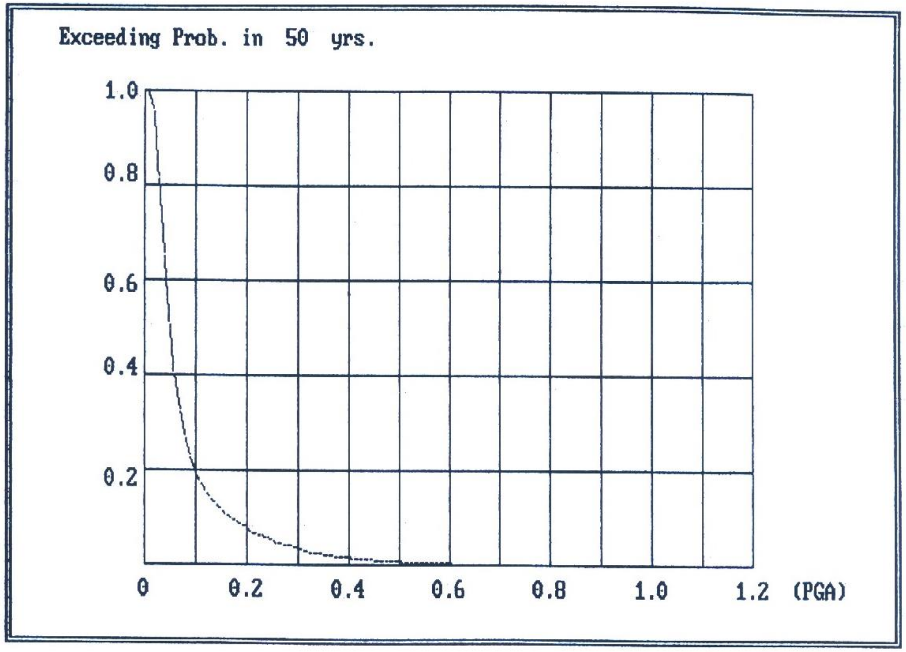


Iso-acceleration map in gals at 10% probability of exceedance in 50 years obtained from conversion of the mean maximum intensity (I) to acceleration values.

Hazard Curves

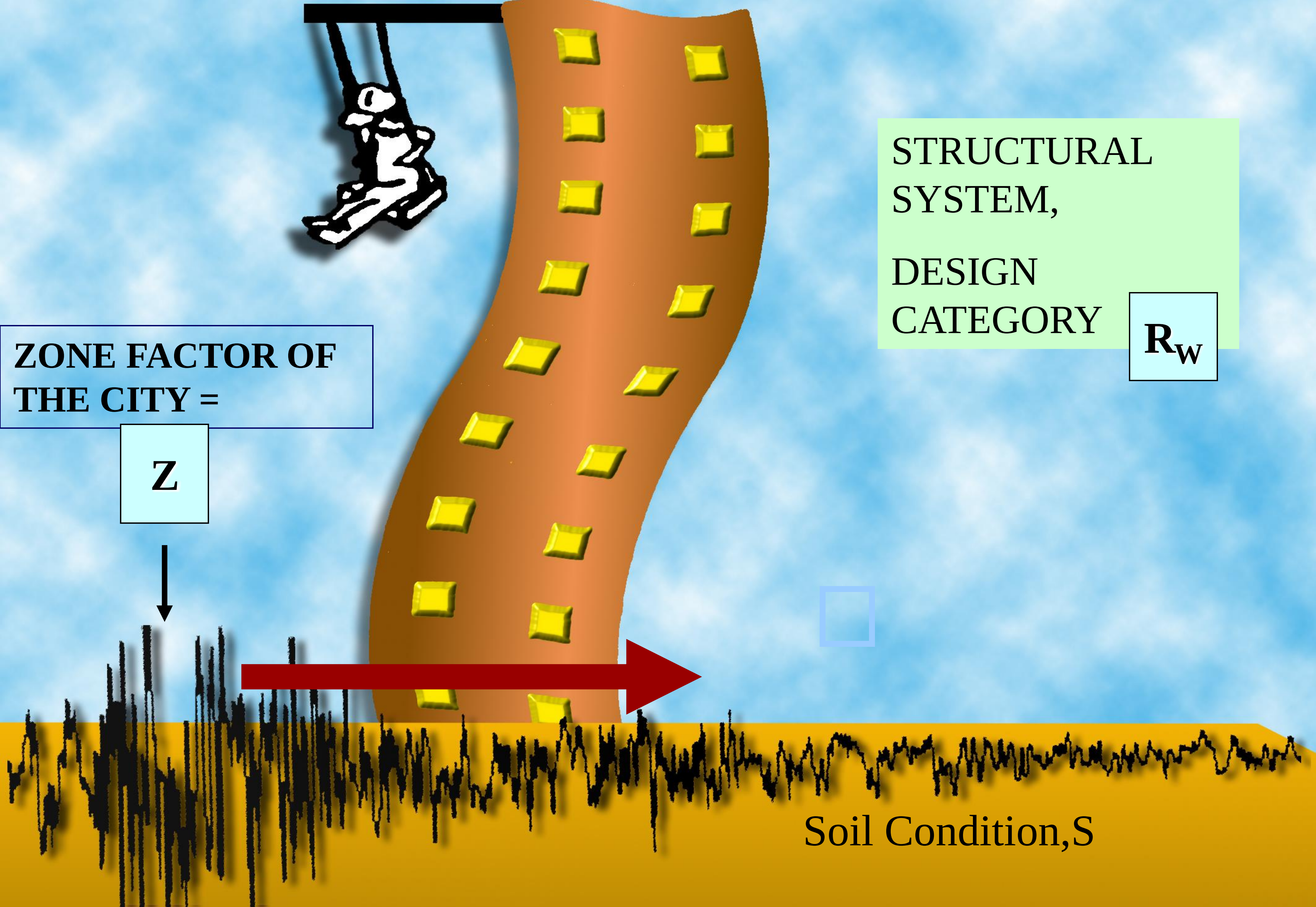
Employing the attenuation relation, the probability distribution of peak ground acceleration (PGA) at a site, was developed by using the step-by-step numerical procedure. This procedure was implemented by the Standard Seismic Hazard Analysis (STASHA) expert system. This expert system was employed to construct hazard curves and associated response spectrum for each site.

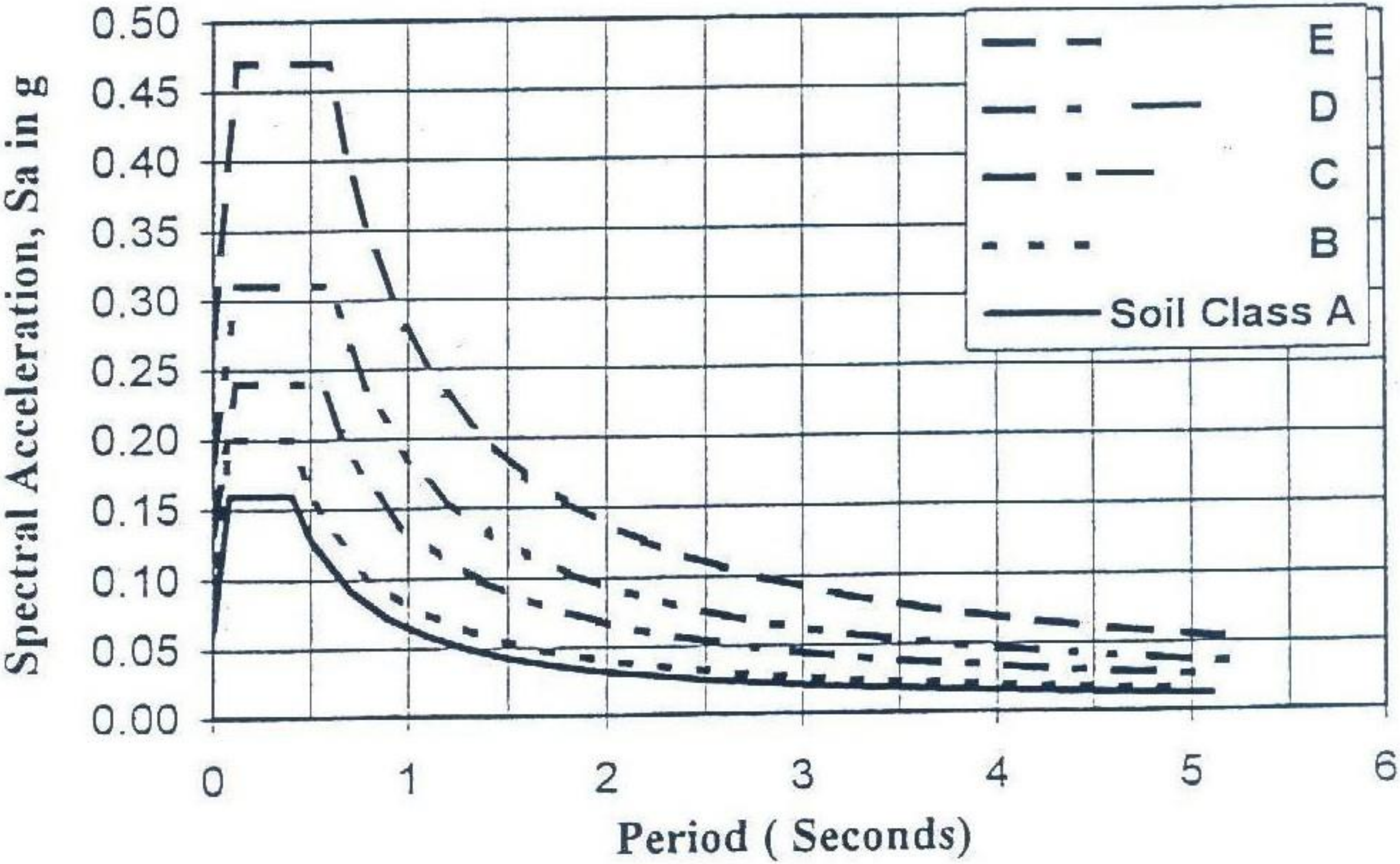




Hazard Curves for Abha Site.

COMPARISON PARAMETERS

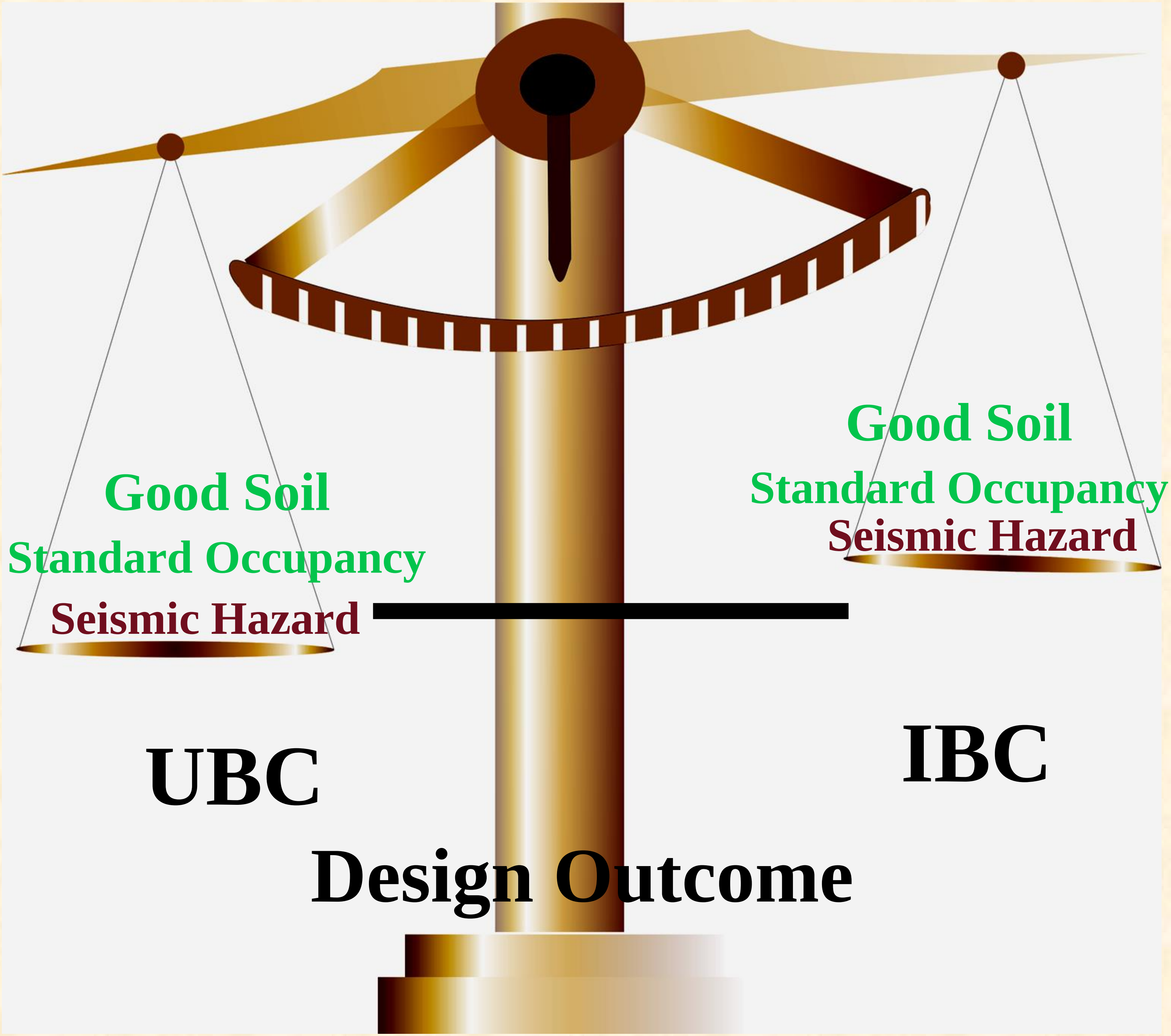




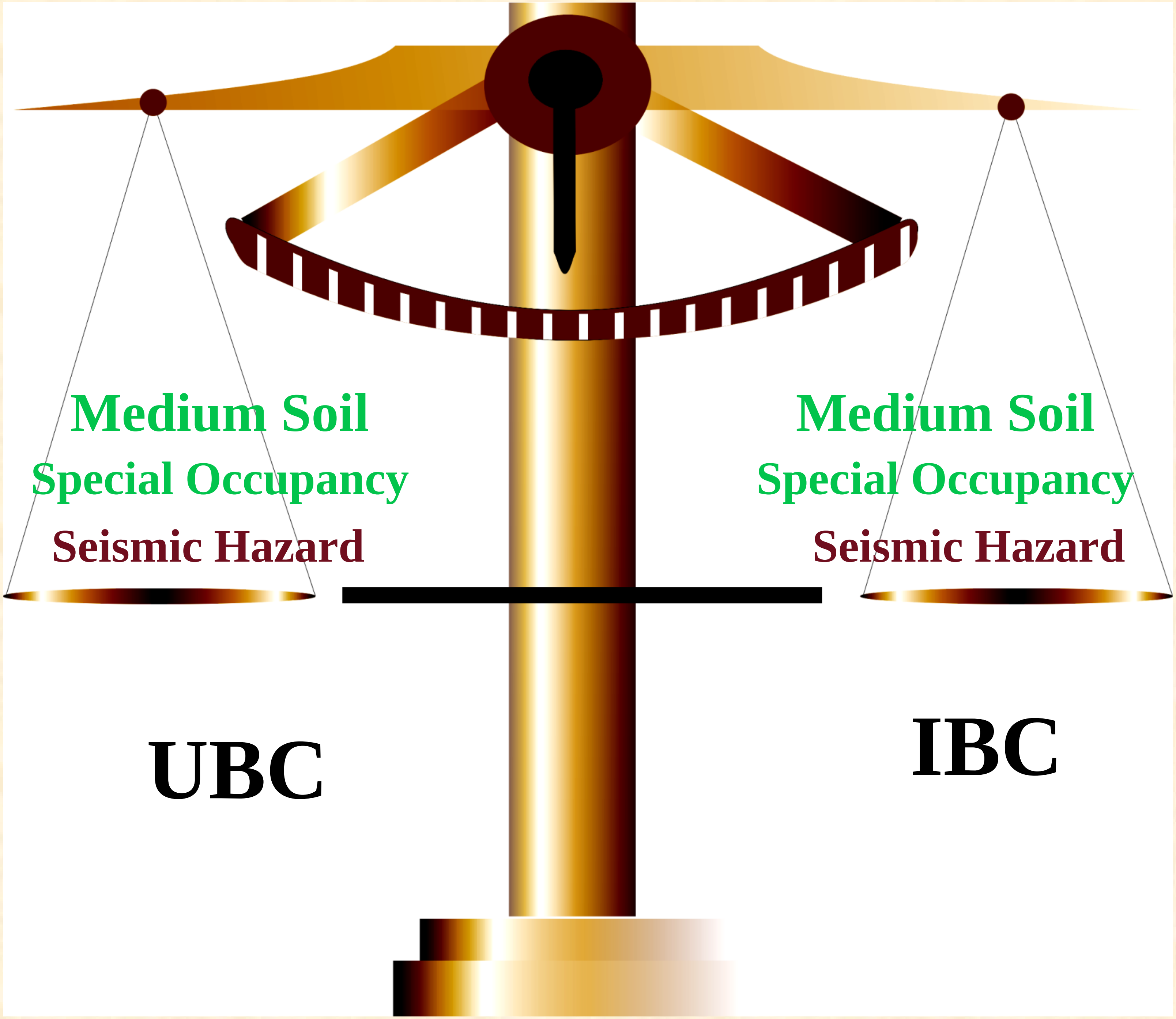
Spectral Acceleration, Sa in g
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0
1
2
3
4
5
6
Period (Seconds)
E
D
C
B
Soil Class A

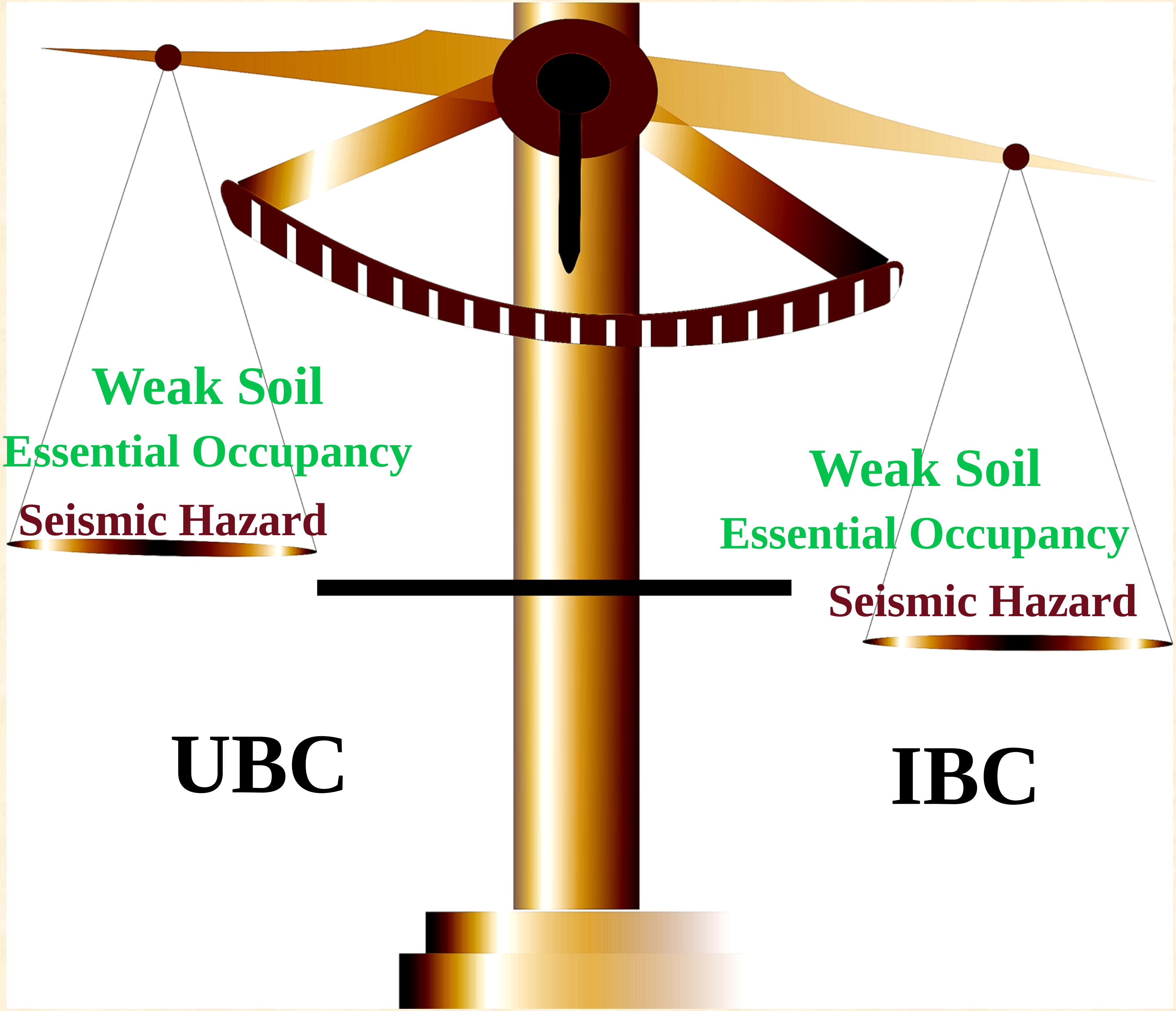
UBC Zonatoin vs. IBC

City	UBC	IBC	
	Zone	Ss	Equ. Ca**
Jizan	2B Ca = 0.2*	0.48g	0.13 1<Ca<2A
Abha	2A Ca = 0.15	0.3g	0.081 1<Ca<2A



Good Soil
Standard Occupancy
Seismic Hazard
Good Soil
Standard Occupancy
Seismic Hazard
UBC
IBC
Design Outcome


Medium Soil
Special Occupancy
Seismic Hazard
UBC
Medium Soil
Special Occupancy
Seismic Hazard
IBC


Weak Soil
Essential Occupancy
Seismic Hazard
Weak Soil
Essential Occupancy
Seismic Hazard
UBC
IBC

CONCLUSIONS

- Historical and instrumental seismicity in the southern Red Sea region for the period 1913 - 2007 has been examined in relation to tectonics and structures indicated by geologic and geophysical data.
- Majority of seismic activities is clustered on or near the transform faults of the deep axial trough in the southern Red Sea.
- The seismically active area between latitude 16.3°N and 17.4° N. is believed to extend northeastwards to the Arabian Shield.
- The apparent low level of seismicity in the shield area might be due to the lack of detection of small events.

- **The b values correlate well with the tectonic environment and seem to increase gradually southwards with the opening of the Red Sea where it has 0.57 for the middle Red Sea and attains 1.06 for the southern Arabian Shield. This may reflects the heterogeneity of the crust and regional stress field.**
- **Four seismic sources were delineated. Sanaa-Dhamar; Southern Red Sea , Northern Yemen, Middle of Red Sea.**
- **Poisson stochastic model and an appropriate attenuation relationship are involved. The results of analysis are presented in the form of Iso-acceleration maps for the return period of 475 years.**
- **PGA value for the bedrock at Yarim and Dhamar cities is about 12 cm/ sec2, 6 cm/ sec2 at Al-Hodaidah, 5 cm/ sec2 at Zabid, 3.9 cm/ sec2 at Farasan, 1.5 cm/ sec2 at Najran, 8 cm/ sec2 at Sadah, 2.16 cm/ sec2 at Jizan and 0.67 cm/ sec2 at Abha city.**

- **The values of PGA is affected by the local soil sediments on the ground surface where PGA value is 32 cm/ sec2, 29 cm/ sec2, 14 cm/ sec2, 11.7 cm/ sec2 at Zabid, Al-Hodaidah, Farasan, and Jizan, respectively.**
- **Maximum simulated time history of PGA on the bedrock and ground surface for southern Red Sea source are 41.1 cm/sec2 and 72.15 cm/sec2 respectively.**
- **Highest value of PGA simulated at Sanaa and Al-Hodaidah is 120 cm/ sec2 with 1% of critical damping. It is noticed that the amplification of Quaternary rocks should be taken into consideration in the design of strategic projects and buildings.**

- **Generally, relative level of ground motion in southern Red Sea is found to be moderate and subjected to more severe seismic hazard compared with the Arabian Shield. The seismic hazard potentialities increase in the southwest of Arabian Shield close to Zabid area due to the amplification of soft soil sediments.**
- **Hazard potentialities for the southern Red Sea are relatively high but the presence of the oceanic crust and salt structures may attenuate the seismic waves.**
- **This study supports the mechanism of sea-floor spreading and believes that the seismic activity in the shield area and the southern Red Sea may be attributed to stresses resulting from subsurface magmatic activity and the spreading centers, respectively.**