

## **Intraplate Earthquakes in Iraqi Western Desert**

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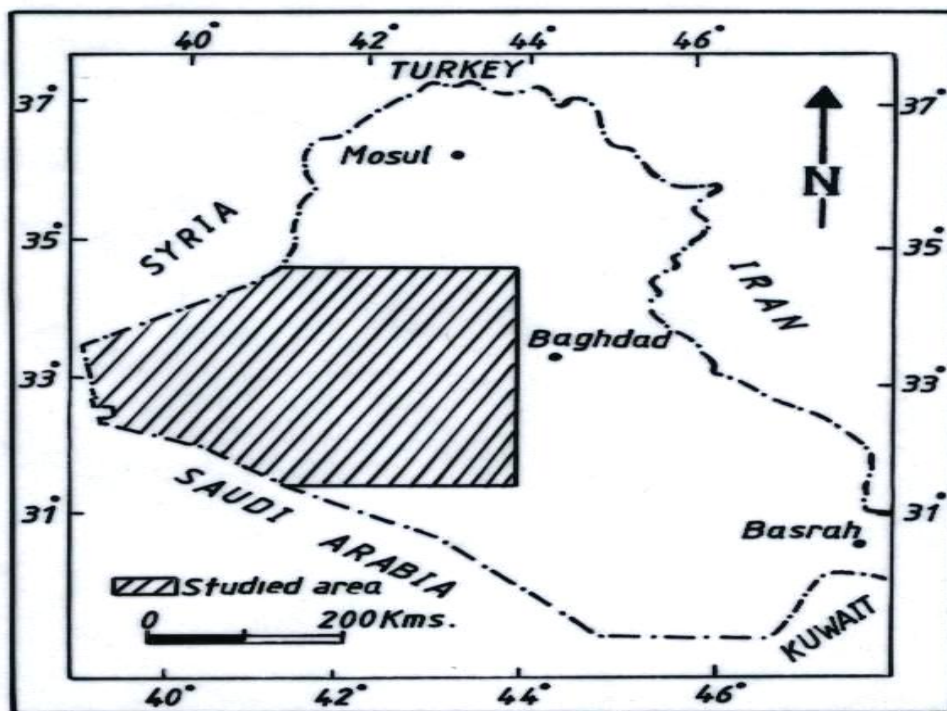
### **Abstract**

The seismicity of Iraqi western desert was analyzed. During the period from 1900 to 2004, there occurred about 40 events with magnitude  $M_w \geq 3.0$ . The area was inactive before 1970. This may be attributed to quietness of the area and / or to missing of data and the poor coverage for the local and regional seismic stations. The relation between earthquake magnitude  $M_w$  and cumulative frequency  $N_c$  for the studied area is  $\text{Log } N_c = 3.51 - 0.54 M_w$ . The spatial epicentral distribution in western desert shows that there are two seismic zone, Zone (I) and Zone (II). Most events were located in and around the Rutbah uplift (Zone II). The focal depth of most events in the area belongs to the crust. In order to understand the cause of intraplate earthquakes in the western desert, the idea of intraplate seismicity occurs in vicinity of " stress concentrators" within preexisting zones of weakness is considered. These concentrators are buried intrusions and intersecting faults. It is found that there is a causal association between the seismicity of western desert and the buried intrusions and fault intersections. A better understanding of the seismicity of western desert requires detailed information about stress and strain within the area, crustal structure, continuous geodetic measurements, heat flow data and detailed microearthquakes monitoring.

### **Introduction**

Earthquakes that occur far from plate boundaries are known as intraplate earthquakes. The globally averaged seismic moment release for intraplate earthquakes is about 5% of the total global moment release (Johnston & Kanter, 1990). Although limited in seismic energy release, their consequences can be disastrous, as illustrated by a very recent example, the  $M_w = 7.7$  earthquake of 26 January 2001, in Bhuj, India. As a result of this earthquake at least 20,000 lives were lost, more than 200,000 people were injured and nearly 400,000 houses destroyed (Rajendran et al., 2001). The nature of intraplate seismicity is not well understood as that of its plate boundary counterparts. Many studies have described several characteristic features of intraplate earthquakes (e.g. Sykes, 1978; Johnston, 1989; Talwani, 1989; Talwani & Rajendran, 1991; Zoback, 1992; Johnston et al., 1994). Intraplate earthquakes are characterized by very low strain rates (Johnston, 1989; Johnston et al., 1994). They have longer return periods compared to their plate boundary counterparts (Gangopadhyay & Talwani, 2003). With few exceptions, most of intraplate earthquakes occur in the upper crust, at depth

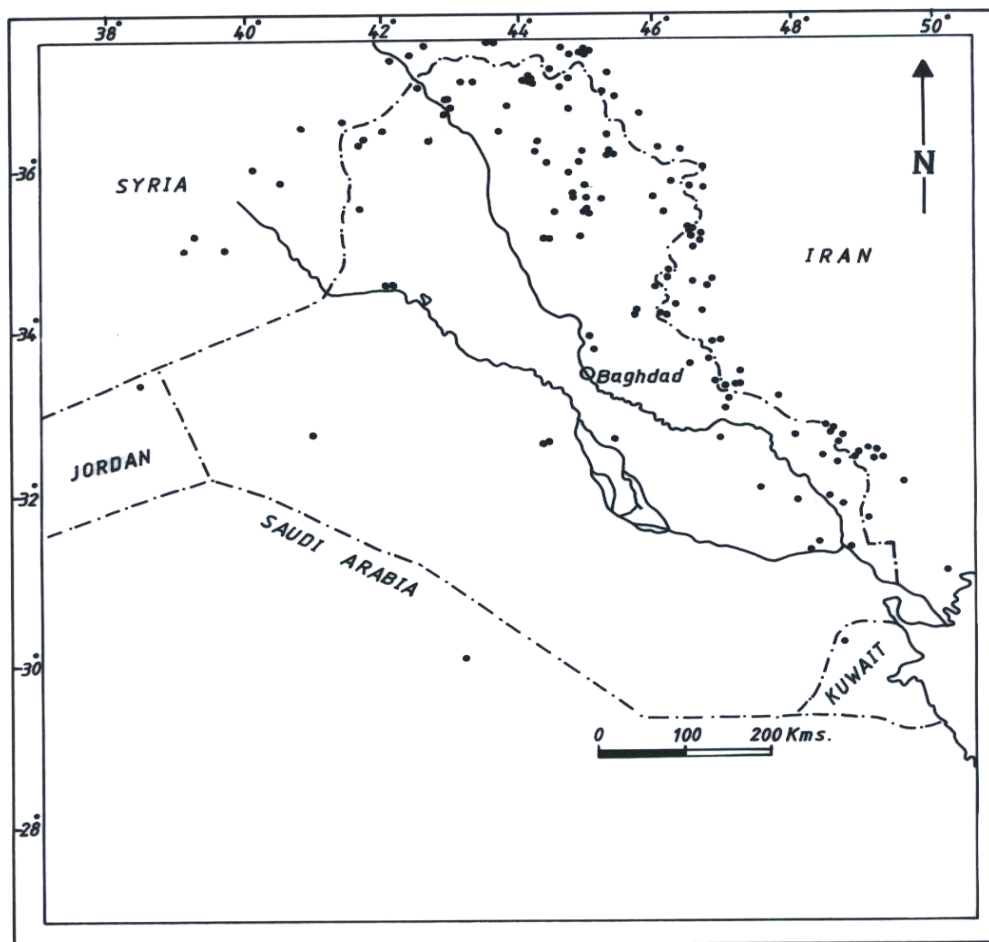
usually shallower than 15 km (Talwani,1989). The low  $b$ - value is a characteristic feature of the intraplate environment (Talwani, 1989). Intraplate earthquakes are characterized also by a general absence of accompanying surface ruptures (Gangopadhyay & Talwani, 2003). To understand where intraplate earthquakes might occur, it is necessary to have idea about the mechanisms that cause them. These mechanisms are subject to considerable debate. Several models have been proposed to explain the intraplate earthquakes. These models involve weak zones, stress concentration, flexural stresses, or combination of the above factors (Assumpcao et al., 2004). The zone of weakness model as a cause for intraplate seismicity is widely accepted (Talwani,1989). Several studies have noted spatial association of intraplate and interplate earthquakes with fault bend and intersections(e.g. Talwani, 1999; Gangopadhyay & Talwani ,2005) .An observed spatial association of intraplate earthquakes with buried plutons and analytical computations led to suggestions of causal association ( Kan, 1977; Barstow et al., 1981). Other proposed models to explain intraplate earthquakes include the deglaciation model, gravitationally induced stresses at structural boundaries and reduction of strength of rocks by mechanical or chemical means (Stein et al., 1979; Goodacre & Hasegawa , 1980; Costain et al., 1987).The objective of this paper is to study seismicity of the western desert in Iraq (Fig.1) as an example of intraplate seismicity. This area includes several population centers, large dam, industrial enterprises and promising hydrocarbon accumulations.



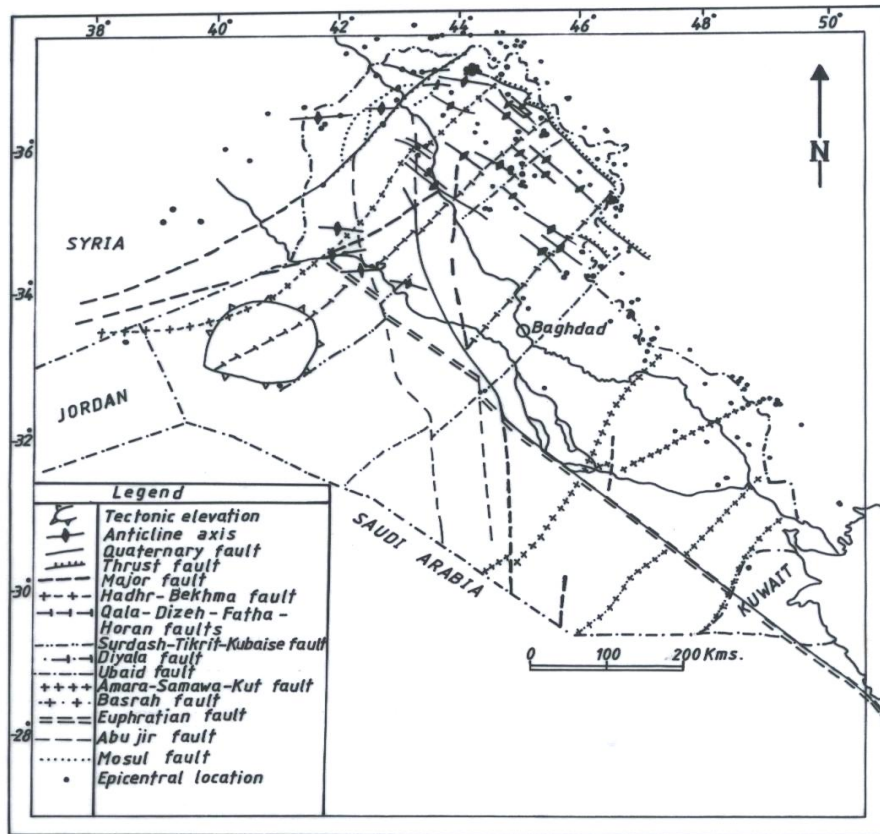
**Fig.1: Location Map of the Studied Area.**

## **Seismicity and Seismotectonic of Iraq**

Iraq is located in a relatively active seismic zone, and most regions of the country were subjected to a seismic activity in the past and may be subjected to seismic activity in the future (Alsinawi & Issa, 1986). The 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 (Alsinawi, 2002). More detailed accounts for seismicity of Iraq is given by Alsinawi & Ghalib (1975), Alsinawi & Issa (1986) and Alsinawi & Al-Qasrani (2003). Fig.2 shows the spatial distribution of earthquakes for the period (1900–1980). Fig.3 shows the seismotectonic map of Iraq which is constructed using all available seismic, tectonic and geological information. It is clear from the map that the distribution of seismic activity in Iraq is not homogeneous and scattered (Alsinawi & Issa, 1986).



**Fig.2: Seismicity Map of Iraq for the Period 1900-1980 (Alsinawi & Issa, 1986).**



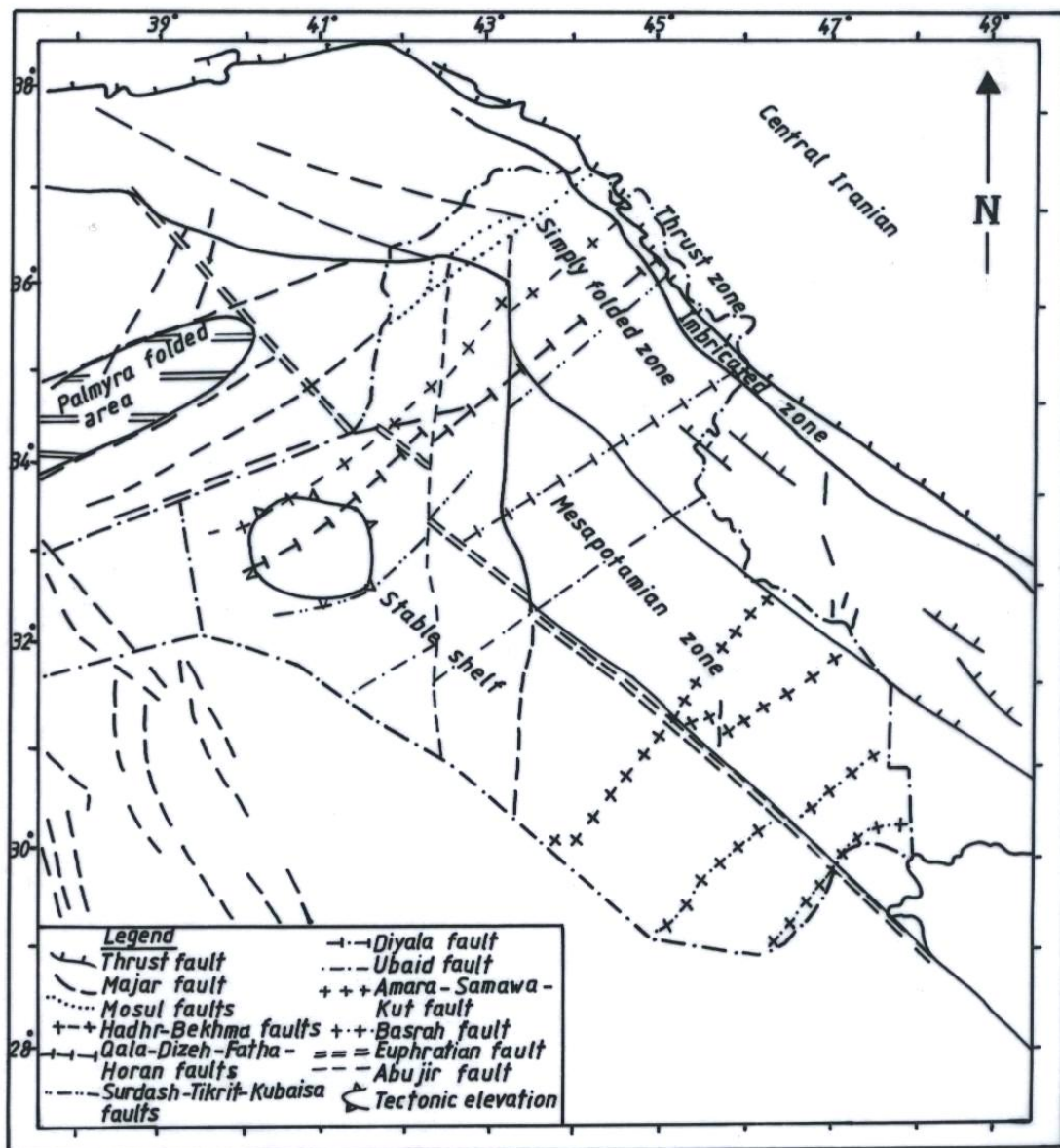
**Fig.3: Seismotectonic Map of Iraq (Issa, 1983).**

### **Tectonic of the Western Desert**

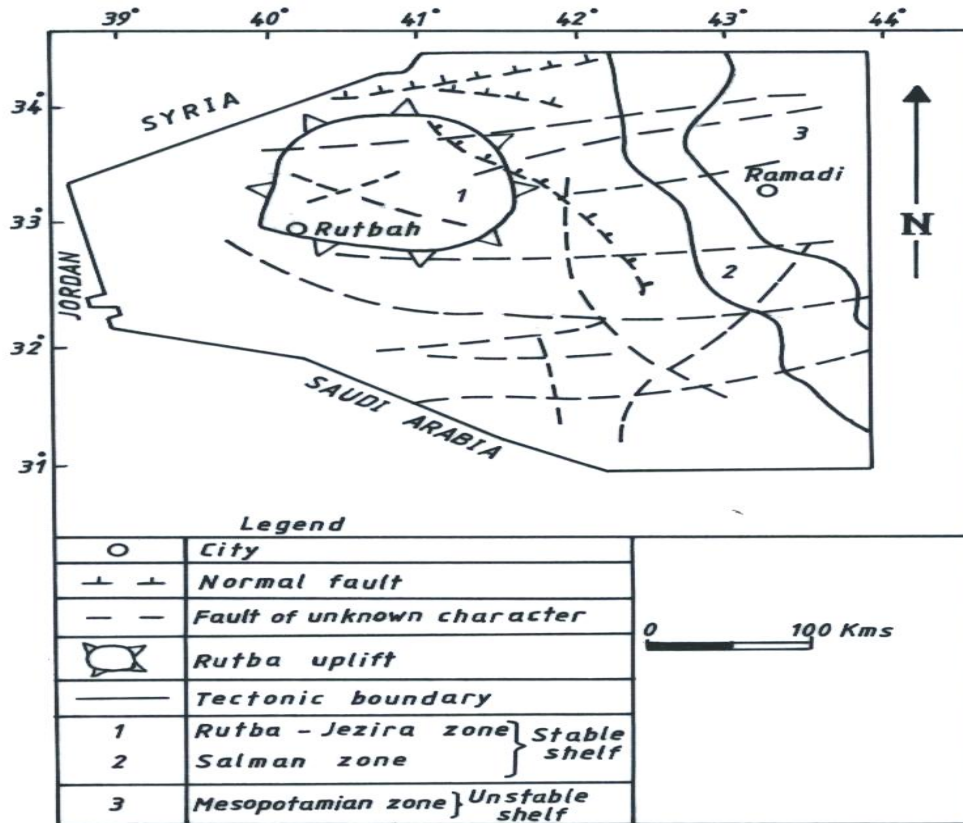
The studied area is situated in the stable shelf ( Fig.4) .The stable shelf was divided into two zones, the Rutbah – Jezira zone on the west and the Salman zone on the east (Buday & Jassim, 1987). The Rutbah – Jezira zone is the more stable unit of the stable shelf. The Rutbah – Jezira zone is divided by the Anah fault into the Rutbah subzone and the Jezira subzone. Most of the area in the present study is located within the Rutbah subzone (Fig.5). The area of the Rutbah subzone is dominated by the huge Rutbah uplift, a unit created during Mesozoic – Tertiary movements (Buday & Jassim, 1987). Detailed description of its evolution is given by Jassim (1981). The top of the present day uplift is the Ga'ara depression with Paleozoic sediment as the oldest rocks on the surface. Its axis run (according to some surface and geophysical, mainly gravity) in N-S direction. Several faults were ascertained partly by geophysical and partly by aerial and other methods of surface investigations (Fig.5).Several investigators contributed to study the tectonic setting of the western desert of Iraq (e.g. Al-Mashadani, 1984; Abbas, 1985; Al-Gebouri, 1988; Al-Sulaiman, 1989; Nadir, 1990). Al-Banna (1992) studied the gravity lineaments, faults trends and depth of the basement rock in western desert. He analyzed the Bouguer anomaly map of the western desert. He found that



the directions of gravity anomalies related to the basement structures have trends N10°W, N20°E, and E-W and N50 °W. The trends N40°W and N50°W are parallel to the lineaments trends in the stable shelf mentioned by Al-Mashadani (1984), and also parallel to the normal faults affected the Arabian plate (Moore , 1979) .The N-S and E-W trends were created by the effect of compressional stresses subjected during the Hegaz and Najd orogenesis , respectively . We constructed a new tectonic map for the western desert (Fig.5) by matching and modification the tectonic maps presented by Buday and Jassim (1987) and Al-Banna (1992).



**Fig.4: Main Structural Zones of Iraq ( Buday, 1973).**



**Fig.5: Tectonic Map of Western Desert of Iraq (Modified from Buday & Jassim, 1987 and Al-Banna, 1992).**

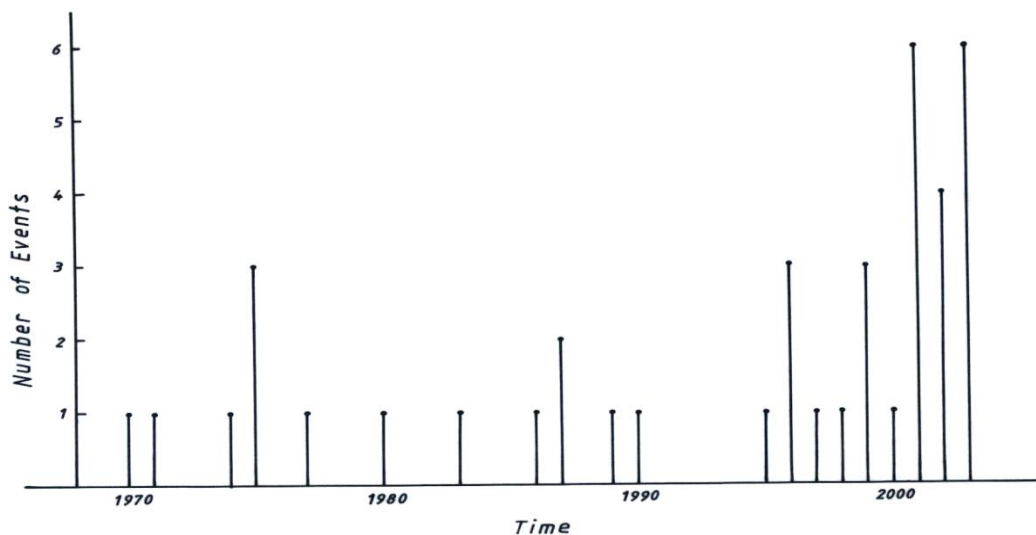
### **Seismicity of the Western Desert**

This study represents a first systematic attempt to evaluate the seismicity and seismotectonic of the western desert as a part from the stable shelf in Iraq. Microseismicity of the studied area was analyzed. Banno (1975) and Alsinawi and Banno (1976) found that a high microseismic background was registered in Ga'ara area, western desert. Microseismicity of Ga'ara area, western desert, as an example of intraplate earthquakes was studied by Al-Heety (1985) and Alsinawi & Al-Heety (1987). A total of (936 hours) of recording were accumulated and analyzed. Twenty five events were identified and classified as local events with epicentral distance ranging between 3.2 to 23 km. The focal depths were found to range between 2.2 to 22 km. Alsinawi & Al-Heety (1987) found that the probable source of seismicity may be attributed to reactivation of preexisting faults or may be associated with epiorogenic activity or uplift of the basement. The earthquakes occurred in the studied area were reported in catalog of Al-Heety (2006) and Bulletins of the International Seismological Center (ISC). These documents are sources for the database of the earthquake catalog of western desert. The current catalog contains

the events with moment magnitude  $M_w \geq 3.0$  within the western desert for the period from 1900 to 2004.

### **Temporal Variation of Earthquakes**

Temporal variation of the seismic activity is a very important tool in seismic hazard analysis. It can be used as a powerful tool for a tentative prediction, especially, if complete information about earthquake occurrence is available. The temporal distribution of events in western desert (Fig.6) shows that the area was inactive before 1970 and subjected to 40 events after that date. This may be attributed to quietness in the seismic activity, and / or to missing of data and the poor coverage for the local and regional stations and this, in turn, affects on the detectability of the events.



**Fig.6: Temporal Variation of Earthquakes in Western Desert.**

### **Frequency-Magnitude Relationship**

The frequency – magnitude distribution of earthquake is well expressed by the Gutenberg – Richter relation (Richter, 1958):

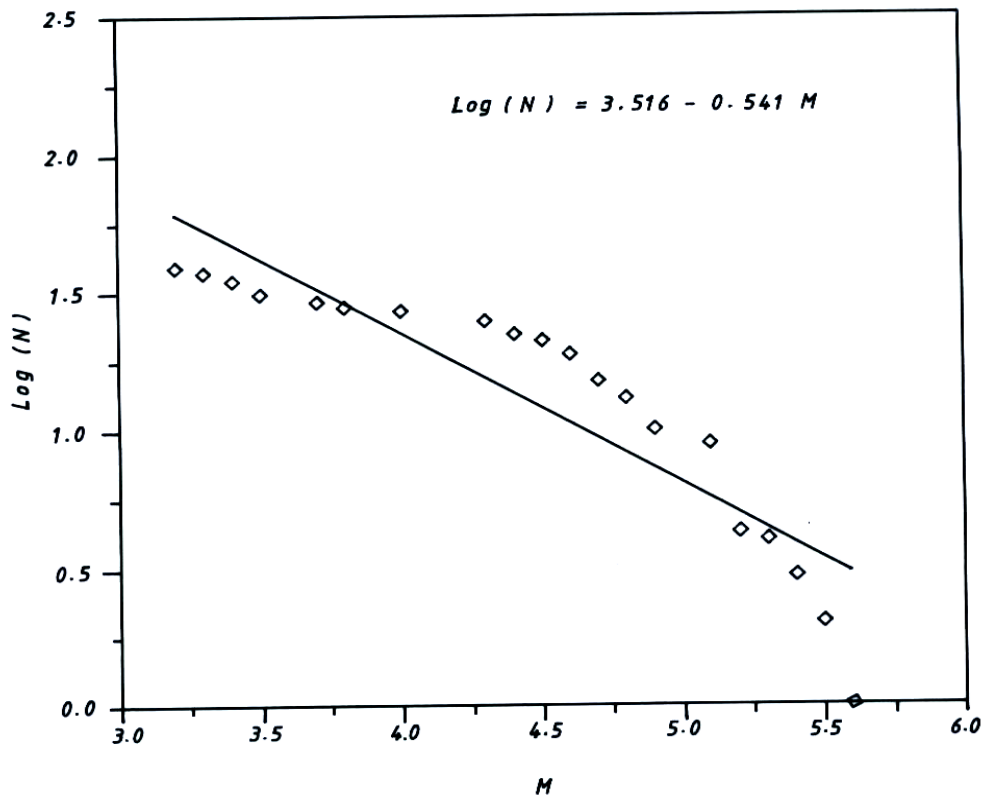
$$\text{Log } N = a - bM \quad \dots (1)$$

Where  $N$  is the number of earthquakes with magnitude  $\geq M$  and  $a$  and  $b$  are constants for a region. The constant  $b$ , known as  $b$ -value, is the slope of log-linear relation. The  $b$ -value generally varies from 0.5 to 1.5 depending on the tectonic setting, tectonic stress and magnitude ranges (Scholz, 1990; Wiemer & Wyss, 1997) but normally comes close to 1 for seismically active regions. The variation of  $b$ -value can be related to stress distribution after the main shock, as well as the history of previous ruptures (Dimri et al. 2005). The regions with lower value of  $b$  are probably the regions under higher applied shear stress after the main shock, whereas the regions with higher values of  $b$  are the areas that experienced the slip (Enescu & Ito, 2002)

Figure 7 gives the magnitude distribution of the earthquake activity( $M_w \geq 3$ ) in western desert from 1900 – 2004 . The figure gets the following relation:

$$\text{Log } N_c = 3.51 - 0.54 M_w \quad \dots(2)$$

Where b- value equals to - 0.54.

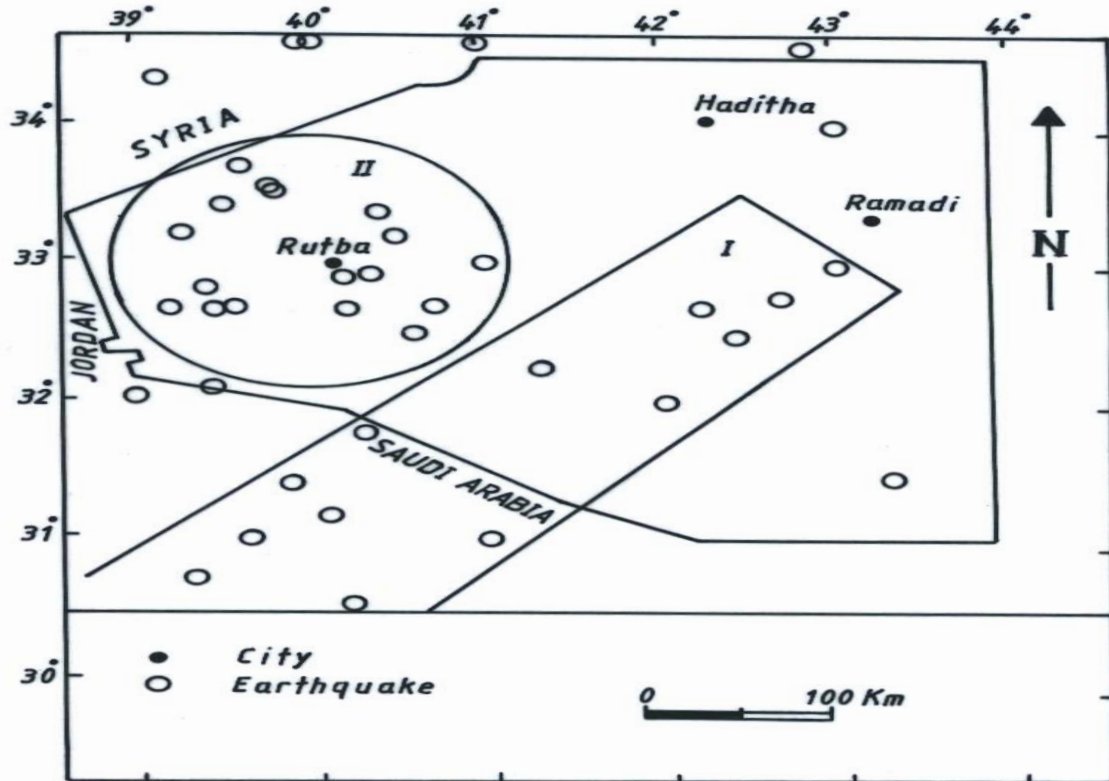


**Fig.7: The frequency–Magnitude Relation of the Earthquakes in Western Desert During 1900 -2004. M(earthquake magnitude) and N(number of earthquakes).**

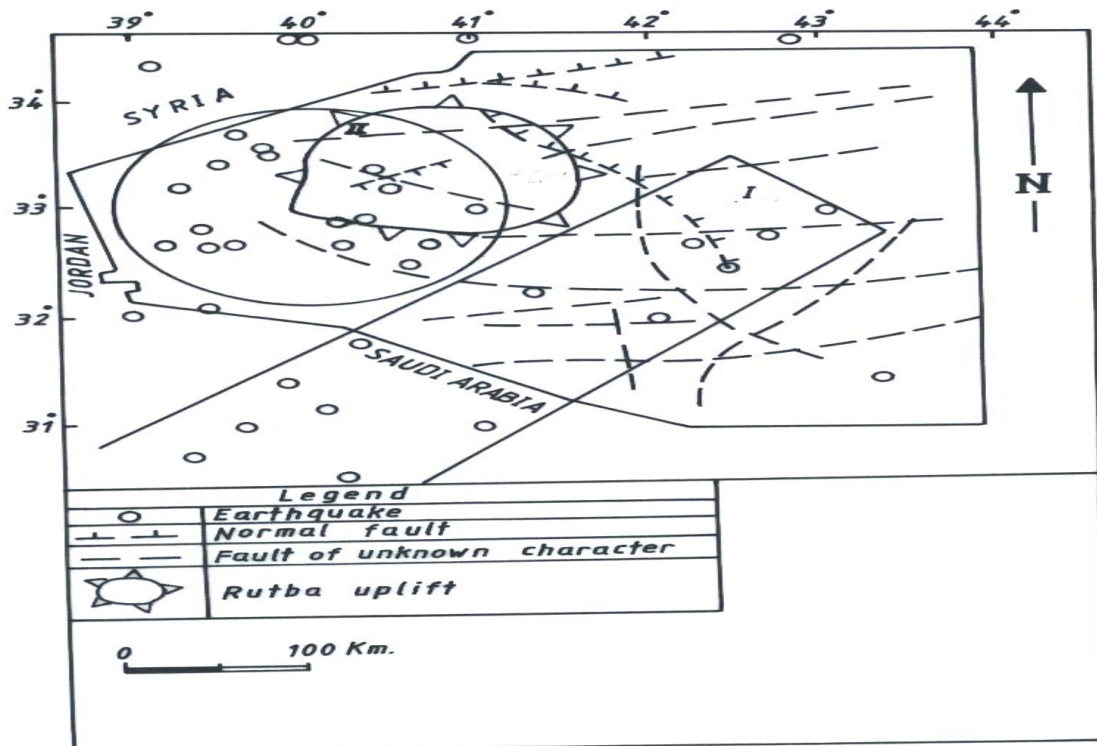
### **Spatial Distribution of Seismic Activity**

Fig.8 shows the spatial epicentral distribution of earthquakes ( $M_w \geq 3.0$ ) in western desert from 1900 to 2004 . From the figure, we can see that most of the earthquakes occurred in the western part of the studied area. In regard to the concentration, there are two seismic zones (Fig.8): the zone (I) and the zone (II). In the zone (I), the epicentral distribution takes the linear pattern, while in the zone (II); the epicentral distribution shows an areal pattern. The zone (II) is more active than the zone (I). Fig.9 shows the seismotectonic map of the western desert. The zone (I) includes many faults with trends E-W, SW-NE and NW-SE. Some events locate on and near to the fault. The zone (II) includes the Rutbah Uplift and most the events locate in and around the uplift. This zone includes also a number of faults that take the same trends of the faults in the zone (I). The focal depths distribution (Fig.10) shows that all the events occurred above the MOHO except one event.

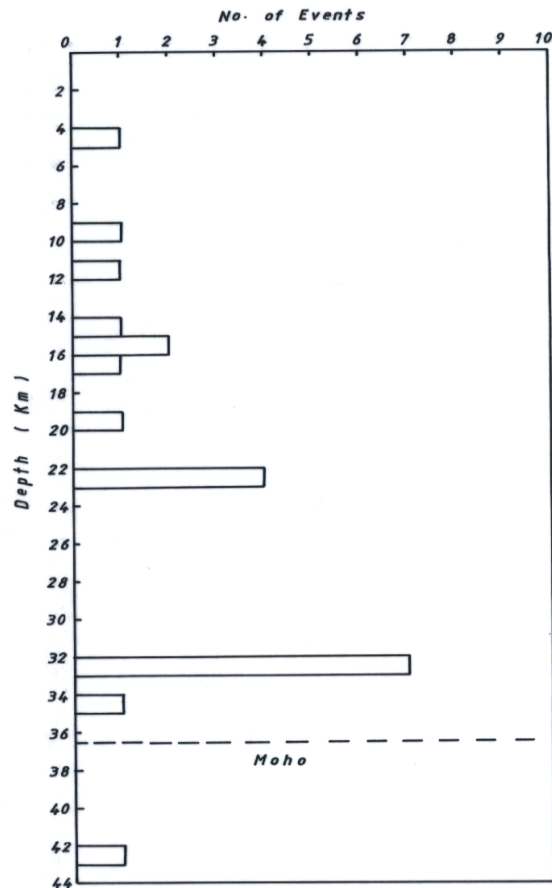




**Fig.8: The Epicentral Distribution of earthquakes with  $M_w \geq 3$  in Western Desert During 1900-2004.**



**Fig.9: Seismotectonic Map of Western Desert.**

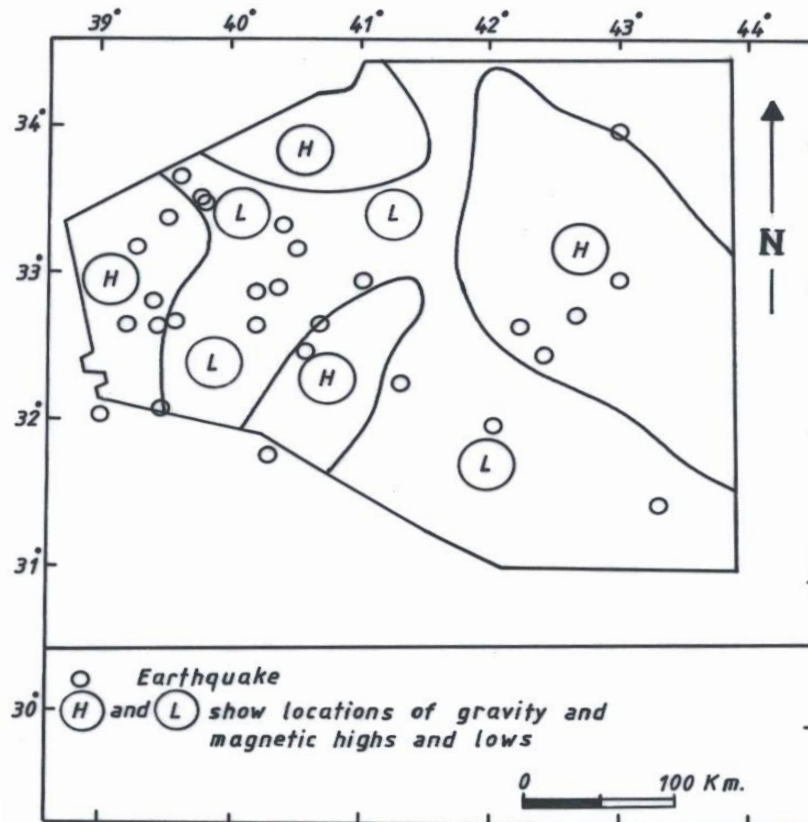


**Fig.10: Variation of Earthquake Focal Depths in Western Desert. Approximate Moho Depth is indicated by dashed line. Moho data is from Al-Heety (2002).**

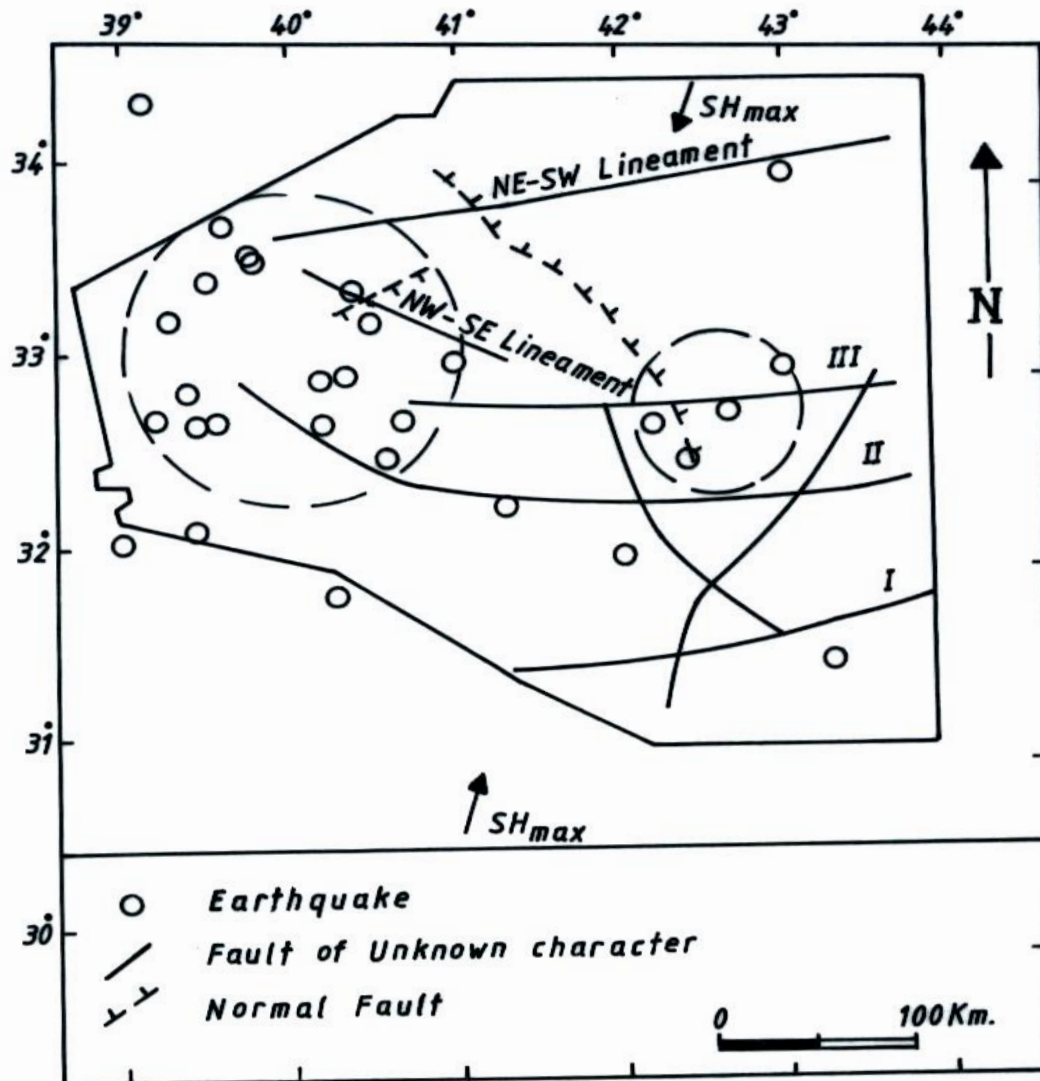
### **The Probable Causes of Seismicity in Western Desert**

It is instructive to consider the seismicity of the western desert in the context of the above ideas. The geological and geophysical mapping is crucial to the understanding of the probable causes of the seismicity. The region is covered by gravity and aeromagnetic data collected by the Iraqi State Organization of Minerals (SOM) in 1976 and C.G.G. in 1974, respectively, and these provide vital clues as to the major geological features of the region. A large –scale seismic refraction survey, that is very important to understand the structure of the Earth's crust in the third dimension, is not carried out in the studied area till now. Al-Banna (1999) used gravity, aeromagnetic, isostatic and the basement depth maps to delineate the main lithological basement rocks. He showed that some regions in the western desert, are characterized by positive gravity and magnetic anomalies coincide with deep basement depth. Such area named as positive (gravity and magnetic highs) regions and marked with letter H (Fig.11). The positive regions are related to these rocks that are characterized by high density and magnetic susceptibility (ultrabasic

rocks). Other areas are characterized by negative gravity and magnetic anomalies coincide with the shallower basement depth. These areas named as negative regions (gravity and magnetic lows) and marked with letter L in (Fig.11). The negative regions are related to low density and magnetic susceptibility (metamorphic or granitic rocks). Depth to the basement rocks in the western desert is ranging 5-13 km according to C.G.G. (1974).Figure 11 shows the gravity and magnetic lows and highs in the western desert along with earthquakes epicenters. Some events are distributed to the edges of the intrusions. The distribution of these intrusions could cause local stress concentration at their contacts with the host rock resulting the observed seismicity .The confinement of seismicity of the western desert to the edges of intrusions implies a causal association. The western desert includes number of faults and lineaments with trends NE-SW, NW-SE and E-W. There three faults with trends E-W (named I, II, and III). These features intersect at different locations (Fig.12).A higher level of seismic activity was clustered around and in these intersections (dashed circles in Fig.12). We interpret this observation to infer that there is a strong association of the seismicity with fault intersections. We can suggest that there is a causal association between the seismicity of western desert and the buried intrusions and fault intersections.



**Fig.11:Locations of Gravity and Magnetic Lows (L) and Highs (H), (Modified Al-Banna, 1999).**



**Fig.12: The Relation between Fault Intersections and Seismicity of Western Desert .The Solid Black Arrow indicates of the Direction of Maximum Horizontal Compression (SHmax). Data of SHmax is from Reinecker, et al., (2005).**

### **Seismicity and Uplifting Activity**

Most of the earthquakes in the western desert locate in and around the Rutbah uplift. This uplift of Mesozoic – Tertiary age remained uplifted and stable during the geological history including the Tertiary (Buday & Jassim, 1987). Geodetic surveys and repeated gravity surveys are used to indicate that the uplifting is still going at remarkable rates or not. Because of geodetic surveys and repeated gravity surveys are not available in the western desert; we can not infer any causal association of the seismicity with vertical movement or uplifting.

## **Discussion and Conclusions**

The seismicity of western desert in Iraq was analyzed based on the available geological, geophysical and seismological data. This analysis allowed us to conclude the following:

1. The temporal distribution of events in western desert shows that the area was inactive before 1970 .This may be attributed to quietness in the seismic activity and/or to missing of data and the poor coverage for the local and regional seismic stations and this, in turn, affects on the detectibility of the events.

2. The value of constant  $b$  in the frequency –magnitude distribution was estimated using the Least Squares Method. The estimated value is  $-0.54$ . The low  $b$ -value is a characteristic feature of the intraplate environment (Talwani, 1989).

3. The spatial epicentral distribution in western desert shows that there are two seismic zones ( zone I and zone II ).The second one is more active than the first zone. Most events in zone (II) locate in and around the Rutbah uplift, the outcropped tectonic feature in the studied area.

4. All the events in the western desert occurred above the MOHO except one event. Most of these events occurred in the lower crust. Most earthquakes in the continental lithosphere occur in the upper crust (Chen & Molnar, 1983; Chen, 1988; Talwani,1989; Cattanea et al.,1999).Maggi et al. (2000a) found no convincing evidence that seismicity occurs any where in the continental mantle except for a single small (ML 3.8), isolated event at 90 km depth reported in Northern Utah ( Zandt & Richins, 1979) .Almost all earthquakes on the continents are confined within a crustal layer that varies in the thickness from about 10 to 40 km, and are not in the mantle ( Maggi et al.,2000b)They found that the aseismic nature of the continental mantle and the lower crustal seismicity beneath some shields are probably related to their water contents . Lamontagne & Ranalli (1996) found that high pressures and /or low static coefficient of friction are required for the occurrence of lower – crustal earthquakes in the Charlevoix, Canada. A low rate of heat flow in these regimes has been suggested as a possible reason for the deep intraplate seismicity (Talwani, 1989). To explain a reason of anomalously deep intraplate earthquakes in northwestern Italy, Cattaneo et al. (1999) suggested a direct link between elastic and rheological properties of the lower crust and upper mantle.

5. To explain the cause of intraplate earthquakes in western desert, we examined the idea that intraplate seismicity occurs in vicinity of "stress concentrators" within pre-existing zones of weakness. These stress



concentrators are structures where plate tectonic stresses can cause a localized build –up of stresses and ultimately, earthquakes. We tested two types of stress concentrators, buried intrusions and intersecting faults.

6. We observed that some events are distributed to the edges of the buried intrusions. The confinement of the seismicity in the western desert to the edges of the intrusions implies a causal association.

7. A higher level of seismic activity was clustered around and in the intersecting faults at different locations in the western desert. This observation was interpreted that there is a strong causal association of seismicity with fault intersections.

8. Most of events in the western desert locate in and around the Rutbah uplift. Because of geodetic and repeated gravity surveys are not available in the western desert; we can not infer any causal association of the seismicity with the vertical movement or uplifting.

9. We can suggest that there is a causal association between the seismicity of western desert and the buried intrusions and fault intersections.

10. A better understanding of the seismicity of western desert requires information about the distribution of stresses and strain within area, geophysical surveys to better resolve crustal structure, heat flow data, detailed microearthquakes monitoring and more detailed studies of the seismicity including accurate hypocenter location and focal mechanisms.

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## الهزات داخل الصفائح في الصحراء الغربية العراقية

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### الخلاصة

تم دراسة زلزالية الصحراء الغربية العراقية للفترة من ١٩٠٠ الى ٢٠٠٤ . تعرضت المنطقة خلال هذه الفترة الى ٤٠ هزة أرضية بمقادير زلزالية عزمية ( Mw ) أكبر من ويساوي ٣ . كانت المنطقة غير نشطة قبل عام ١٩٧٠ وربما يعزى هذا الى هدوء المنطقة و/ أو غياب البيانات والتغطية الفقيرة للمحطات الزلزالية المحلية والإقليمية . يعبر عن العلاقة بين المقدار الزلزالي والتكرار التراكمي للهزات الأرضية بالمعادلة:  $\text{Log } N_c = 3.51 - 0.54 M_w$  . تركزت الهزات الأرضية في الصحراء الغربية العراقية في نطاقين هما : النطاق ( I ) والنطاق ( II ) ، وكان النطاق ( II ) أكثر نشاطاً من النطاق ( I ) . تقع أغلب الهزات في النطاق ( II ) في وحول نهوض الرطبة . العمق البؤري لأغلب الهزات المسجلة يعود للقشرة . لفهم سبب حدوث الهزات داخل الصفائح في الصحراء الغربية العراقية تم اختبار فكرة أن الزلزالية داخل الصفائح تحدث في جوار مراكز الجهد خلال انطقه الضعف السابقة . هذه المراكز هي المقتحات المدفونة والصدوع المتقاطعة . هناك علاقة سببية بين زلزالية الصحراء الغربية والاندفاعات المدفونة وتقاطعات الفوالق . إن عدم توفر المسوحات الجيوديسية والجذبية المتكررة في الصحراء الغربية لا يسمح لنا استنتاج وجود علاقة سببية بين حدوث الهزات الأرضية والحركات العمودية او النهوض . إن فهما أفضل لزلزالية الصحراء الغربية يتطلب معلومات تفصيلية حول الجهد و الإجهاد في المنطقة ، تركيب القشرة الأرضية ، بيانات انسياب الحرارة ومراقبة تفصيلية للزلزالية الدقيقة في المنطقة .