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HISTORICAL SEISMICITY OF THE STABLE CONTINENTAL REGIONS (SCRs) IN THE ARABIAN PLATE (PRELIMINARY STUDY).

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Abstract

Historical earthquakes catalog, which were felt in the Stable Continental Regions (SCRs) of the Arabian plate for the period (600 to 1900 A.D.), was compiled. The spatial distribution of these earthquakes appears as clusters of events in the northeastern parts, and absence of events in the other parts. This may be attributed to concentration of the population centers in the northern parts relative to other parts and / or to that the seismicity level is very low. These events have a shallow focal depths. This is a characteristic feature of the SCRs. The cumulative strain release curve exhibits two periods of high seismicity separated by low seismicity period. There is a relative quite period extends from (1194 to 1900).This quite period may appear hiatus in seismic activity or in the documentation . The b–value in magnitude relationship was low and this low value is a characteristics feature of the SCRs earthquakes.

Key words: HISTORICAL SEISMICITY . STABLE CONTINENTAL REGIONS (SCRs) . ARABIAN PLATE

Introduction

Until now, plate interiors are known to experience rare, large earthquakes; for the continents such events control the seismic hazard of a significant fraction of the world's population. Earthquake that occur far from plate boundaries are known intraplate earthquakes. Plate tectonics does not emphasize earthquakes far from plate boundaries mainly because their globally averaged energy release is almost negligible compared to that from earthquakes associated with plate boundaries.

A comprehensive study of intraplate earthquakes found that the globally averaged seismic moment release for intraplate earthquakes is about (1026 dyne cm) per year (Johnston and Kanter, 1990). Comparatively, this is about (0.5 %) of the global average.

Intraplate earthquakes occur in plates that are characterized by very low strain rates (Johnston, 1989; Johnston et al., 1994). Although their potential for widespread destruction is large, intraplate earthquakes have longer return periods compared to their plate boundary counterpart. Because of this long recurrence time, major earthquakes may occur in areas that have been historically seismically inactive.

To understand where intraplate earthquakes might occur, it is necessary to have an idea about the mechanism that causes them. Primarily because of

rarity of intraplate earthquakes and a general absence of accompanying surface ruptures, their mechanisms are not well understood. Gangopaldhyay and Talwani (2003) reviewed models that have been proposed to explain intraplate earthquakes. They found that intraplate seismicity occurs in the vicinity of "stress concentrators" within pre–existing zones of weakness. These stress concentrators are structures where plate tectonic stress can cause a localized build–up of stresses and ultimately, earthquakes. These include intersecting faults, buried plutons and rift pillows.

Because of our study area represents continental region, we use term Stable Continental Regions (SCRs) to refer to them as intraplate regions. Stable Continental Regions (SCRs) are defined as "regions of continental crust that have not experienced any major tectonism, magmatism, basement metamorphism or an orogenic intrusion since the early cretaceous, and no rifting or major extension or transtension since Paleogene" (EPRI, 1994).

The objective of this study is to compile a historical earthquakes catalog for SCRs of the Arabian plate and to analyze the continental historical Seismicity of the plate.

Historical Earthquakes Catalog

The Arabian region and the Middle East have good documented historical data back to some (4000 years). Boundaries of the SCRs of Arabian plate are directly extracted from the EPRI (1994) maps. A historical catalog of the felt events in SCRs of the Arabian plate for the period from (600 to 1900) was compiled. The earthquakes that occurred or felt at the Arabian plate were reported in different regional and global catalogs. These catalogs are sources for the database of our catalog. The source catalogs are the catalog of Alsinawi (1988), the catalog of shallow intraplate earthquakes(Triep and Sykes, 1996), the Earthquake of Database of the Arabian Peninsula (Seismic Studies Center–King Saud University, 1999) and the updated global earthquake catalog for Stable Continental Regions (Schulte and Mooney, 2004).

According to Schulte and Mooney (2005), and in an attempt to remove events that are in fact related to plate boundary deformation, events within (200 km) of plate boundaries, as well as, event within (40 km) of the SCR–ACR boundaries (Active Continental Regions; Regions of continental crust that do not satisfy the definition above) , were removed from the database. We also excluded the events that were felt at the SCRs regions and the surroundings regions at the same time because these events may be occurred out of the SCRs and were felt here.

We appreciated the approximate locations for the events that were felt at the known cities (e.g., Baghdad, Wasite,….ect).We considered the geographical locations of these cities representative of the approximate epicentral locations of the events.

Some of source catalogs (e.g., Alsinawi, 1988) used to compile our catalog, contain detailed information about the damage experienced. This offered possibility of giving a rough intensity estimate at the approximate locations affected by the seismic events. Alsinawi (1988) used the methodology given by Poirier and Taher (1980).

If no magnitude estimate was available, nor aerial intensity data, a cutoff maximum intensity of (VII) on the Modified Mercalli scale (or conversions to it) was used. This minimum size cutoff is necessarily approximate because of the multiple magnitude scale in use, their non–uniform application, and differing interpretations of data on historical events.

A uniform magnitude scale, the moment magnitude (Mw) was applied through

the catalog according to the following steps:

1. For events with reported estimated magnitude (Mw) that value is preserved.

2. For events with estimated epicentral intensity (Io), (Ms) is calculated using the standard Gutenberg and Richter equation (Gutenberg and Richter, 1956)

$Ms=1+2/3Io$ (1)

3. The hierarchical scheme developed by Tanner and Shepherd (1997) to assign (Mw) values to most earthquakes in the catalog is used:

(+Mw) calculated from (Ms), ($Mw \approx Ms$) where (Ms) has been reliably determined for ($Ms > 6.6$) and for ($Ms \leq 6.6$), we use the following equation

$Mw=2/3Ms+2.34$ (2)

(+Mw) calculated from mb through two–steps process of first converting (mb) to (Ms) using the equation

$Ms=1.74mb-3.95$ (3)

then; using one of the relationships given above.

The focal depths of the events were estimated using an empirical relationship given by Shebalin (1961):

$I=1.5M-3.5logh+3.0$ (4)

The estimated focal depths range from about (5 to 35 km), i.e., earthquakes of the SCRs of the Arabian plate have shallow focal depths and occur in the crust. This is a characteristic feature of the SCRs seismicity.

Though earthquakes of our catalog have not enough accuracy in their occurrence time, epicentral locations, intensity and magnitudes, they remain important for the purposes of seismicity, seismotectonic and seismic hazard studies. The current catalog contains events within SCRs of the Arabian plate from (600 to 1900 A.D.) (Appendix A).

Spatial Distribution of SCRs Seismicity

The spatial pattern of SCRs earthquakes is usually a series of clusters, although linear patterns have often been delineated within these clusters. For example, on a large scale, the seismicity in New Madrid zone appears to be clustered but within the zone, there is an obvious NE alignment along the Reelfoot rift zone (Talwani, 1989). Al-Banna (1996) concluded that the active seismic area (cluster) is an area of intersection of many seismic strip sources .

To study the spatial distribution of the historical SCRs earthquakes, we appreciated the approximate locations for the events that were felt at the known cities and we excluded the events that were felt at regions or countries such as at Iraq, Syria, …etc., because an acceptable determi–nation of their location is impossible.

Figure (1) shows the approximate locations of the historical SCRs earthquakes in the Arabian plate. The accuracy of locations of these earthquakes my be of the order of a few tens of kilometers or more.

There are clusters of SCRs events in the northeastern parts of the plate and absence of the events in the other parts of the plate. This may be attributed to concentration of the population centers in the northern parts relative to other parts and / or to that seismicity rate is very low.

Temporal Distribution of the SCRs Seismicity

Through study of the temporal distribution of seismicity within the intraplate setting of the southeast United States, it has been found that seismicity is temporally stationary (Talwani, 1989). However, large temporal changes of small to moderate magnitude seismicity are often observed in areas with intraplate seismicity (e.g., Sykes, 1978). This also been observed in less seismically active areas in Norway (Large Oslo earthquake in 1904, see e.g. Bungum et al., 1986, and Meloy sequence ,Bungum et al., 1982). In such cases, seismic monitoring over only a few years

will not give a true indication of the seismic potential within an area.

Figure (2) shows the temporal distribution of the historical SCRs earthquakes. It was found that in general, the seismicity is temporally stationary except in some periods , the seismicity rate (number of events) increased. To study the temporal distribution of the SCRs seismicity, we determined the Following:

I. Frequency – Magnitude Relationship

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

$$\log N = a - bM \qquad (5)$$

Where (N) is the number of earthquakes with magnitude (M) and more and (a) and (b) are constants for a region. The constant (b), known as b–value, is the slope of the log–linear relation. Agrawal (1991) states that tectonic earthquakes are characterized by the b–value from (0.5 to 1.5) and are more frequently around 1.0 for seismically active regions. Studies of Mogi (1963) and Scholz (1968) reveal that the b–value depends on the percentage of existing stress to the final breaking stress within the faults.

Fitting equation (5) to the historical events of the SCRs regions in the Arabian plate by using the graphical approach give (a) and (b) as (3.93) and (0.47), respectively (Figure 3). The low b–value is a characteristic feature of the intraplate environment (Talwani, 1989). 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 value of (b) are the area that experienced the slip (Enescu and Ito, 2002).

II. Seismic Strain Release

Figure (4) shows cumulative strain release curve, the energy (E) was calculated using the following equation (Gutenberg and Richter, 1956)

$$\log E = 11.8 + 1.5M \qquad (6)$$

The graph clearly exhibits periods with low and high seismicity (increase or decrease in number of events and / or increase or decrease in the magnitude). There are two high seismicity periods stated in (859) and (1117), respectively. These high seismicity periods were separated by period of low seismicity as shown in Figure (4). The Arabian plate appears relatively quite region for the period from (1194 until 1900). This period may appear hiatus in seismic activity or in documentation .The average annual release is corresponding to an earthquake of magnitude (6.2).

Discussion and Conclusions

The first objective for this study has been to compile historical catalog for the felt events in the SCRs of the Arabian plate. The second objective has been to analyze the historical seismicity of SCRs. We used several source catalogs as a database for our catalog. Some of source catalogs (e.g., the catalog of Triep and Sykes, 1996; the Catalog of Schulte and Mooney, 2004) contain information about the epicentral location and magnitude (Mw) for some events. Other source catalog (Alsinawi, 1988) contains detailed information about damage experienced. This offered possibility of giving a rough intensity estimate. If no magnitude estimate was available, nor areal intensity data, a cutoff intensity of (VII) on the Modified Mercalli scale (or conversions to it) was used.

Some of source catalogs contain information about the epicentral location (Lat.; Long.) for some events. Other source catalog reported the cities and countries affected by the events (e.g., Baghdad, Wasite, Iraq, ...etc.). In such cases, we considered the geographical coordinates of the cities affected by events, represent the approximate epicentral locations for those events. Though, these epicentral locations have not enough accuracy, they remain important for purposes of the seismicity and seismotectonic studies.

The estimated focal depths of the events indicate that events have shallow depths. SCRs seismicity is characterized by a shallow focal depths and deep focus is not commonly observed in SCR seismicity (Rajendran and Rajendran, 1999). Talwani (1989) found that with few exceptions most of intraplate earthquakes occur in the upper crust, at depths usually shallower than about (15 km). There are however a few locations where events have been observed at greater depths.

In our study, the b–value was low. The b–value for SCRs tend to be lower than those for plate boundary events, which are usually around (1). One possible explanation for this observation is that within the plate the rock are not as intensively fractured (Talwani, 1989). Shaik and Srivastava, 2003) said that b–value depends on the mechanical heterogeneity of the rock mass and increases with the increase in heterogeneity (intensive fractured rocks). Thus there tend to be fewer smaller events relative to larger events (low b–value) than would be the case in a plate boundary where because of greater abundance of fractures,

there would be a larger ratio of smaller events to larger events (large b–values).

This study led to the following conclusions :

1. A historical catalog for the felt events in the SCRs regions in the Arabian plate for the period from (600 to 1900 A.D.) was compiled.

2. The spatial distribution of SCRs seismicity shows cluster of events in the northern parts of the Arabian plate and absence of that in other parts. This may be attributed to concentration of the population centers in the northern parts (e.g., Baghdad, Wasite) relative to the other parts and / or to that the seismicity rate is very low.

3. The cumulative strain release curve exhibits two seismically active periods separated by period of low seismicity. There is a relative quite period extends from (1194 to 1900 A.D.). The average annual release corresponding to an earthquake of magnitude (6.2).

4. The b–value in frequency–magnitude relationship for the studied area was (0.47). This low b–value is a characteristic feature for SCRs earthquakes.

5. The focal depths of the SCRs earthquakes range from about (5 to 35 km). The Shallow focal depths is a remarkable feature for SCRs seismicity.

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Appendix (A)
Historical Earthquake Catalog of the SCRs Regions in the Arabian Plate .

Date A.D	Lat. (N°)	Long. (E°)	Region	Intensity	Depth (km)	M_w	Ref.No.
658	33.50	47.80				5.5	2
678	33.62	43.50	Dijlah &Tharthar	VII-VIII	25.95	6.3	1
749	35.46	42.60	Al-Hadr	IX–X	15.33	7.1	1
849	33.30	44.40	Baghdad	VIII	22.75	6.5	1
859Dec.	33.30	44.40	Baghdad	VIII	22.75	6.5	1
871	32.20	46.30	Wasit	VII	26.82	6.0	1
872	32.20	46.30	Wasit	VIII–IX	19.95	6.7	1
872June21	34.11	43.79	Samarra	VII–VII	25.95	6.3	1
873June	30.45	47.70	Basra	IX	19.30	7.0	1
880Nov.	33.30	44.40	Baghdad	VII	26.82	6.0	1
881Sep.29	33.30	44.40	Baghdad	VII			1

Date A.D	Lat. (N°)	Long. (E°)	Region	Intensity	Depth (km)	M_w	Reference No.
902June	33.30	44.40	Baghdad	IX	19.30	7.0	1
973Sep.	32.20	46.30	Wasit	VII–VIII	08.76	5.2	1&3
977	33.30	44.40	Baghdad	VII			1
1058Dec.08	34.30	44.70				5.6	3
1115	31.87	44.41	Kufa	IX–X	15.33	7.1	1
1117 May	33.30	44.40	Baghdad	VII	26.82	6.0	1
1130Feb.27	33.60	45.70				6.1	3
1135March	33.30	44.40	Baghdad	VII	26.82	6.0	1
1150	33.30	44.40	Baghdad	VII–VIII	25.95	6.3	1
1155	33.30	44.40	Baghdad	VI	34.90	5.6	1
1177	33.30	44.40	Baghdad	VII–VIII	25.95	6.3	1
1194March	32.00	44.30				4.7	3 & 4
1430	32.20	46.40				5.5	3
1457	31.90	46.90				5.7	3
1641	33.30	44.40	Baghdad	VI–VII	30.59	5.8	1
1680	34.50	41.80	Rawa	VI	34.90	5.6	1
1702	33.30	44.40	Baghdad	VII			1
1769	33.30	44.40	Baghdad	VII	26.82	6.0	1
1786July28	30.50	47.80				5.5	2
1827	33.20	46.10				4.8	3
1832	25.40	49.60				5.5	2
1862	35.45	44.40	Kirkuk	VII–VIII	25.95	6.3	1
1864Dec.07	33.30	45.90				5.9	3
1865	33.39	45.94	Jassan	VII	26.82	6.0	1
1867	33.83	45.50	Mandali	VII			1
1873	33.30	44.40	Baghdad			5.6	1

References : Alsinawi , 1988/ Seismic Studies Center- King Saud university, 1999 /Triep and Sykes,1996;(4) Schulte and Mooney , 2004.

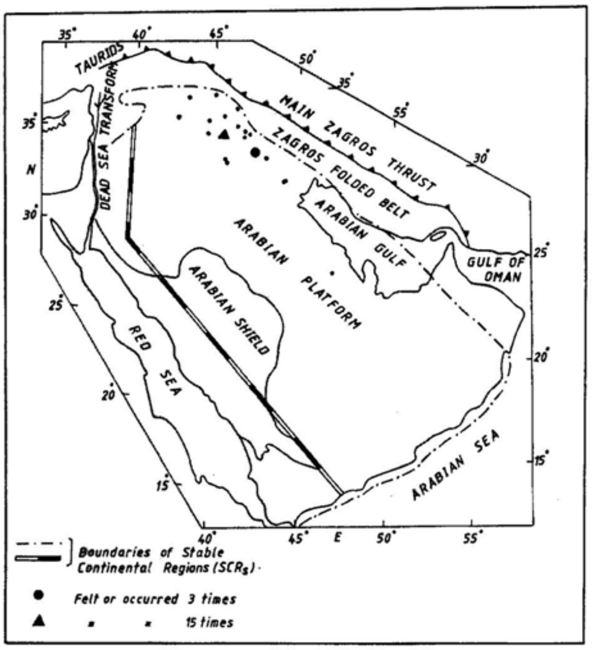

Figure (1) Spatial Distribution of SCRs Seismicity in the Arabian Plate.

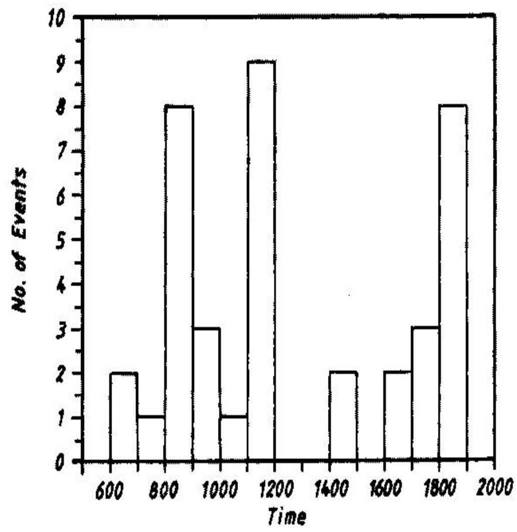

Figure (2) Temporal Distribution of the SCRs Seismicity in the Arabian Plate.

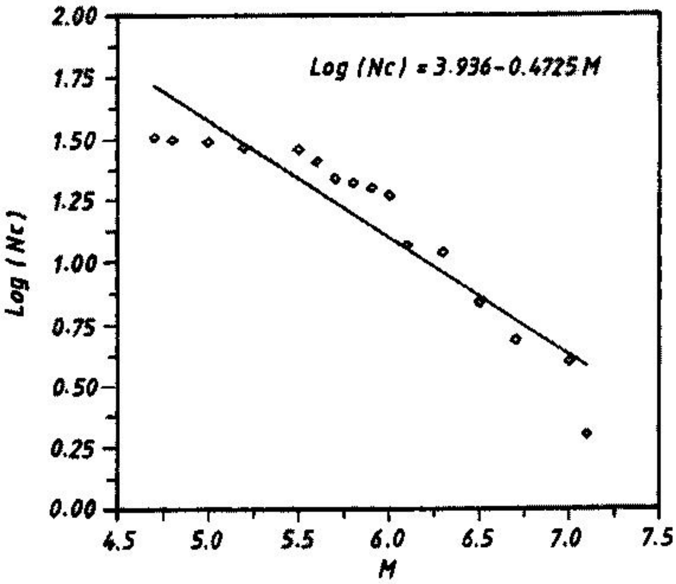

Figure (3) Frequency–Magnitude Relationship.

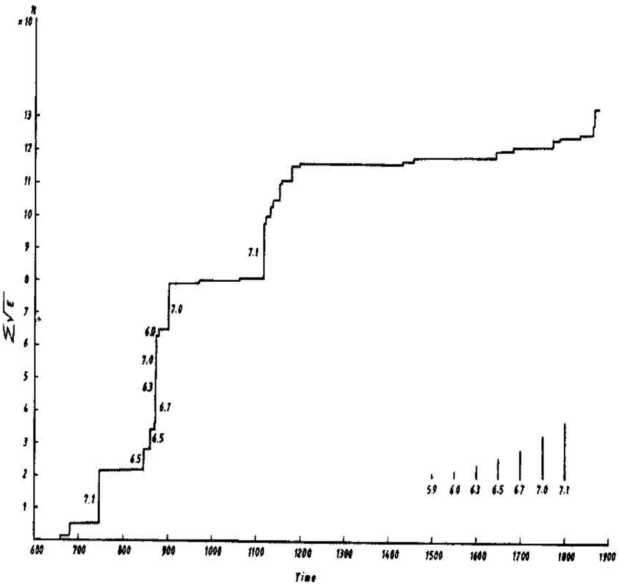

Figure (4) Cumulative Seismic Strain Release.

الزلزالية التاريخية للمناطق القارية المستقرة في الصفيحة العربية

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الخلاصة

تم إعداد فهرس بالهزات الأرضية التاريخية التي تم الإحساس بها في المناطق القارية المستقرة في الصفيحة العربية للفترة من 600 إلى 1900 بعد الميلاد. يبدو التوزيع المكاني لهذه الهزات بشكل تجمعات من الحوادث في الأجزاء الشمالية الشرقية وغياب الحوادث في الأجزاء الأخرى ، وربما يعزى هذا إلى تركيز مراكز الاستيطان في تلك الأجزاء نسبة إلى الأجزاءالأخرى و/ أو إلى أن مستوى الزلزالية كان واطئ جدا . تمتلك الهزات أعماقا بؤرية ضحلة وهذه ظاهرة مميزة للمناطق القارية المستقرة . يعرض منحني الطاقة المتحررة وجود فترتين تتميزان بنشاط زلزالي مرتفع تفصل بينهما فترة من النشاط الزلزالي الواطئ . توجد فترة هدوء نسبي تمتد من 1194 إلى 1900 ، وهذه الفترة ربما تبدو كفجوة في النشاط الزلزالي أو التوثيق . تكون قيمة الثابت (b)في علاقة التكرار- المقدار الزلزالي واطئة وهذه القيمة الواطئة هي ظاهرة مميزة للهزات في المناطق القارية المستقرة .