THE 11th March, 2013 EARTHQUAKE IN NORTH OF MOSUL VICINITY, NORTH IRAQ

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ABSTRACT

Iraq is located in the northeastern corner of the Arabian Plate, which is in collision with the Iranian (Eurasian) Plate. The contact between the two plates exhibits active seismicity forming active Zagros Seismic Belt. Mosul city and surroundings, although being far enough from this active seismic belt, still suffer from many earthquakes, which can be felt in a diameter of about 100 Km, the center being in Mosul city.

On the 11th of March 2013, at 5:58 pm, Monday a shock was felt in Mosul city and its surroundings to the northeast, north and northwest. The shock lasted for 5 seconds and was registered in Mosul Seismological Center with magnitude of 4.9 degrees on Richter scale. Two other shocks were recorded after few days. People in the villages located north of Mosul have heard high roaring, which accompanied the shock. Many old buildings, among them the church of Tell Asquf village was cracked and the plaster of the church's dome fell down in fragments. Many other mud huts and some buildings showed severe cracks in many other villages. No rupturing on the Earth's surface was reported in the involved areas. No live causalities and/ or wounded people were reported.

In this study, the historic seismicity of Mosul and near surroundings is reviewed. Few events, including historical earthquakes are mentioned too. Details of the present earthquake are given with documentary photographs. The effect of a reverse fault is thought to be the most reliable source for the shocks. Moreover, a fourth earthquake hit the northern part of the area; this was not recorded seismologically, therefore, field data were used to estimate the magnitude, using special charts, which indicate the estimated magnitude.

دراسة لزلزال يوم الحادي عشر من آذار لعام 2013 في منطقة الموصل، شمال العراق

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المستخلص

يقع العراق في الحافة الشمالية الشرقية من الصفيحة العربية والتي هي في حالة اصطدام مع الصفيحة الإيرانية (الأوروسية)، وان الحد الفاصل بين الصفيحتين يشهد نشاط زلزالي ويمثل نطاق زاگروس الزلزالي النشط. بالرغم من إن مدينة الموصل والمناطق المجاورة لها لا تقع بالقرب من هذا النطاق النشط، إلا أن المنطقة المعنية تشهد نشاطا زلزاليا والذي يمتد على مساحة قطرها حوالي 100 كم، ومركزها في مدينة الموصل.

بتاريخ 11 آذار من عام 2013 الساعة 5:58 مساء والذي صادف يوم الاثنين، حدثت هزة أرضية وشعر بها أهالي مدينة الموصل والمناطق الشمالية الشرقية والشمالية والشمالية الغربية منها. استمرت الهزة الأرضية لمدة خمسة ثواني وسجلت في مركز الرصد الزلزالي لمدينة الموصل بمقياس 4.9 درجات على مقياس ريختر. وان أهالي القرى

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الواقعة على أطراف مدينة الموصل سمعوا دويا هائلا صاحب الهزة الأرضية، أشبه بانزلاق كتل صخارية كبيرة على صفيحة معدنية، أعقبتها هزتان متتاليتان. وجراء الهزة الأرضية، تصدعت العديد من المباني الجديدة والقديمة ومن ضمنها كنيسة قرية تل أسقف، حيث تساقط الغطاء الجبسي لقبة الكنيسة وسقطت أرضا على أشكال قطع مختلفة الأحجام، وكذلك بعض الدور الطينية والمباني في العديد من القرى الموجودة في المنطقة، ظهرت فيها تصدعات متنوعة، ولكن لم تحدث تشققات في القشرة الأرضية ولم تقع إصابات أو خسائر بشرية.

تم التطرق في هذا البحث الى التاريخ الزلزالي لمدينة الموصل والمناطق المجاورة لها، مع ذكر بعض الحوادث التاريخية. وكذلك ذكرت تفاصيل عن الهزة الأرضية الأخيرة المسجلة في مدينة الموصل، مع بعض الصور التوثيقية عن الأضرار التي حدثت في المباني، إضافة الى ما ذكره بعض من أهالي المنطقة المعنية بالزلزال. وحدثت هزة أرضية رابعة لم تسجل في المرصد الزلزالي في الموصل، عليه استخدمت معلومات حقلية عن الأضرار الناجمة لتقدير شدة الهزة وذلك باستخدام جداول عالمية لتقدير شدة الهزات الأرضية.

INTRODUCTION

Mosul city is located in the central northern part of Iraq, which is tectonically located in the extreme northern part of the Arabian Plate. Mosul has a population of about 2 million. Its surroundings include large fertile plains with tens of villages, which still include some mud huts, and many monasteries, some of which are few hundred years old. Mosul and surroundings suffered from earthquake shocks, in historic times. Some of the events are well documented. However, all the recorded shocks are not considered as disasters.

▪ Location

The area involved in this study is located in Mosul city and its surroundings, especially at the northeast, north and northwest (Fig.1). The studied area includes many towns and tens of villages in which the shocks were felt. Those, investigated are: Shaikhan (Ain Sifni), Tell Kaif, Batnaya,Tell Asquf, Sharafiyah, Alqoh, Beristiq, Mahat, Bet Nar, Kani Sard, Quetan, Gadad, Taq Harb, Taq Mechiel, Nargizliyah, Sarishka, Khoshabin, Nafiriyah, Hatara, Badriyah and Faida (Fig.1).

▪ Aim

The aim of this study is to document the earthquakes and their damages, to collect data on the effect of four earthquakes that took place in the north of Mosul, to determine the relation between their epicenters and the regional geology of the area and to estimate the magnitude of the fourth shock that was not recorded in Mosul Seismological Center

▪ Materials Used and Methodology

In order to fulfill the aim of this study, the following data were used:

- Historical earthquake data, as available in historical books
- Data of Mosul Seismological Observatory
- Geological and structural maps of the studied area

The historical earthquake data was reviewed to indicate the recorded events and related damages, if any; such as Al-Hassany (1988) and Al-Warid (1989). Seismological data was reviewed to indicate seismic zonation (Al-Sinawi, 2006) and the zone where the studied area is located.

In order to collect data from the involved area, field work was carried out that included investigation of the studied area to check any rupture in the earth surface and mass movements. Local people were asked about the shock to indicate the details of the events, as described by the people in different parts of the area. Moreover, in the villages; old people were asked about old events they remember and what were the damages, causalities,

approximate dating and any other details. Furthermore, in the monasteries, notes written by the monks, concerning old earthquakes, were studied but no related data was found.

The data of the Mosul Seismological Observatory concerning the earthquake, including magnitude, coordinates and focal depth of the epicenter, lasting interval, timing, and the diameter of the involved area were acquired.

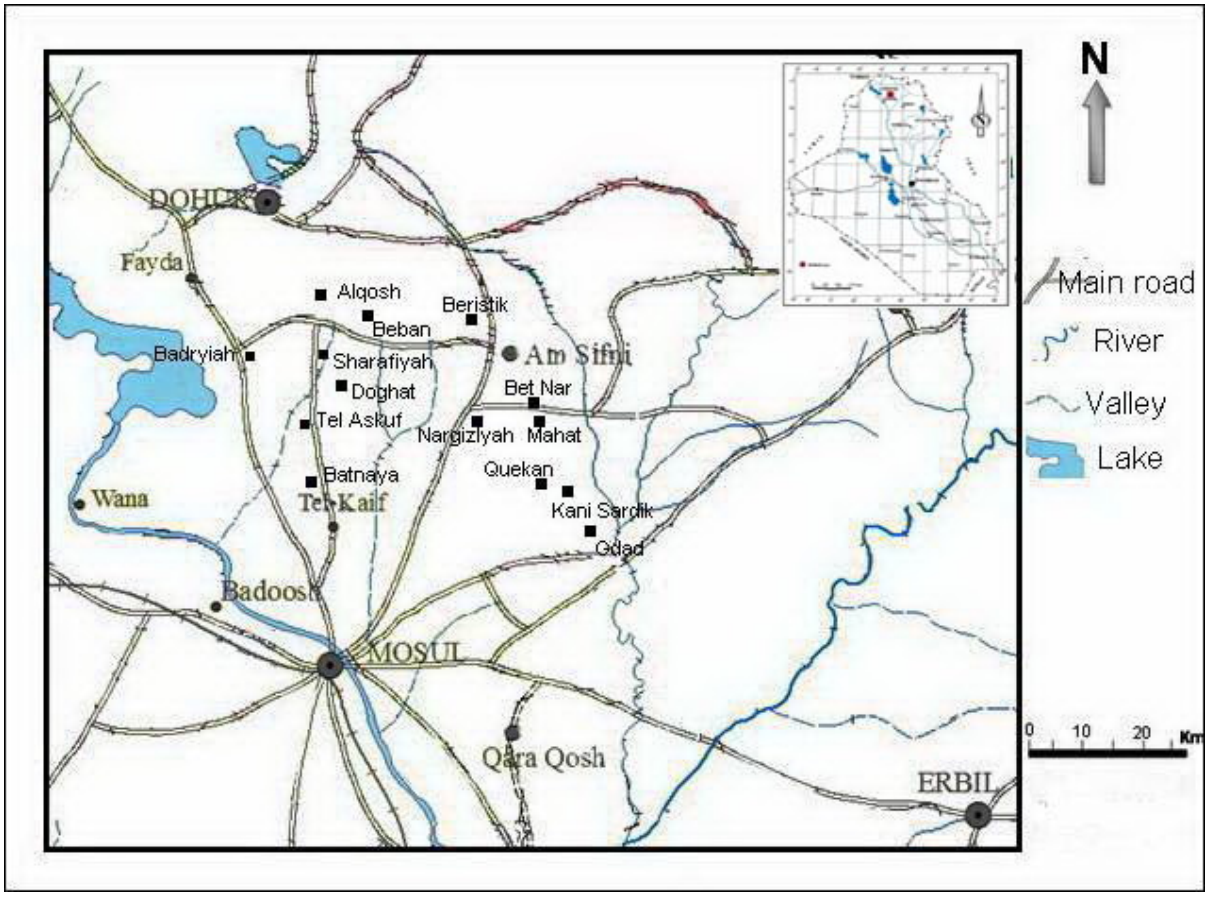

Fig.1: Location map of the studied area showing the investigated villages

GEOLOGICAL SETTING

▪ Structure and Tectonics

The studied area is located within the Unstable Shelf, Low Folded Zone, Cham Chamal – Butmah Subzone and partly within the High Folded Zone, (Al-Kadhmi *et al*., 1996 and Jassim and Buday in Jassim and Goff, 2006). However, according to Fouad (2012), the area is located within the Low Folded Zone of the Outer Platform of the Arabian Plate and partly within the High Folded Zone. The anticlines are long and narrow with NW – SE trend, almost asymmetrical. Kand, Ain Sifni and Maqloub anticlines are the most prominent structures in the area, which is a gently undulating area rising northwards until up to Alqosh and Ain Sifni mountains, which form the first outstanding ridge that makes the contact between the Low and High Folded Zones. One strike – slip fault and one thrust fault occur in the studied area. The majority of the area, from the neotectonic point of view, is uplifting about 0.4 cm/100 year (Sissakian and Deikran, 1998).

- **Stratigraphy**

The studied area is covered mainly by the clastics of Injana (Late Miocene) and Mukdadiya (Late Miocene – Pliocene) formations, both consist of cyclic sediments of sandstone and claystone; the sandstones of the latter is partly pebbly. In the western parts of the area, Bai Hassan Formation (Pliocene – Pleistocene) is exposed; it consists of coarse conglomerate alternating with red claystone in cyclic nature, with rare sandstone. The Fatha Formation (Middle Miocene) is exposed locally; it consists of cyclic sediments of red claystone, limestone and gypsum, the uppermost cycles include fine red sandstone. The Pila Spi Formation (Middle – Late Eocene) is exposed in the extreme northern part of the studied area; it consists of well bedded limestone, dolomitic limestone, dolomite and rare intercalations of marl (Sissakian, 2000 and Sissakian and Fouad, 2012) (Fig.2).

- **Geomorphology**

The studied area includes structural – denudational unit represented by anticlinal and monoclinal ridges forming the limbs of the existing anticlines. The Pila Spi Formation forms permanent ridge, which exhibits different types of mass movements, and well developed flat irons. The majority of the area is covered by thin mantle of depositional pediments. Some valleys have terraces and are filled by valley fill sediments. In areas where the Fatha Formation is exposed, karst features are well developed.

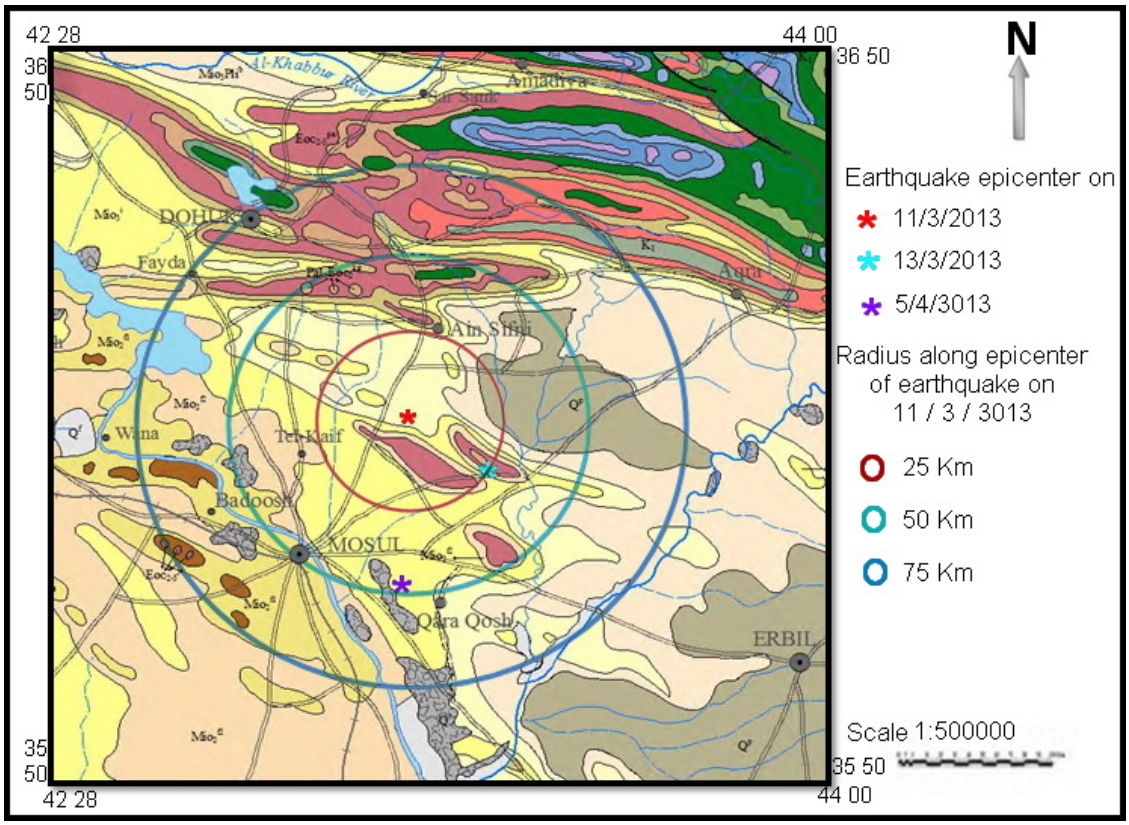

Fig.2: Geological map of the studied area (After Sissakian, 2000) showing three epicenters of the earthquakes and three circles with diameters of 25, 50 and 75 Km from the epicenter of the first earthquake

SEISMICITY

▪ Magnitude and Intensity

The severity of an earthquake is described by both **magnitude** and **intensity**. These two are frequently confused referring to different, but related, observations. **Magnitude is** usually express in **Arabic numeral** characterizing the size of an earthquake by measuring indirectly the energy released. By contrast, **intensity** indicates the local effects and potential damage produced by an earthquake on the Earth's surface as it affects humans, animals, structures, and natural objects such as bodies of water. Intensities are usually expressed in **Roman numerals,** and represent the severity of the shaking resulting from an earthquake. Ideally, any given earthquake can be described by only one **magnitude**, but many **intensities** since the earthquake effects vary with circumstances such as distance from the epicenter and local soil conditions. In practice, the same earthquake might have magnitude estimates typically differing by few tenths of a unit, depending on which magnitude scale is used and which data are included in the analysis (Hough, 2007).

▪ Historical Seismicity in Mosul and Northern Vicinities

Iraq has a long well documented history of seismic activity. Many seismic events have been documented for the period from 1260 BC through to 1900 AD. These historical events define a well established pattern of seismic activity, which correlates well with the geological and tectonic setting of the country and agrees with the modern epicenter determination after 1900 AD (Al-Sinawi and Ghalib, 1995 in Al-Sinawi, 2006).

Tens of earthquakes were recorded in the studied area and surroundings, with different magnitudes. According to Scientific Research Council (SRC) (1985), the following epicenters were recorded (in Richter scale):

- 2 epicenters of magnitude (4 – 5) degrees with focal depth range (0 – 33) Km
- 2 epicenters of magnitude (4 – 5) degrees with focal depth range (34 – 59) Km
- 1 epicenter of magnitude (5 – 6) degrees with focal depth range (60 – 95) Km

Moreover, SRC (1985) has reported about 6 historical earthquakes that happened in Mosul city. The collapse of the Hatra town, about 100 Km south southwest of Mosul; is referred as due to an earthquake (ATOMOENERGOEXPORT, 1985). According to Al-Warid (1989) five historical earthquakes were recorded in Baghdad and were felt in Mosul, Tikrit, Anah and Al-Jazira vicinity; in 1118, 1134, 1178, 1208 and 1648. Among the most recent events in the mid eighties of the last century, which caused damage to many houses is the earthquake of Al-Jirn village, about 35 Km south of Mosul; no causalities were reported.

According to Al-Sinawi (2006), the following epicenters were recorded:

- 1 epicenter of $5.4 < Sm > 5.9$
- 1 epicenter of $4.8 < Sm > 5.3$
- 3 epicenters of $4.2 < Sm > 4.7$
- 2 epicenters of $3.6 < Sm > 4.1$
- 2 epicenters of $3.0 < Sm > 3.5$

Moreover, Al-Sinawi (1996) in Al-Sinawi (2006) mentioned that "The seismicity of Iraq is of intermediate character and of shallow focal depths. The seismicity of the folded area is due to forces resulting from the movements of the Arabian Plate towards the north and northeast. The forces that formed the major geological structures along the plate boundaries are still active, causing stress and strain accumulation and deformation. The overall seismicity of Iraq is influenced mainly by the Zagros and Taurus systems with partial neotectonic activation of the upper crust".

- **Seismic Zoning**

The studied area is located within the Zones VIII and IX of the Historical Isointensity Map of Iraq (Al-Sinawi and Al-Qasrani, 2003, in Al-Sinawi, 2006). Moreover, the area is located near the Zagros Line Source (Al-Sinawi and Hamad, 1992, in Al-Sinawi, 2006).

The studied area is located within the Isointensity Zones V and VI (Al-Sinawi, 2006). The former is characterized by minor earthquake damages, whereas the latter is of moderate damages.

According to the Seismicity Index Map of Iraq (Al-Sinawi and Al-Qasrani, in Al-Sinawi, 2006), the studied area is located in three zones with values of Seismicity Index number (ST) 0.1, 0.2 and 0.3, respectively. This means that the area suffers an earthquake with magnitude $M \geq 4.0$ every (2 – 5) year.

According to the Seismic Acceleration Map of Iraq with design period of 100 years (Al-Sinawi, 2006), the studied area is located in a zone of (0.4 – 0.5) g. The minimum and maximum values of the zones in Iraq are (0.1 – 0.2) g and (0.8 – 0.9) g, respectively, the latter being in the extreme northern part of Iraq, whereas the former runs almost parallel to the Euphrates River.

THE PRESENT EARTHQUAKES

- **General**

On Monday, the 11th of March 2013 at 5:58 pm, an earthquake occurred in Mosul and its northern vicinity to about (60 – 70) Km. The earthquake was of magnitude 4.9 degrees on the Richter scale and lasted 5 seconds. In the northern village, of Tell Asquf, which is about 35 Km north of Mosul, the shock was felt more vigorously and was accompanied by roaring sound that frightened the villagers. Accordingly, the plaster of Mar Yacoub (Saint Jacob) church's dome cracked and failed.

A second earthquake occurred in the same vicinity on Wednesday, the 13th of March, 2013 at 9:00 am, with magnitude of about 4.5 degrees on the Richter scale and lasted for about 4 seconds. A third earthquake occurred in the same vicinity on the 5th of April at 8:00 pm and a fourth one occurred on the 9th of May at 6:15 am. The last three earthquakes were in decreasing magnitudes; hence the last one was not felt in Mosul, but only in the Shaikhan vicinity.

The locations of the three epicenters are shown in Figs. (2 and 3), whereas the fourth one is unknown, because it was not felt in Mosul. The epicenters and magnitude of the three earthquakes are shown in Table (1).

Table 1: Locations and magnitudes of the four earthquakes
(Mosul Seismological Center)

Location		Date	Magnitude (Richter scale)	Time	Lasting time(Sec)
Latitude	Longitude				
36° 33' 29"	43° 19' 43"	11/03/2013	4.9	5:58 pm	5
36° 28' 50"	43° 26' 41"	13/03/2013	4.5	9:00 am	4
36° 18' 12"	43° 18' 31"	03/04/2013	4.5	8.00 pm	4
Unknown	Unknown	09/05/2013	3 – 3.5*	6:15 am	Unknown

*Estimated from field observations based on mentioned data in Tables (2, 3 and 4)

▪ **Field Investigation**

To observe the effects of the earthquakes in the studied area, tens of villages were visited (Fig.1) and the villagers were questioned for the indications and/ or the effects. More attention was paid for those located near the epicenter of the main involved earthquake. Usually, the teachers of schools, old people and the mayors of the villages were asked for the followings:

- How the shock was felt.
- If the shock was accompanied by a sound.
- If some houses and/ or buildings were collapsed and/ or cracked due to the earthquake.
- Any rapture found in the village or nearby vicinity.
- If some kitchen stuff/ and or any of the furniture collapsed.
- If some of the animals has exhibited any abnormal movements and/ or sounds.
- If they remember old earthquakes in their residential areas.
- If some landslides occurred, especially those villages, which are located near the mountains.

▪ **The Collected Data**

The collected field data from the investigated villages can be summarized as follows:

- The shock was felt very clearly in the majority of the investigated villages, beside Mosul and Shaikhan. However, the fourth shock was felt only in Shaikhan town and Mahat village (Figs.1 and 2).
- Vigorous sound was heard accompanying the shock. Local people described it as scratching sound of fallen large blocks on a metal plate. The sound was heard in Tell Asquf village, as the farthest one from the epicenter of the related epicenter. The sound of the fourth shock, however, was described in Mahat village as the sound of flowing water along a waterfall.
- Within the investigated villages, tens of houses were cracked to different degrees, but none were collapsed. The cracks were usually in zigzag forms in the fences, roof fences, walls, ceilings, and foundations. The length and width of the cracks are variable, depending on the type and age of the houses; some of these are yet not completed, and the location of the village, relative to the epicenter. The lengths and width of the cracks range from (2 – 10) m and (1 – 4) cm, respectively. However, some mud huts were collapsed.
- No rapture was found in the investigated area, neither was found by the villagers.
- Many kitchen staff fell down and/ or clearly shocked. In Mahat village, in one of the houses, a TV set was toppled from its table.
- No abnormal behavior of animals was recognized by the villagers. The authors believe that the villagers were not concentrating to receive this phenomenon, as they are not familiar with such events. Moreover, the timing of the shocks in all these earthquakes was not favorable for the villagers to recognize the phenomenon.
- None of the villagers remembered old earthquakes in their residential areas or nearby vicinity. The visited monasteries did not include such events in their documentaries.
- No landslides were mentioned by the villagers, neither was seen during the field investigation, by the authors.

RESULTS

An earthquake shocked Mosul city and the northern vicinities on the 11th of March, 2013; other two shocks took place on the 13th March and 5th of April, respectively. The epicenters of the earthquakes and, their magnitudes are listed in Table (1). Moreover, a fourth earthquake took place on the 9th of May, 2013, but this one was felt only in the extreme northeastern part of the studied area.

Data is collected on the effect of the earthquakes during field investigation in tens of villages in the studied area. The effect of the main earthquake, which took place on the 11th of March, 2013 was very clear in many villages, including cracks of houses and buildings, collapse of mud huts and was accompanied by vigorous roaring sound. The effect of the other three earthquakes is not as clear as that of the first one. The epicenters of the first two earthquakes are located near a reverse fault along the southwestern limb of Maqloub anticline. The magnitude of the fourth earthquake is estimated from the collected field data based on special instructor Tables (2, 3 and 4).

DISCUSSION

The epicenter of the earthquake of 11th March and the following one (of 13th March) are located along a thrust fault, which runs almost NW – SE, parallel to the main anticlines in the studied area (Sissakian, 1995). The third one (of 5th April) is located more southwards, (Fig.2). The authors believe that the thrust fault, although not deep as the epicenters, had played a big role in the concentration of the main earthquakes and the rebounding shocks.

The fourth earthquake (of 9th May) was felt only in Shaikhan town and Mahat village (Figs.1 and 2), which is located in the extreme northeastern part of the studied area and was not felt in Mosul Seismological Center. It is also located along a longitudinal fault (Sissakian, 1995). It had very limited effect on the mentioned village, where small cracks appeared in two houses, and in one of them a TV set was toppled. These data were used to estimate the magnitude of the earthquake depending on the data mentioned in Tables (2, 3 and 4) as no seismological center in the area exists. Therefore, and because the event was not recorded in Mosul Seismological Center, the authors estimated the magnitude of the earthquake to be in the range of (3 – 3.5) degrees on the Richter scale.

Depending on earthquakes classification in categories ranging from Minor to Great, which is based on their magnitude (Table 1), the first three earthquakes in the studied area are classified as Light, whereas the fourth one is classified as Minor (Table 5). However, depending on Mercalli Intensity scale (Table 4) the first three earthquakes are Light earthquakes with (IV – V) degrees, whereas the fourth one is a Minor earthquake with intensity of (III – IV) degrees.

Table 2: Earthquake Severity (Richter scale) (Fréchet *et al*., 2008)

Magnitude (Richter)	**Earthquake Effect**
Less than 3.5	Generally not felt, but recorded
3.5 – 5.4	Often felt, but rarely causes damage
5.5 – 6.0	At most slight damage to well-designed buildings. Can cause major damage to poorly constructed buildings over small regions
6.1 – 6.9	Can be destructive in areas up to about 100 Km across where people live
7.0 – 7.9	Major earthquake. Can cause serious damage over larger areas
8 or greater	Great earthquake. Can cause serious damage in areas several hundred kilometers across

Table 3: Earthquake Severity (Richter scale) (Fréchet *et al*., 2008)

Magnitude	Earthquake Effect
2.5 or less	Usually not felt, but can be recorded by seismograph
2.5 – 5.4	Often felt, but only causes minor damage
5.5 – 6.0	Slight damage to buildings and other structures
6.1 – 6.9	May cause a lot of damage in very populated areas
7.0 – 7.9	Major earthquake. Serious damage
8.0 or greater	Great earthquake. Can totally destroy communities near the epicenter

Table 4: Description of earthquake effects
(Based on U.S. Geological Survey document, 2012)

Magnitude (Richter)	Description	Intensity (Mercalli)	Average Earthquake Effect	Average Frequency of Occurrence (estimated)
Less than 2.0	**Micro**	**I**	Micro earthquakes, not felt, or felt rarely by sensitive people. Recorded by seismographs (Fréchet *et al*., 2008)	Continual/ several million per year
2.0 – 2.9	**Minor**	**I** to **II**	Felt slightly by few to many people. No damage to buildings.	Over one million per year
3.0 – 3.9		**II** to **IV**	Often felt by at least some people, but very rarely causes damage. Shaking of indoor objects can be noticeable	Over 100,000 per year
4.0 – 4.9	**Light**	**IV to VI**	Noticeable shaking of indoor objects and rattling noises. Many people to everyone feel the earthquake. Slightly felt outside. Generally causes none to slight damage. Moderate to significant damage very unlikely. Some falling of objects.	10,000 to 15,000 per year
5.0 – 5.9	**Moderate**	**VI** to **VIII**	Can cause moderate to major damage to poorly constructed buildings. At most, none to slight damage to all other buildings. Felt by everyone. Deaths can depend on the effects.	1,000 to 1,500 per year
7.0 – 7.9	**Major**	**VIII** to **XII** (AK, 2012)	Causes damage to many to all buildings over areas. Some buildings partially or completely collapse or receive severe damage. Well-designed structures are likely to receive damage. Felt in enormous areas. Death toll is usually between none and 250,000	10 to 20 per year
8.0 – 8.9	**Great**		Major damage to poorly-designed buildings and most structures, likely to be destroyed. Will cause moderate to heavy damage to normal and earthquake-resistant buildings. Damaging in big areas. Possible total destruction. Definitely felt in unusually large regions. Death toll is usually between 100 and one million; however some earthquakes of this magnitude have killed none	One per year (rarely none, two, or over two per year)
9.0 – 9.9			Severe damage to all or most buildings with massive destruction. Damage and shaking extends to distant locations. Ground changes. Death toll usually between 1,000 and several million	One per 5 to 50 years

Table 5: Classification of earthquakes according to their magnitudes
(after U.S. Geological Survey, 2012)

Class	**Magnitude** (Richter scale)
Great	8 or more
Major	7 – 7.9
Strong	6 – 6.9
Moderate	5 – 5.9
Light	4 – 4.9
Minor	3 – 3.9

The investigated villages showed different earthquake affects, especially on houses and buildings. The effects were clearly indicated by different cracks, their severity depends on the location of the village, relative to the epicenters, age of the affected houses and/ or buildings and the type of the construction materials. Figures (3 – 9) are different examples from the affected houses and buildings in the investigated villages.

Fig.3: The cracked dome of Mar Yacoub Church (left),
the fallen plaster pieces (right) in Tell Asquf village

Fig.4: General view of Beristiq village in Shaikhan vicinity

Fig.5: Collapsed mud huts in Beristiq village

Fig.6: Two houses in Beristiq village showing cracks in concrete foundation (**left**) and wall (**right**)

Fig.7: Cracks in roof fences of a house in the Youth Centre in Shaikhan town

Fig.8: Crack in a fence of a house (**left**) and a wall in recently built mosque (**right**), in Shaikhan town

Fig.9: Cracks in a roof fence of the youth center in Shaikhan town

The most affected houses in the studied area were in Shaikhan town and Beristiq village (Figs.4, 5, 6, 7, 8, and 9), which are far from the epicenters of the earthquakes, as compared to the other affected villages (Figs.1 and 2). The drawn three circles with diameters of 25 Km, 50 Km and 75 Km, respectively show the distance of the affected aforementioned localities from the epicenter of the first earthquake. The effect of the earthquake in Shaikhan town and Beristiq village could be attributed to the presence of a strike – slip fault, which runs in NNW – SSE direction (Sissakian, 1995 and Fouad, 2012). The mentioned fault dissects

Ain Sifni anticline and extends southwards to dissect Maqloub anticline and meets the thrust fault along which the epicenters of the first two earthquakes are located. The weakness zone along this fault, most probably had contributed to the severe effect of the earthquakes as compared to the other investigated villages.

According to the recorded epicenters, the location of the first earthquake is in Kani Sardiq village (Figs.1 and 2). However, in this village no effect was seen on the houses, as discussed with the villagers, although they felt the shock and heard a roaring sound. No effect was observed in the nearby villages of Gadad, Taq Harb and Taq Mechiel (Figs.1 and 2). The most affected locations are in Shaikhan, Beristiq and Mahat; although they are far from the epicenter of the earthquake. Figure (1) shows the southwestern limb of Ain Sifni anticline, and more specifically the flexure point of the southwestern limb. Moreover, the presence of a strike slip fault (Sissakian, 1995 and Fouad, 2012) in the area, had contributed to the increasing effect of the earthquake.

It is worth mentioning that local people in the investigated area believe that the reason for the recently occurred earthquakes is the oil production operations that recently had started in the area. Moreover, many other earthquakes have occurred in the area after writing this article.

CONCLUSIONS

From this study, the followings can be concluded:

- The epicenters of the first and second earthquakes are located along a reverse fault that runs along the southwestern limb of Maqloub anticline.
- The epicenter of the first earthquake is located in Kani Sardiq village, which shows no effect on its houses.
- The first three earthquakes were felt in all investigated villages, as well as in Mosul city.
- The shock was accompanied by a vigorous roaring sound, which was described by the villagers as the sound of fallen large rock masses on a metallic plate.
- The most affected area is located along the southwestern limb of Ain Sifni anticline, which is about 25 Km northwest of the epicenter. This is attributed to the presence of a strike slip fault; close to the area of study.
- The first three earthquakes were of Light type, whereas the fourth one was of Minor type; both on Richter and Mercalli scales, with magnitudes of 4.9, 4.5 and 4.5 degrees, respectively, and with estimated magnitude of (3 – 3.5) degrees for the fourth one. According to Mercalli scale, the first three earthquakes have intensity of IV – V, whereas the fourth one is of estimated intensity of III – IV.

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