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Macroseismic survey and geological investigations following the Al Hoceima (Morocco) earthquake of February 24, 2004

Le séisme d´Al Hoceima (Maroc) du 24 février 2004 ; macrosismicité et investigations géologiques

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Abstract. The Al Hoceima region of northern Morocco experienced an earthquake of magnitude Mw 6.4 on February 24, 2004, the strongest recorded in the region until then. This earthquake was devastating in a radius of about thirty kilometers around and was felt several hundred kilometers from the epicenter. In this paper, we present results of field investigations carried out in the Al Hoceima region following this event, which allowed the implementation of a macroseismic survey and an analysis of changes in surface geology. The macroseismic questionnaires collected from the population and the regional services of various departments made it possible to compile the isoseismal map of the main event.

We found a macroseismic intensity of IX in the locality of Ajdir where the instrumental epicenter is located, while the maximum intensity of X was recorded few kilometers away in the localities of Imzourène and Béni Bouayyach, since the damage observed there is slightly higher than that in Ajdir. We attribute this maximum intensity at these two urban centers to amplification due to seismic site effects. The macroseismic map thus compiled, further shows that the isoseists have a submeridian direction, suggesting that the fault that generated the main shock is of the same direction.

Geological investigations carried out in parallel with our macroseismic investigation allowed us to find numerous ground instabilities and fissures, the majority of which consist of collapses and detachment of blocks, mudslides and landslides. They were triggered and, in some places, reactivated under the effect of the February 24, 2004 earthquake. These ground movements occurred in places mostly with steep slopes. These geological observations are the result of fresh manifestations that allow to link them to seismic activity. This freshness was further confirmed by the testimony of population and residents.

Keywords: Macroseismicity, geological investigations, land instabilities, Al Hoceima, Morocco.

Résumé. La région d'Al Hoceima au nord du Maroc a connu le 24 février 2004 un séisme de magnitude Mw 6.4, le plus fort enregistré dans la région. Ce séisme fut dévastateur dans un rayon d'une trentaine de kilomètres et fut ressenti à plusieurs centaines de kilomètres de l'épicentre. Les travaux de terrain effectués dans la région d´Al Hoceima à la suite de ce séisme ont permis de réaliser une enquête macrosismique ainsi que l´analyse des modifications survenues au niveau de la géologie de surface. Le dépouillement des questionnaires macrosismiques collectés auprès des populations et des services régionaux des différents départements a permis d´élaborer la carte d´isoséistes de l'évènement majeur.

Une intensité macrosismique de IX a été relevée dans la localité d´Ajdir où a été localisé l´épicentre instrumental. Par contre, l'intensité maximale de X a été enregistrée dans les localités d´Imzourène et de Béni Bouayyach, vu que les dégâts constatés sont légèrement supérieurs à ceux d'Ajdir. Cette intensité maximale est attribuée vraisemblablement pour ces deux lieux à l´effet de site. La carte macrosismique ainsi compilée montre que les isoséistes présentent une allure subméridienne, suggérant ainsi que la faille qui a généré le choc principal est de même direction.

Les investigations géologiques menées parallèlement à l´enquête macrosismique ont abouti à la localisation de nombreuses instabilités de terrain et des fissures dans le sol, dont la majorité sont des écroulements et détachements de blocs, des éboulements et des glissements de terrain. Elles ont été déclenchées et par endroit réactivées sous l´effet du séisme du 24 février 2004. Ces mouvements de terrain ont été localisés dans les endroits où la pente élevée est importante. Des manifestations fraîches permettent de relier ces observations géologiques à l'activité sismique. Cette fraicheur a été en outre, confirmée par le témoignage des populations et des riverains.

Mots-clés : Macrosismicité, investigations géologiques, instabilités de terrain, Al Hoceima, Maroc.

INTRODUCTION

On February 24, 2004, at 2:27 am, the Al Hoceima area was struck by a strong earthquake of magnitude M 6.4 on the Richter scale. The hypocenter of this event is located in the rural municipality of Ait Youssef Wali (35,203 ° N 3.901 ° W) about 10 km south of the city of Al Hoceima (El Mouraouah *et al.* 2004), with an estimated depth of 7 Km. It was recorded by more than fourteen (14) seismic stations of the Moroccan telemetry network. This shock was felt in a radius of 300 km around the epicenter in several provinces of northern Morocco and southern Spain.

This earthquake caused a death toll of about 700 people and caused the injury of several hundred people. Many rural habitations made of clay, stone and wood were totally destroyed. In addition, hundreds of solidly built houses were completely destroyed or seriously damaged, which made thousands of people in the area, homeless. Similarly, the earthquake triggered numerous land instabilities and ground fissures.

The very day of the earthquake, fieldwork was organized and initiated in the disaster area. The goal was two-fold. First, deploy a local dense seismic network of seismographs to monitor the seismic crisis and the evolution of the seismicity of the region. Second, carry out a macroseismic survey and undertake analysis of the geological effects of the earthquake on the environment in the region.

The Al Hoceima region is the most seismically active region of Morocco. Indeed, the study of the historical seismicity of Morocco (El Mrabet 1991) revealed that this region has historically experienced many destructive earthquakes. More recently, this region was shaken by a magnitude Mw 6.0 earthquake on May 26, 1994 (eg Calvert *et al.* 1997, El Alami *et al.* 1998) followed by several hundreds of aftershocks, many of which were felt by the population. This 1994 event engendered a maximum intensity of VIII on the MSK-64 intensity scale (Medvedev *et al.* 1963) and was particularly destructive. It caused many slopes and coastal cliffs instabilities and also caused partial and occasionally total destruction of several buildings. This region is known for frequent landslides that can be damaging to the habitat, the roads and the infrastructure.

In this paper, we present the results of our macroseismic survey that we started on the same day of the advent of the February 24, 2004 earthquake. We present as well our results relative to the study of land instabilities in a number of localities in the affected area.

GEOLOGICAL SETTING

The Rif is undoubtedly the region in Morocco most affected by various land instabilities. These phenomena impact the natural environment and present a major and permanent threat to the buildings and the roads infrastructure. Various scientific studies have reported these phenomena and focused on landslides at specific regions of the Rif such as Maurer (1968), El Mrabet (1991), El Fellah (1994), Fares *et al*., (1994), Margua (1994), El Fellah *et al*. (1996), Talhaoui *et al*. (1999), Azzouz *et al*. (2002), El Fellah & Chalouan (2002), El Khattabi *et al*. (2002), El Mouraouah *et al*. (2004), Talhaoui *et al*. (2005), Nachite (2009), RMSI (2012), El Fellah & Mastere (2015), Yazidi *et al*. (2017), Labriki *et al*. (2017), Rfifi & Ait Brahim (2018), Labriki *et al*. (2019) and Mastere *et al*. (2020).

These studies reported a combination of a number of factors that cause land instabilities. For instance, Talhaoui *et al*. (2005) undertook a study of the geological risks in connection with seismic activity in the region of Al Hoceima (Morocco), based on the identification of recent changes which affected geological formations, following the 1994 Al Hoceima seismic earthquake. This study allowed identifying a number of parameters that link seismicity to ground instabilities. A quantification of the major factors responsible for triggering these instabilities shows that the slope and seismic activity are the leading factors in the occurrence of landslides.

The area, affected by the Al Hoceima 2004 earthquake, is located in the eastern part of the Bokoya Massif (Fig. 1). This area is bounded to the north and east by the Mediterranean Sea, and to the south by the Tisirène flyschs with a rugged topography (Fig. 1). The northwestern, northern and northeastern parts are dominated by very steep cliffs.

The Al Hoceima region belongs to the internal domain of the Rif belt. It is marked by a stack of several structural units separated from each other by thrust faults and unconformities. Among these units, the external limestone dorsal “la dorsale calcaire” which is essentially formed of rigid carbonate materials (flint and dolomite limestones) displaying remarkable topographic highs, particularly on the Mediterranean coast of the Al Hoceima region (Fig. 2).

MACROSEISMIC OBSERVATIONS

Fieldwork

Since the magnitude M5.9 Agadir earthquake in 1960, the main shock of Al Hoceima, which took place on February 24, 2004, magnitude M6.4 is the second major destructive event that Morocco knew during a century-long period. All seismic studies on this event concluded that the hypocenter was located at a depth between 5 km and 13 km. Immediately following this earthquake, several studies were carried out dealing mostly with its seismicity and seismological aspects (e.g., Jabour *et al.* 2004, Talhaoui *et al.* 2004, Stich *et al.* 2005). However, a study by Ait Brahim *et al.* (2004) focused on surface deformations including a macroseismic survey of some of the affected area. This survey was rather provisional and only few seismic sites were surveyed.

During the three weeks that followed the main shock (from February 24 to March 15, 2004), the population of the region affected by this event was surveyed in order to investigate about the effects felt during the main earthquake. The goal is to translate the damage caused and the perception of the event to seismic intensities and thus, compile a macroseismic study of this event.

During the first three days after the main shock, it was difficult to communicate with the affected people. The occurrence of relatively strong-magnitude aftershocks had a major psychological impact on a large population. When moving away east or west from the most affected cities (Imzourène and Ajdir; cf. Fig. 3), it became clear that the area affected by the quake was rather quite large. In order to avoid the chaotic atmosphere that prevailed around the strongly affected area, it was necessary to start our macroseismic survey rather in remote areas.

The reconnaissance survey on the ground was completely carried out by a team of the Geophysical Laboratory of the CNRST. It was decided to avoid distributing the questionnaires since the population was still frightened. Instead, the investigating team filled up the questionnaires after questioning people in the affected zones. More than 350 effective questionnaire responses are obtained covering this area.

Macroseismic Survey

In overall, more than fifty localities were visited. The macroseismic survey was carried out with detailed inspections of the buildings located in the damaged areas. The questionnaires collected during field work were processed for evaluation of felt intensities in the different surveyed sites. The analysis of these questionnaires allowed assigning intensity values to the visited sites according to the MSK-64 intensity scale (Medvedev *et al.* 1963). We adopt this scale since it is the most used one in Morocco for assessing earthquakes caused damages. The MSK-64 scale takes intensity values from I to XII and has the advantage to take into account the quality and type of constructions (type A-clay house, mud, mud-bricks, rural houses, stone buildings, Type B - constructions in ordinary bricks or concrete blocks, mixed masonry-wood constructions, stone block structures and Type C reinforced concrete constructions, wooden constructions).

It is also important to mention that this scale has five grades of damage to buildings; from grade 1 corresponding to slight damage (plaster cracking, falling of small plaster debris, etc.) to grade 5 corresponding to the total collapse of the construction considered. In addition, the effects seen in the MSK scale concern both people and their environment, any kind of structures and natural sites.

The distribution of the intensities thus documented, helped compiling an isoseismal map for the February 24, 2004 Al Hoceima earthquake (Fig. 4). Figure 4 shows that in the locality of Ajdir, where the instrumental epicenter was determined, there is an intensity of IX on the MSK-64 scale. However, a slightly higher intensity of X is located south-east of Ajdir, in the cities of Imzourène and Beni Bouayach where class C buildings (reinforced concrete constructions) have suffered damage of grade 5 (total collapse of the building) and many affected by grade 4 damage (wall breaches and partial collapses). It is important to note that these two localities are located in the Bas-Nekor Basin which is in fact a deep basin delimited by the NNW-SSE fault of Imzourène and the Trougout N-S fault. This basin has accumulated quaternary alluvial deposits ranging in thickness from 400 to 500 m (Meghraoui *et al.* 1996). The significant depth of this basin

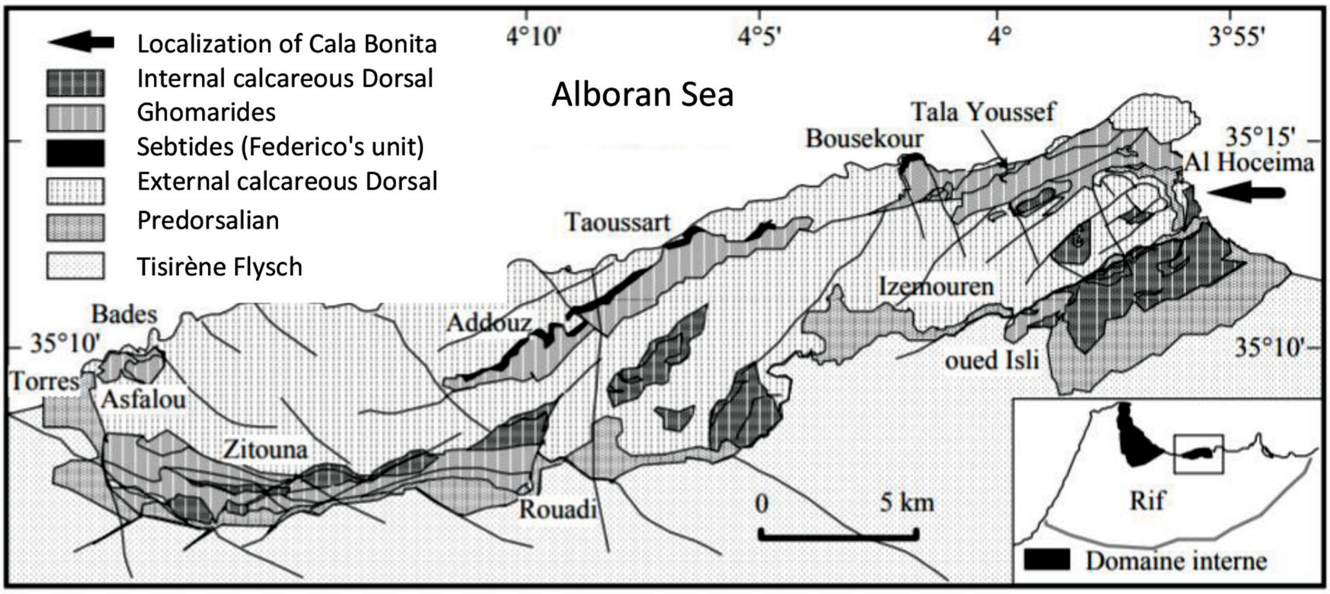


Figure 1. Structural map of the Bokoya Massif (after Azzouz *et al.* 2002).

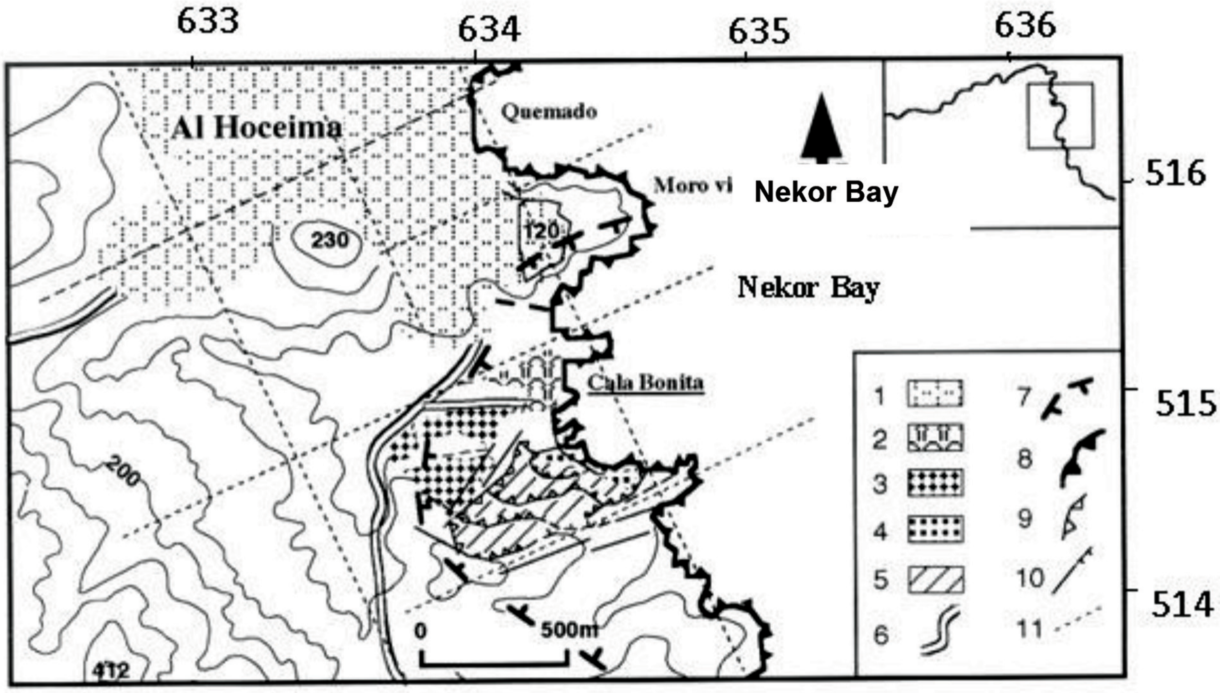


Figure 2. Topography map of the surroundings of the Al Hoceima city, showing the Cala Bonita landslides. 1, urban area; 2, camping; 3, recent dwellings; 4, rubble and debris; 5, flats; 6, main road; 7, zone which depends on the coastal dynamics; 8, sea cliffs >50 m; 9, cliffs related to landslides; 10, fissures-cracks and secondary ruptures; 11, alignment of the main neotectonic faults (after Azzouz *et al.* 2002).

and its filling by recent sedimentary deposits has probably induced an amplification of the seismic waves at these two localities and thus, generated higher intensities than the one documented at the level of the instrumental epicenter in Ajdir. We thus, attribute this higher (X) intensity to seismic site effects since these localities are few kilometers away from the instrumental epicenter.

A maximum intensity of VIII is estimated in the majority of localities to the west and south-west of Al Hoceima, where constructions are mostly class B buildings. The majority of class B buildings suffered grade 3 damage (light and deep cracks in the walls), few have suffered damage grades 4 or 5. Some type C houses, identified at this level, suffered grade 1 to 2 damages.

Further west, a maximum intensity of VII has been noted in areas Rouadi and Beni Hadifa, where most houses are solidly built (class C). In these areas, no serious pathology has been identified, the buildings were marked by the grade 1 damage. The same remark can be made about the coastal area on the east side of the lower Nekor depression. (Hdid, Trougout, Iouerdijène and Imyayen).

Nevertheless, in the cities of Snada, Beni Boufrah and Torres El kal'a to the west and Beni Bou Ya'koub, Kourouna and Boudinar to the east (Fig. 3), although the damage affecting the constructions allows to evaluate the intensity felt to VI, the fear and panic seriously affected the populations in these areas.

The delimitation of the isoseismal zones allowed to compile an isoseismal map of the earthquake of February 24th, 2004 (Fig. 5). This map shows that the seriously damaged area is delimited by an epicentral area with a sub-meridian principal direction. The Other isoseismal curves roughly follow the same direction and suggest that the fault that gave rise to the main shock is probably in the same direction.

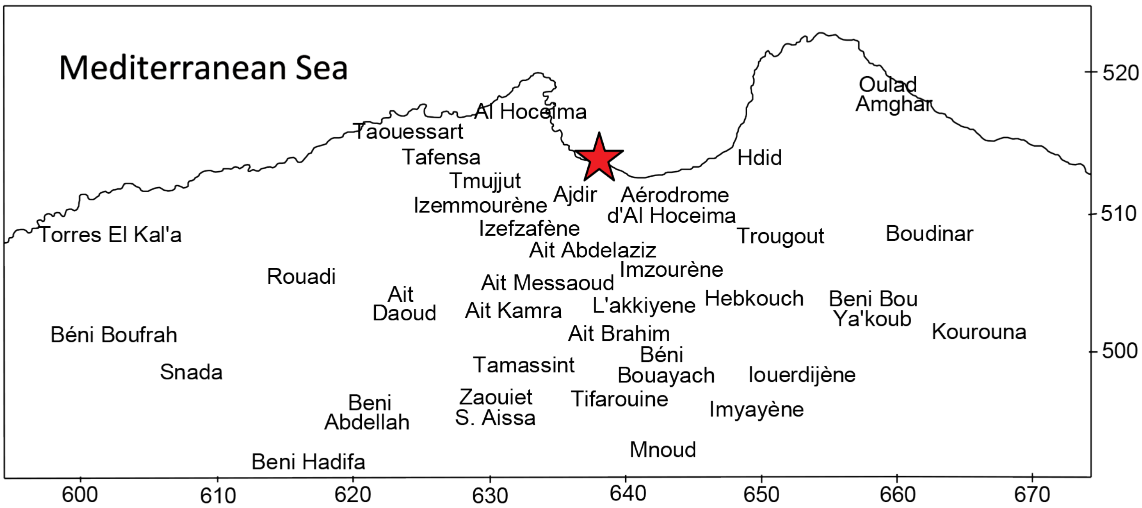


Figure 3. Map of the localities surveyed, about ten sites located and visited on both sides of the Ajdir zone (site of the instrumental epicenter of the earthquake of February 24, 2004).

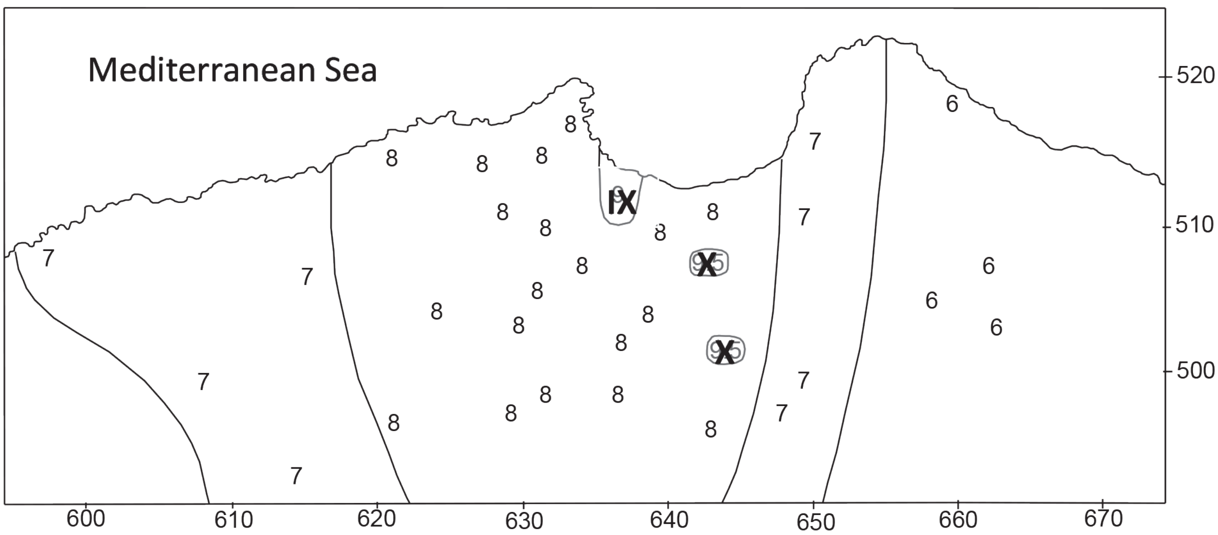


Figure 4. Isoseismal map of the earthquake of February 24, 2004. This map shows values of felt intensities estimated in each site surveyed in this macroseismic study. The epicenter area, located nearby the location of Ajdir, is delimited by the isoseismal corresponding to intensity 9 (IX). The isoseismals are aligned roughly along a sub-meridian direction. The intensities higher than IX recorded at Imzourène and Béni Bouayach are attributed to site effects since these localities are few kilometers away from the instrumental epicenter.

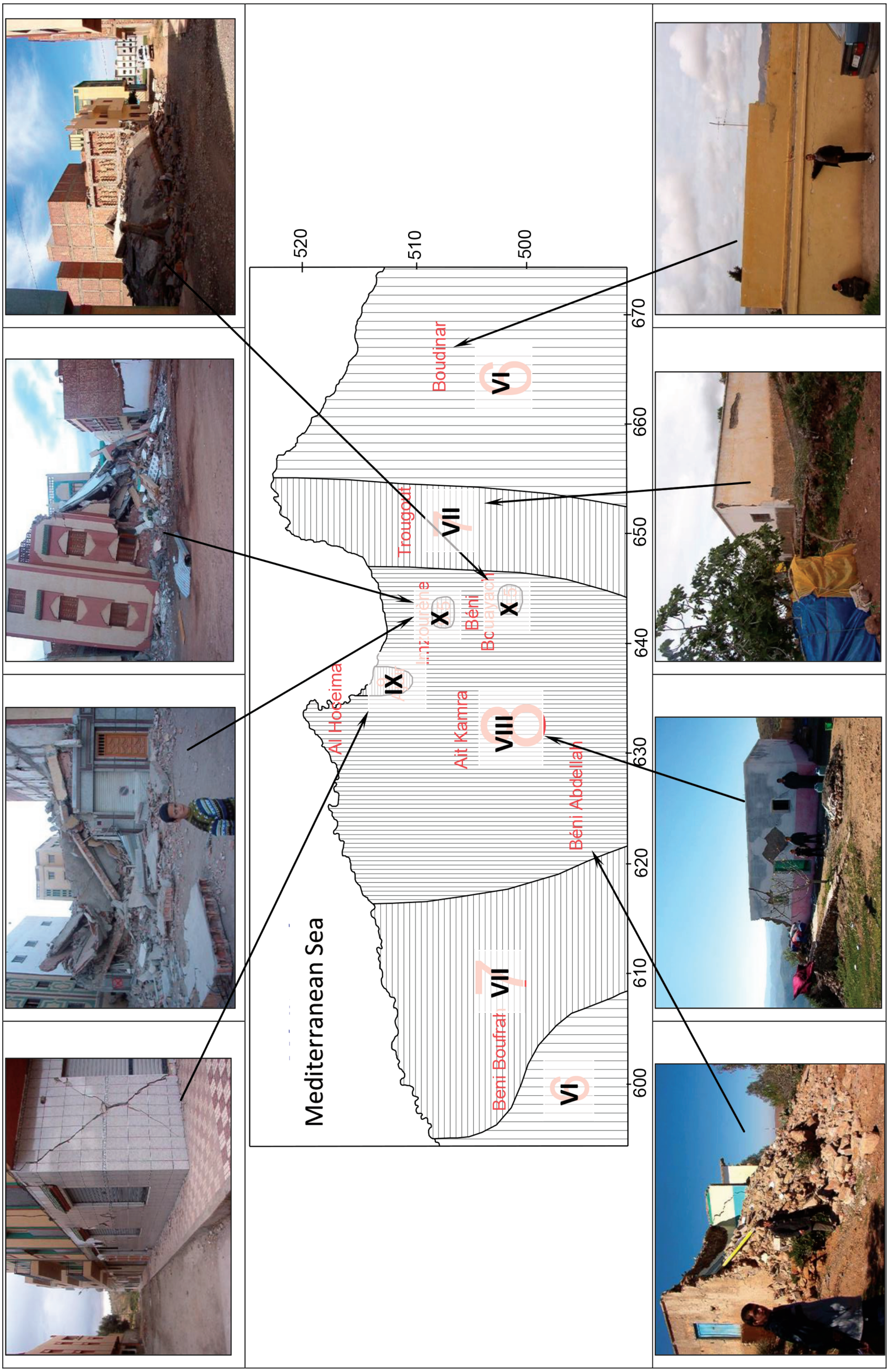


Figure 5. macroseismic map of the earthquake of February 24, 2004 and examples of damage observed in different localities.

LANDSLIDES IN THE DISASTER AREA

Fieldwork carried out in the study area allowed to locate two types of mass movements: those triggered after the 2004 seismic event - mainly rock collapses and mudslides - and other older instabilities which are replays that consisted of rock-falls within known landslides in the region (Fig. 6).

Geological investigations, undertaken in parallel with the macroseismic survey, highlighted that the seismic crisis of February 2004 induced significant changes in the geological environment of the affected area. Several slopes' instabilities, the majority of which are rockslides and rock-detachments, landslides and mudslides were triggered and, in some places, reactivated under the effect of the earthquake of 24 February 2004.

In the field, all the observed ground instabilities were geologically surveyed. The objective is to determine geological indices that caused their triggering under the effect of the main shock and its aftershocks.

Landslides

At the O. Mansor site (Picture 1 - Tab. 1), the landslide located at this site was reactivated during the earthquake of February 24, 2004. Numerous limestone blocks of metric dimensions which, by getting detached from the carbonate formations constituting the higher part of the slope, form clusters of rock at the foot of the slope. Some of the detached blocs collapsed in the direction of the slope to reach the road.

Similarly, the effect of seismicity is noted at the Tala Youssef site, where the Al Hoceima region famous landslide is developing. Potential reactivation indices were thus,

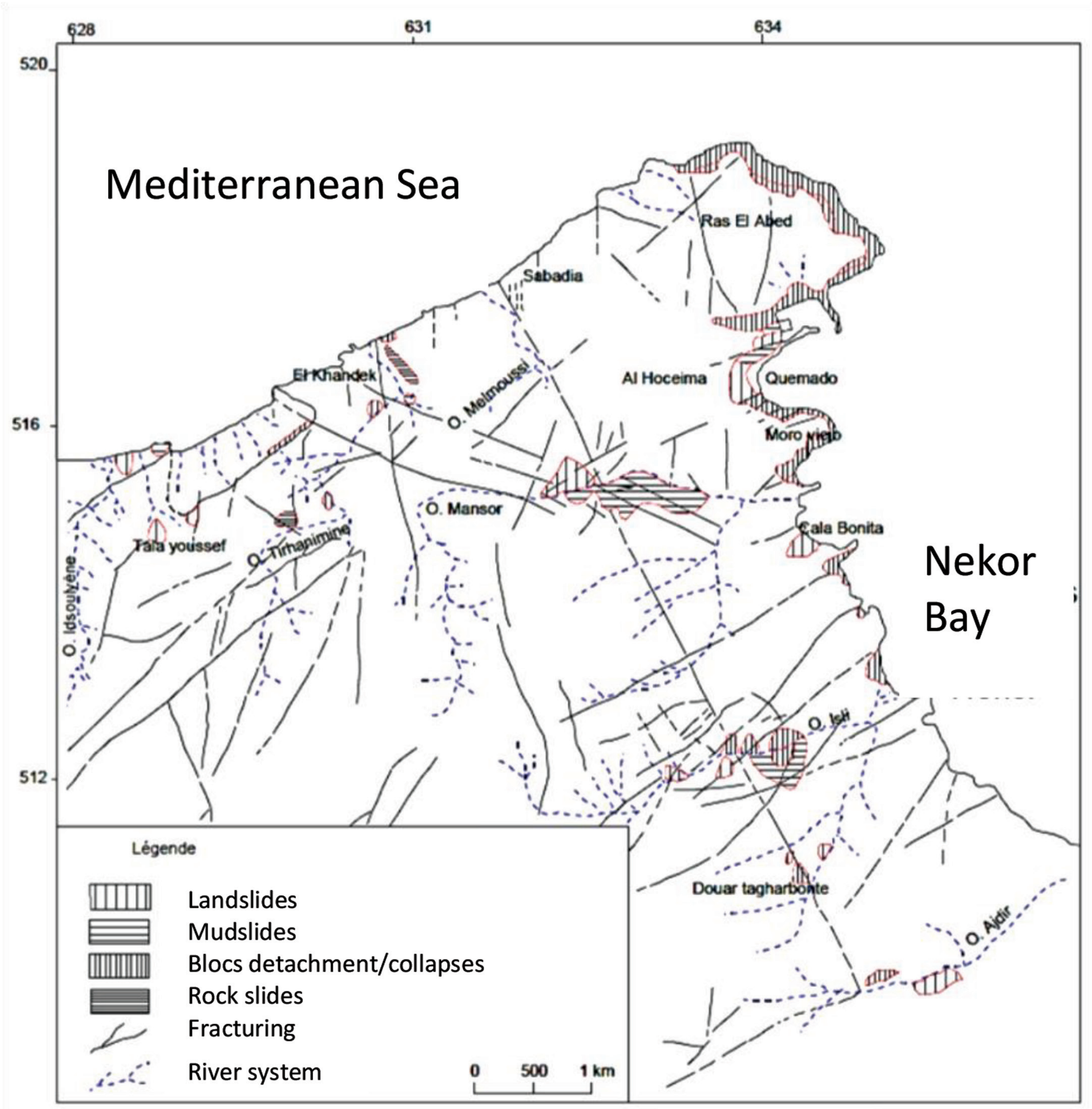


Figure 6. Map of landslides located in the study area (after Talhaoui et al. 2005).

identified as a result of the earthquake of February 2004. Thus, many cracks with a centimetric opening were located at this level. They line-up along N20 to N40 and N60 to N70 directions and affect the upstream portion, where field packets are put in potential imbalance (picture 2 - Tab. 1). Eastward, the permanent movement of this landslide was identified by fissures of about 40 to 50 cm of opening marked on the ground along directions N100 to N110 (picture 3 - Tab. 1). Other elements made it possible to further highlight the reactivation of this landslide such as a stretching of electrical wires intended to supply electricity to the upstream village (picture 4 - Tab. 1).

Alongside these movements, which seem to know an ongoing activity, some are marked by the cessation of replay or a momentary stability, such as the Quemado landslide. Apart from the northern and southern parts, the slope vegetation (picture 5 - Tab. 1) has probably contributed to maintain the stability of the site, although our field observations indicate that this stability is rather momentary.

Similar findings were observed at the port of Al Hoceima. The landslide that developed at this site probably did not react under the effect of the earthquake of February 24, 2004. Also, built constructions at the top the slopes showed no sign of noteworthy damage. Vegetation seems to play an effective stability role (Picture 6 - Tab. 1). Nevertheless, despite this plant protection, cracks develop in the retaining wall built at the foot of the cliff to maintain its precarious balance (picture 7 - Tab. 1).

Table 1. pictures taken during field visits carried out following the February 24, 2004 earthquake in the Al Hoceima region.

 ***Picture – 1, Tab. 1***	The current state of the landslide located at the site of Sidi Mansour after the earthquake of February 24, 2004
 ***Picture - 2, Tab. 1***	The recent movement induced by the February 24, 2004 earthquake in the Tala Youssef landslide. Several fresh cracks are tracing upstream and field packets are in potential imbalance.
 ***Picture - 3, Tab. 1***	Cracks induced by the recent seismic activity at the Tala Youssef Douar. They have openings about 40 cm to 50cm.

 ***Picture - 4, Tab. 1***	Landslide in activity indicated by the stretching of the electric wire located at the Tala Youssef Douar.
 ***Picture - 5, Tab. 1***	The vegetation has contributed to maintaining stability of the slope in the area of Quemado during the earthquake of 24 February 2004.
 ***Picture - 6, Tab. 1***	The recent reforestation of the moving slope in the landslide of the port of Al Hoceima seems to have played the role of effective stability. No remarkable movement indices under the seismic effect have been recorded in this site.
 ***Picture - 7, Tab. 1***	Cracks in the retaining wall built at the foot of the slope to maintain stability. They attest to the continuous sliding movement of land at the port of Al Hoceima.

Collapses and Rockslides

This type of ground movements was a direct result of seismic activity although some of them were the result of the replay of landslides at Sidi Mansour, Tala Youssef and Cala Bonita.

In the area of Cala Bonita, which is a site marked by a permanent ground movement, the seismic shaking was quite felt at this site. At the time of the earthquake of February 24, 2004, several rockslides were triggered (picture 1- Tab. 2). Ground masses, in which distinguished facies of the different units marking the lithostratigraphy at this location, were moved in the direction of the slope until reaching the sea (picture 2 - Tab. 2). Also, fissures and cracks were noticed in massive gray dolomites upstream of the slope (picture 3 - Tab. 2).

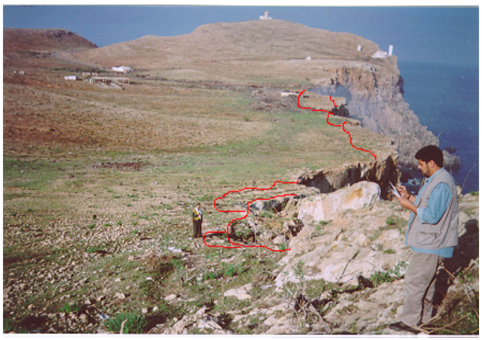
At the Moro viejo site located to the east of Al Hoceima, masses of limestone blocks of metric dimension, after being detached from the top of the cliff, collapsed under the effect of seismic loading. In the area displaying potential indices of movement, several fissures were identified. The earthquake of February 24, 2004 triggered rock-falls of metric to pluri-metric dimension. Field observations carried out in this sector made it possible to note the freshness of the markers of these land instabilities (picture 4 - Tab. 2).

North of the city of Al Hoceima, in the area of Ras El Abed, field visits made after the main shock allowed us to witness the impact of seismic activity on the geological environment. Many substantial fissures subsequent to this seismic event appeared along the cliff (pictures 5 and 6 of Tab. 2). In places they show openings of 30 to 50 cm and are aligned in the directions N120 to N130 and N150 to N160.

South of Al Hoceima, along the Isli River, the Rockslides were located in Tertiary flysch rock formations (picture 7 - Tab. 2). These ground movements were triggered under the seismic effect in the muddy landslides that developed in these formations under the effect of precipitation.

Table 2. Pictures taken during field trips carried out following the February 24, 2004 earthquake in the Al Hoceima region.

 ***Picture - 1, Tab. 2***	The Cala Bonita landslide showing local rockslides, triggered under the effect of the recent seismic activity recorded in the region of Al Hoceima.
 ***Picture - 2, Tab. 2***	In the Cala Bonita area, we noticed that the seismic activity has caused an imbalance of large ground masses.
 ***Picture - 3, Tab. 2***	About 10 to 15 cm-wide open fissures in the ground triggered upstream of the slope following the earthquake of 24 February 2004 in the Cala Bonita landslide.

 ***Picture - 4, Tab. 2***	Detached limestone blocks following the February 24, 2004 earthquake in the Moro Jievo area on the east of Al Hoceima.
 ***Picture - 5, Tab. 2***	Fissures that appeared in the limestone of Ras El Abed. They were triggered following the earthquake of February 24, 2004, following directions between N120 to N130 and N150 to N160.
 ***Picture - 6, Tab. 2***	Fissures in limestones located in the Ras El Abed sector, triggered following the earthquake of February 24, 2004. They show openings of about 30 to 50 cm.
 ***Picture - 7, Tab. 2***	Rockslides triggered downstream of the Isli River following the recent seismic activity recorded in the region of Al Hoceima.

Blocks Detachment

We found this type of terrain instability in areas where the slope tends to become near-vertical at the top of the slopes. Under the effect of recent seismic activity, boulders from carbonate formations of the calcareous dorsal or on top of the Paleozoic Ghomarid nappes, which are generally highly fractured, fall and travel considerable distances. These phenomena present a major threat to local constructions, especially in the village of Tighanimine on the west of Al Hoceima and in the sector of Cala Bonita on the south.

Indeed, metrics boulder caused, after covering a distance of about 20 m, the destruction of the wall of a house in the village of Izemmourène, southeast of Al Hoceima (picture 1 - Tab. 3). Also, a boulder rolled down from the top of the hill to the road at Izafzafène (picture 2 - Tab. 3).

DISCUSSION

Macroseismicity is a discipline that studies earthquakes effects and damages as observed or felt by animals, people, buildings and the natural environment. In the present study we note and list such observations as caused by the Al Hoceima earthquake activity of February 2004. Thus, in this article, we report both the intensities that affected the populations and buildings as well as the effects on the geological environment of the region. We further compile a macroseismic map, which shows the effects of this earthquake on constructions and structures in place and we further undertake field-geological investigations that help us identify the areas affected by land movements.

This macroseismic map assigns intensity IX to the instrumental epicentral zone. On the other hand, we find a slightly higher maximal intensity (~X) a few kilometers to the SW of this instrumental epicenter. This zone of maximum intensity is located within the Bas-Nekor basin and falls away from the instrumental epicenter. We attribute this difference between the maximal intensity site and the actual epicenter to seismic site effects due to the presence of alluvium in this basin, which must have amplified the seismic waves. This site effect was further documented by Douiri *et al.* (2015) for the city of Imzourène within the Bas-Nekor basin.

An intensity of VIII is widely distributed in a N-S to NNE-SSW direction (Fig. 5). Thus, contrary to the general NE-SW trend shown in the provisional isoseismic map of Ait Brahim *et al.* (2004), the isoseismal curves of our present study show rather N-S to NNE-SSW direction (Figs. 4 and 5).

Geological investigations carried out in the Al Hoceima region following the main earthquake, allowed the compilation of a map of ground movements triggered by the 2004 seismic activity as well as older mass-movements, which were triggered following other important earthquakes. This allowed to identify the different types of land instabilities as well as their spatial evolution in the study area. Furthermore, the analysis of the consequences of this earthquake made it possible to distinguish between land movements, which are in permanent activity from those under an apparent and temporary

Table 3. pictures showing examples of Rockfalls observed during field trips carried out following the main shock of 2004 in the Al Hoceima region.

 ***Picture - 1, Tab. 3***	Effect of the phenomenon of Rockfall triggered as a result of seismicity. The wall of the house was destroyed by a boulder at Izemmourène.
 ***Picture - 2, Tab. 3***	Boulder fell from the top of the hill during the earthquake of February 24, 2004 in the area of Izefzafène.

equilibrium. In this respect, at the Al Hoceima region, our field observations show that the ground instabilities located in the sectors of Sidi Mansor, Tala Youssef and Cala Bonita present higher degrees of risk. Indeed, fresh open cracks at instability-planes breakout as well as patches of potentially unbalanced terrains were identified. These observations are clear indications of a hazard threatening urban agglomerations which develop in these zones.

The factors involved in triggering ground movements are classified into two groups. There are permanent factors intrinsic to the site which includes topography and geology and those rather due to dynamic action, including seismicity which we cite in the context of this work. In fact, both of these factors contribute inseparably to the triggering of ground movements. Thus, geological investigations undertaken in sites of land instabilities show that the nature of lithologic sequences plays a major role in triggering ground instabilities within vulnerable slopes (e.g. Azzouz *et al.* 2002, Talhaoui *et al.* 2005, Labriki *et al.* 2019). A correlation between the ground movements typology and the litho-stratigraphic nature of a site has been established. Thus, most of the ground instabilities are observed in zones with a heterogeneous litho-stratigraphy such as in the cases of the Sidi Mansor, Tala Youssef, Ajdir and Cala Bonita sites.

In other zones where the nature of the terrain is rather massive such as in the sectors of Ras El Abed and Moro Viejo, land instabilities are characterized by rapid and discontinuous movements. These are mainly collapses and fall down of rocky blocks. In some places, these phenomena further participate in driving the plane of the cliff backwards. This situation leads us to underline the danger which threatens the urban expansion of the city of Al Hoceima in these places.

The degree of heterogeneity of a slope cannot be limited to the type of materials and their mode of arrangement, there is also the density of the fracturing which provides an essential and favorable element to trigger ground movements (Fig. 6). The intensity of fracturing within a slope determines the degree of risk associated with land movements. Movements along the faults that structure the rocky massifs constituting the Ras El Abed and the Moro Viejo zones provides us with information on the discontinuities favorable to the collapse and detachment of blocks. The expansion of the Al Hoceima city in these sectors is occurring at the expense of sites under critical risk. The instability is manifested by the appearance of cracks in the massif, in places these are filled with clay material. Under the effect of a major earthquake movement with an epicenter close to the city, subsequent modifications to areas of weakness can generate significant damage. In this regard, tectonic analysis shows the danger presented by shaking faults under seismic effects (Azzouz *et al.* 2002, Talhaoui 2005).

Topographic and geological investigations, carried out in sites subject to ground movements that were triggered by seismicity in the Al Hoceima region, allow us to focus on the major role of the slope. The quantification of the triggering factors makes it possible to point out the main role that the steepness of slopes plays in the genesis of these phenomena (Azzouz *et al.* 2002, Talhaoui *et al.* 2005, Rfifi & Ait Brahim 2018). It presents a state of imbalance that can generate ground movements. The presence of dipping layers or intense fractures within the slope induces rupture surfaces. This state of potential imbalance constitutes a favorable condition for earthquakes to induce the triggering of ground movements in the Al Hoceima region.

CONCLUSION

Following the 2004 Al Hoceima earthquake, seismic activity at the region induced numerous instabilities of geological outcrops as a result of neotectonic activity that the geological formations undergo. The present study allows appreciating the severity of the impact of the 2004 Al Hoceima earthquake and its aftershocks both on the geological and the built environments.

The processing of macroseismic data enabled us to compile the macroseismic map of the February 24th, 2004 earthquake. The isoseismal curves of the maximum felt intensity appear to follow a sub-meridian direction, suggesting that the causative fault of the main shock is of the same direction. Although the maximum intensity recorded is IX on the MSK-64 scale, a slightly higher maximum intensity of X has been estimated in the localities of Imzourène and Béni Bouayyach. The damages observed in these places can probably be attributed to site effects.

The earthquake of February 24, 2004 triggered several land instabilities. Fieldwork conducted in the region made it possible to emphasize that landslides were either directly initiated by the seismic activity or reactivated as a result of it. Orography, the state of fracturing and seismic activity are the leading factors in triggering ground movements: landslides, Rockslides, rock falls, ... The rate of fracturing within a slope is a key factor to help determine the degree of risk linked to a landslide. The replay of the faults, structuring the rock mass constituting the Ras El Abed and Moro Viejo zone, provides information on the discontinuities favorable to collapses and blocks detachment. The extension of the city of Al Hoceima in these places is done at the expense of sites at critical risk. Thus, under the effect of a major seismic movement that occurs close to the city, the subsequent modifications that the zones of weakness may undergo can cause significant damage.

Finally, it is worth noting that although, the main shock did not cause significant surface fractures, many cracks were identified in different directions. They were probably generated by aftershocks, rather superficial, of the February 24, 2004 earthquake.

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