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Contribution of Seismic and Magnetic Data for the Prevention of Geotechnical Risks Related to Building Cracking in Agadez Region (North Niger)

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Abstract

This study tries to highlight the role of magnetic and seismic data in the prevention of building cracking, which constitutes a geotechnical risk in Agadez City. This city is built on the faulted and fractured sandstone formations of the "Agadez Sandstones Formations", which were deposited in unconformity on the basement of the Aïr Mountain. This study focuses on the prevention of geotechnical damages related to building cracking in the Agadez region through geophysical methods, which are well known for investigating tectonic structures and their directions on the surface and subsurface. A methodological approach integrated the seismic and magnetic data interpretation combined with field measurement on the cracked building and its underlying substratum, represented by Agadez sandstones and basement. The extraction of seismic lineaments from the West African seismic map showed the seismic directions oriented NW-SE (N135˚ to N160˚), passing through the studied area. The structural interpretation of the magnetic map shows that the Agadez region is also affected by the subsurface lineaments mainly oriented in NW-SE (N135˚) directions, which are similar to the identified seismic lineaments in the same zone. A structural study carried out on the Agadez sandstones and the underlying basement showed that faults and fractures oriented N120˚ to N165˚ affect both the basement of the Aïr Mountains and the sandstone formations on which the city of Agadez is built. These observations showed that building cracking in the Agadez region has a higher propagation tendency according to the directions ranging from NW-SE (N135˚) to NNW-SSE (N165˚). Therefore, the building's cracking has a stronger propagation component according to these mean directions that are not recommended for building. To prevent and reduce the risks related to building cracking in Agadez region, it is highly recommended to build in the minor directions of cracking propagation, which correspond to NE and SW directions.

Keywords

Seismic, Magnetic, Prevention, Building Cracking, Agadez, Niger

1. Introduction

This study tries to highlight the role of magnetic and seismic data in the prevention of building cracking, which constitutes a geotechnical risk in Agadez City. This city is built on the faulted and fractured sandstone formation of the "Agadez Sandstones", which was deposited in unconformity on the basement of the Aïr Mountain [1]. The studied zone represents the N-S interface between the Tim Mersoi basin (TMB) and the basement of Aïr Mountain (AM). According to previous geological and structural works [2]-[4], the Tim Mesoi basin consists mostly of sandstone formations deposited during periods ranging from Cambro-Ordovician (400 Ma to Cretaceous 96 Ma, **Figure 1**). The basement part of Aïr Massif is represented by the rejuvenated Palaeoproterozoic rocks, the Palaeozoic "younger granites", and Cenozoic volcanic rocks described mainly in the eastern part, corresponding to the Téfidet Graben. The structural analysis of these previous data [2]-[4] showed that all these geological units (basement and basin) are affected by brittle deformations in the state faults and or fractures with several orientations. Thus, the main directions of faults were made into evidence at the regional scale in the Agadez region (**Figure 1**):

- the In-Azaoua-Arlit fault system, N-S (N0˚) trending and the Madaouéla fault system oriented NE-SW (N30˚, **Figure 1**);
- the NW-SE (N130˚ to N140˚) trending faults system, affecting the Aïr Mountains, frequent in the basement part and less frequent in the Tim Mersoï basin;
- the NEE-SWW (N70˚-N80˚) fault system more described farther to the west in the DASA area, has been reactivated in a dextral sense during the Upper Cretaceous as indicated by the results of structural study obtained in the Tim Mersoi basin by [2]-[4].

2. Material and Methods

The methodological approach is based on the review literature, field investigation and processing and statistical analysis of field-collected data.

2.1. Review Literature

The reviewed literature was focused on bibliographic research of thesis, scientific articles, scientific reports and all other documents relative to the geology and tectonics of the studied zone. This step led to retrace the great features of tectonic history of the studied zone and compare them with the results obtained by the present study.

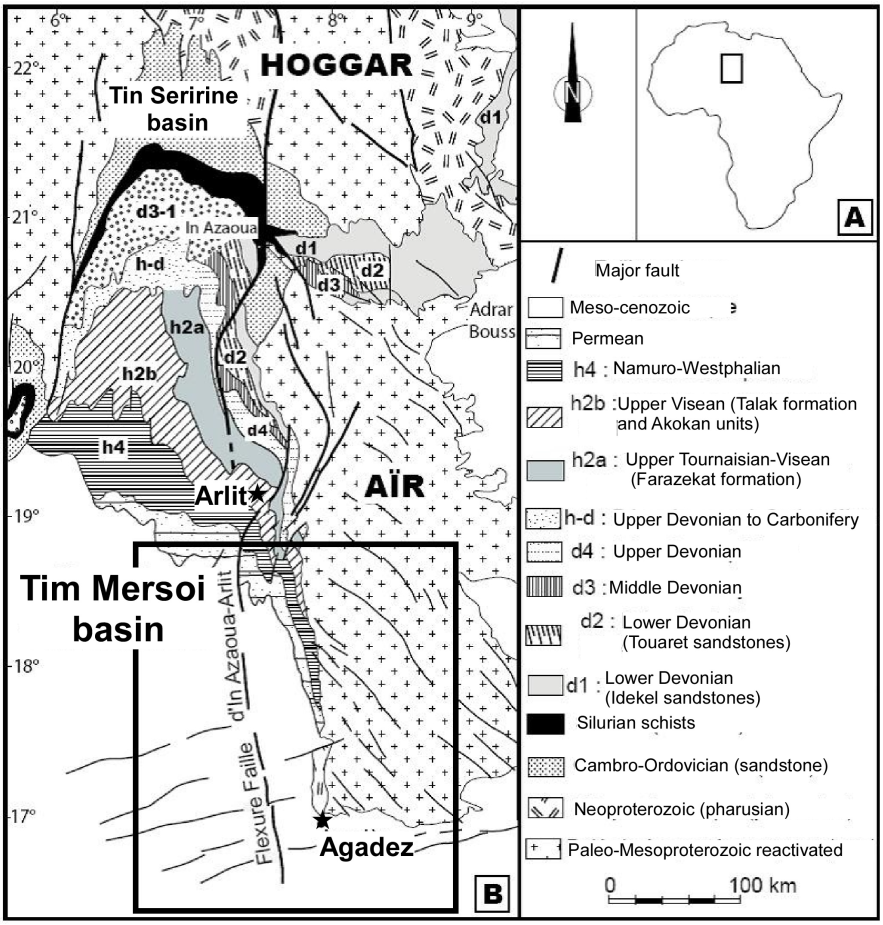

Figure 1. Location of survey area within the geological and structural map of the Eastern part of Tim Mersoï Basin, from the previous geological and structural data [2]-[4].

2.2. Geophysical Data Interpretation

The interpreted seismic and magnetic maps are respectively from High Authority of Nuclear Emery of Niger Republic (HANEA, Niger) and Project for Reinforcement and Diversification of the mining sector in Niger (PRDSM, Niger). These geophysical data were integrated with the Software "ArCGis 10.1" when seismic and magnetic lineaments were extracted and interpreted (Figure 2 and Figure 3). This step led to determining the main directions of crack propagation in the deep and subsurface.

2.3. Field Investigation

The field investigation consisted of prior identification of the most affected sectors by cracking events and in situ structural measurement of crack planes. This stage was carried out using geological materials, such as GPS (for the location of the site) and Compass (for direction and dip acquisition of a structure).

2.4. Processing and Statistical Analysis Collected Data

Processing and statistical analysis of measured structures was carried out using the software MS Excel 2013, which is well known for its statistical analysis. Field photographs were processed by the Software of computer-assisted design "Canvas 11". The measured planes of cracks were inputted into MS Excel 2013 software and statistically analyzed with this software. The step allowed the classification of all measured crack planes by the direction intervals of 45˚ from the North (Table 2 and Figure 5).

3. Results and Discussion

3.1. Seismic Data

Structural analysis of seismic cartographic data [5] highlighted two regional lineament systems: the NNW-SSE trending seismic lineament affecting both the Aïr basement and Tenere basin in the East and N-S fault system extended in the Tim Mersoi basin in the West (Figure 2). In addition, some localized seismic lineaments oriented NEE-SWW and cutting the regional lineaments were identified in the western region of Agadez. This regional lineament would control the setup of the uranium mineralization in Arlit region [6], and in Tenere basin, it constitutes a NNW-SSE petroleum system of Termit basin [7].

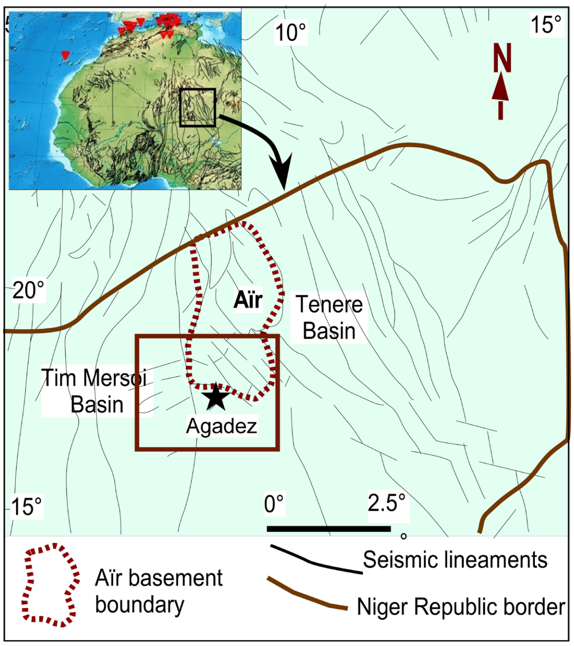

Figure 2. Seismic lineaments of Niger Republic and Agadez region extracted in the case of this study from seismic map West Africa [5], showing the NNW-SSE and N-S trending fault system affecting the survey area.

3.2. Magnetic Data

Lineaments extraction (in the case of this study) from aeromagnetic cartographic data [8] of Agadez region at 1/200,000th (Figure 3) showed two main directions of magnetic lineaments according to their size: minor and major. The major part of these magnetic lineaments is oriented in NW-SE direction (mainly N135˚ to N140˚). In addition, a major magnetic lineament oriented N-S (Figure 3) corresponding to In-Azaoua-Arlit fault system revealed by previous geological works was identified (Figure 1). These similar directions were also previously identified by seismic cartographic data (Figure 2). These observations reveal that the subsurface seismicity directions of Agadez region are mainly NW-SE trending. Those cannot be recommended or avoided for the construction of big buildings.

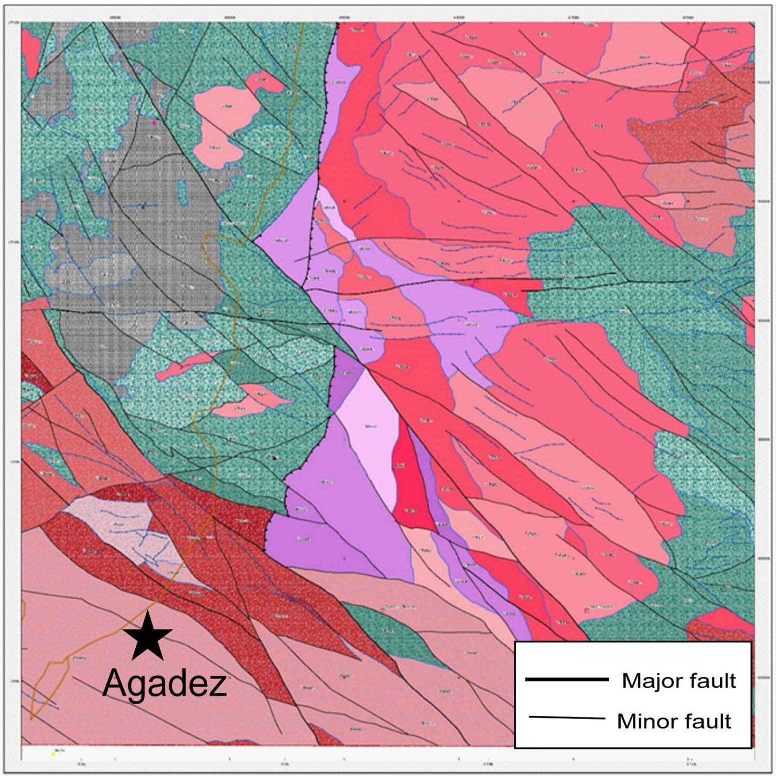

Figure 3. Lineaments extraction from aeromagnetic cartographic data [8], showing the NW-SE major directions of magnetic lineaments affecting the Agadez region.

3.3. Field Data

Field investigations and measurements of crack planes were carried out on Agadez sandstone formations and buildings (Figure 4). The obtained microtectonic data are presented in Table 1 and Table 2. The structural and statistical analysis of the obtained data showed that the cracking events affect both the Agadez sandstone formations and buildings (Figure 4). To determine the major direction of their propagation, the 220 measured planes were statistically analyzed by direction intervals of 45˚ from the North (Table 2 and Figure 5). The obtained results of statistical analysis by the percentage of directions show that:

North to Northeast (N0˚-N45˚) directions: 25%,

Northeast to East (N45˚-N90˚) directions: 30%,

East to Southeast (N90˚-N135˚) directions: 12.73% and

Southeast to South (N135˚-N180˚) directions: 32%.

According to these observations, the directions ranging from NW-SE (N135˚) to N-S (N180˚) are the majority with 32%, followed by NE-SW (N45˚) to E-W (N90˚) directions with 30%. Therefore, the buildings cracking events have a stronger propagation component according to the mean directions which are NW-SE (N135˚) trending.

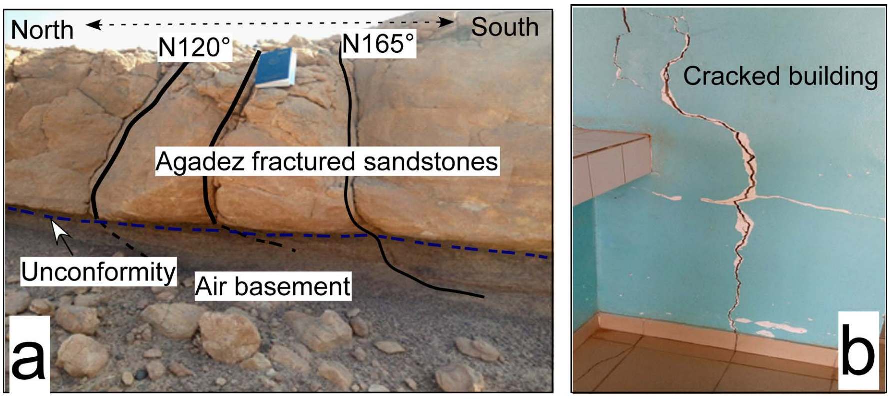

Figure 4. *In situ* photography showing (a) Agadez fractured sandstones with its underlying basement of Aïr and (b) state of cracked building in Agadez City.

Table 1. Some of measured cracks from building and Agadez sandstone formations.

Direction	Dip values	Dip sector
N120˚	85˚	SW
N150˚	75	NE
N80˚	90	V
N150˚	90	V
N90˚	80	S
N50˚	70	SE
N70˚	90	V
N135˚	80	SW
N140˚	85	SW
N35˚	90	V
N85˚	90	V
N160˚	90	V
N180˚	70	E
N40˚	70	SE
N85˚	90	V
N100˚	50	SSW

Note: S: South, N: North, W: West, E: East, V: Vertical.

Table 2. Statistic of measured cracks according to their directions.

Direction intervals	Effective	Percentage (%)
[N0˚-N45˚]	55	25.00
[N45˚-N90˚]	66	30.00
[N90˚-N135˚]	28	12.73
[N135˚-N180˚]	71	32.27
Total	220	100.00

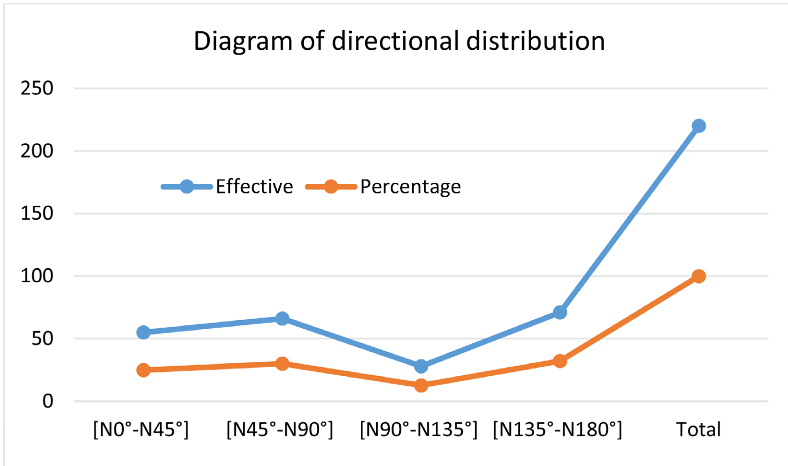

Figure 5. Diagram of directional distribution of all planes of cracks measured on Agadez sandstones and on building.

3.4. Discussions on Origin of Building Cracking

1) Tectonic origin

Analysis of seismic and magnetic cartographic data showed two main directions: N-S and NWW-SSE directions. According to the previous geological and structural works, the N-S regional lineament systems corresponding to the In-Azaoua-Arlit fault system extended in the Tim Mersoi basin in West. Another N-S regional direction called "Raghane fault system" affects similarly the Precambrian Aïr basement and Tenere basin in East (**Figure 1**). The NNW-SSE lineaments represent the relay of N-S regional fault systems and cause the building cracking in Agadez region [1]. According to several authors, these two fault systems were the focus of three seismic events (4th July 1969, 19th May 1967 and 18th January 2017 [1]-[3] [5]). According to geological data obtained in Hoggar [9]-[13], these regional fault systems derive from the Pan-African reactivation of three major sub-meridian shear zones in Hoggar: East Ouzzal shear zone (3˚30'), Tekouyat shear zone (4˚50') and Raghane shear zone (8˚30'). In the Aïr mountain of Niger, this Pan-African reactivation caused the formation of the juxtaposed terranes from West to East Assodé terrane, Barghot terrane and Aouzgueur Terrane, all limited by the N-S major shear zones [12]-[14]. A recent study carried out by [15] on the studied region has shown the Evidence of brittle tectonic continuity between the basement of Aïr Mountain and its overlying sandstone formations on which Agadez City was built.

2) Anthropic origins

The first anthropic origin of building cracking in Agadez region is the uranium coal mining operation carried out in the three different mining sites in the region (Somaïr, and Cominak for uranium mining in Arlit sector and Sonichar for coal mining in Tchirozerine sector, Figure 1). The structural work on the mining sites of Somaïr, Cominak and surrounding city of Arlit [6], described the fractures with variable orientations: the N140˚ to N170˚, the N100˚ to N120˚, the N40˚ to N50˚, the N60˚, and the N70˚ to N80˚, all caused by the use of dynamites during the uranium mining. According to this author [6], these fractures constitute the geotechnical risks and serious accidents related to the falling of the blocks during the uranium mining.

The second environmental origin would correspond to the vibrations of supersonic airplanes during take-off and landing. It can be noted that Agadez City has two airports: Airport of Agadez and the American Battalion 201 Airport (Figure 6). The projection of coordinates of all studied sites on the Google Earth map has shown that the most affected buildings by cracking events in Agadez are surrounding the airports areas.

The third origin of building cracking in Agadez region can also be the non-respect of geotechnical standards of civil engineers for the building construction. Indeed, the field observations carried out in the case of this study showed that some buildings are built along the slope of streams, sometimes with incorrect cement dosage and or without reinforced concrete.

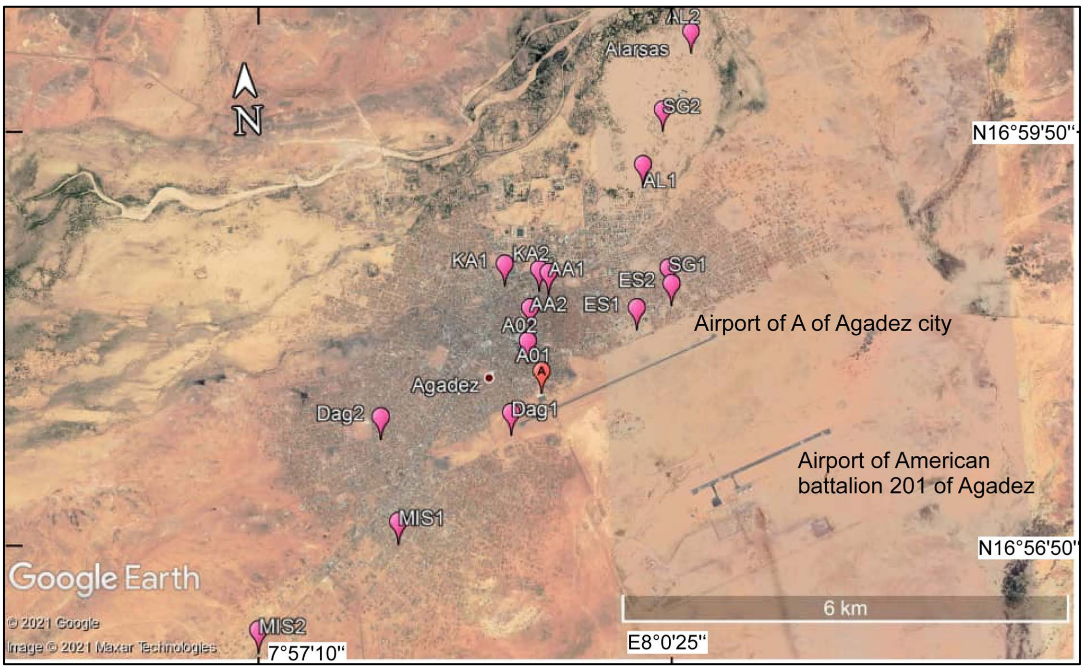

Figure 6. Location of studied sites where building are mostly affected by cracking events. Legend: Dag: Dagmanet site, Mis: Misrata site, ES: Emair-Sabon Gari site.

4. Conclusion

This study aimed to highlight the important contribution of seismic and magnetic data in preventing geotechnical risks related to building cracking. A combined analysis of seismic, magnetic, and field data determined the major directions of crack propagation. The results showed that the main directions of crack propagation correspond to the NW-SE to N-S trending seismic and magnetic lineaments. Field verification indicated that these lineaments correspond to a system of cracks and fractures oriented in the same directions (NW-SE to N-S), affecting both sandstone formations and buildings in Agadez City. Therefore, these directions are not recommended for building construction due to the high level of cracking. Instead, directions corresponding to NE-SW (N45˚) to E-W trending (N90˚) are highly recommended for building construction in this region.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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