Project ID: **Fly-Radar**

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Call: **H2020-MSCA-RISE-2020**

WP1: Mars Surface and subsurface analyses and terrestrial analogs

D1.2: Preliminary Terrestrial Analog Description

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0. Publishable Summary

The main characteristics of the sites that have been selected to test and evaluate the Fly Radar system are given in this report. The parameters The parameters which governed the choice of sites are as follows:
- Arid areas preventing signal absorption problems related to water
- Little or no soil covering the rocks of interest
- Rich geology from the surface to a depth of 10-15 m
- Varied geology between sites
- A geology possibly similar to Martian geology in some aspects
- Sites of scientific interest or of interest for the conservation and discovery of the natural heritage (geosites)

The chosen sites cover the majority of the existing geological conditions on Earth and are, for some, analogues of Martian sites. Some of them offer a strong geopatrimonial interest. The complexity of the sites varies. Some sites are simple and can be studied first (Erfoud, Azrou, Djebel Bou Dahar, Port Tarfaya). Others have more complex geometry and less contrasting lithologies. They will have to be studied in a second step. One site has been selected in Europe. This is the Tabernas Desert site which has the advantage of proximity and geological simplicity. This site will make it possible to test the Fly Radar systems under simple logistical conditions. Finally, the Dallol site, initially planned, was described in the project. The current geopolitical conditions do not allow its exploration in the near future. The report ends with a short description of the general logistical needs to proceed to the tests in the best conditions.

1.Introduction

The Fly-Radar system will be tested in conditions of varied geology, some of which will be similar to Martian sites. The aim of this report is to describe a collection of geological sites that can be used for the evaluation of the performance of the system.

The parameters which governed the choice of sites are as follows:
- Arid areas preventing signal absorption problems related to water
- Little or no soil covering the rocks of interest
- Rich geology from the surface to a depth of 10-15m
- Varied geology between sites
- A geology possibly similar to Martian geology in some aspects
- Sites of scientific interest or of interest for the conservation and discovery of the natural heritage (*nb: in the following these sites will be called "geosite"*)

Some sites meet most of the criteria. Others allow precise evaluation of the instrument in a simple geometric and lithological context. We have chosen the majority of sites in Morocco. Indeed, the arid climate makes it easy to meet the criterion of absence of humidity. In addition, Morocco is a country with a varied geology in which it is possible to find the different geological contexts described in document D1.1. We have kept the description of the Ethiopian site of Dallol although the current geopolitical context is not favorable to its exploration. We have selected a site in Spain whose proximity will allow us to carry out the first tests with the fewest possible logistical constraints, in particular concerning the transport of equipment. The logistical advantages and limitations of each site are given. Before the conclusion, this report ends with a short description of the general logistical needs to proceed to the tests in the best conditions.

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2. Descriptions of the test sites

The Fly-Radar system must be able to explore the different geological contexts present on Earth and on Mars. This is why the sites described below are for somewhat "analogous" to Martian contexts. For others, these sites are of terrestrial geological interest. They make it possible to complete the tests in geological contexts specific to Earth, or even not yet discovered on Mars.

Eight potential sites (table 1) were selected to test the FlyRadar system on scientific or geosite criteria (geosites: sites of geopatrimonial interest). These sites were potentially Mars-like sites whose geology was already well known or could easily be. If “geosites”, these sites must present characteristic geological contexts that have to to be preserved and presented to the general public. The selected sites should cover a large sampling of the geologies described on Mars in D1.1. In addition, the sites must be favorable for exploration by radar, that is to say not be clayey, nor have liquid water in the underground, and a rich geology to 10-15m depth.

2.1 Tabernas Desert (Spain) – deformation and architecture of fluvial terraces

Location and geology: The Tabernas Desert is located in Andalusia (Spain) in the Almeria region. It occupies an area of about 280 km2 covered with short vegetation. The rains are rare. The climate is arid. The Tabernas sedimentary basin is filled with Neogene detrital and carbonate sediments deformed in a compressive context in the Betic Cordillera. The regional geomorphology was subsequently shaped by the brief and heavy rains. Riverbeds, mostly dry, cut into the Tertiary sediments and are marked by numerous alluvial terraces that have undergone the recent phases of the Betic collision.

Interest of the site: The timing and intensity of the Betic deformations is still regionally debated (Geach et al., 2015). This recording has been made since the beginning of the Quaternary in the alluvial terraces bordering the rivers. The internal geometries of the different terrace levels would make it possible to complete the outcrop information and to specify a relative calendar of recent Betic deformations in the region. Due to its proximity, the Tabernas site will also allow the Fly Radar system to be tested by simplifying administrative and logistical procedures. One can notice that the Tabernas desert is the place where the Roslind Franklin rover of the ExoMars mission is tested (e.g. Veneranda et al., 2021).

Logistical parameters: The Tabernas desert is accessible by many good roads and tracks from the Almeria airport. The Tabernas desert is in a national parc for which it will be necessary to obtain authorization for scientific investigations. The nearest city is Tabernas where all accommodation amenities are available.

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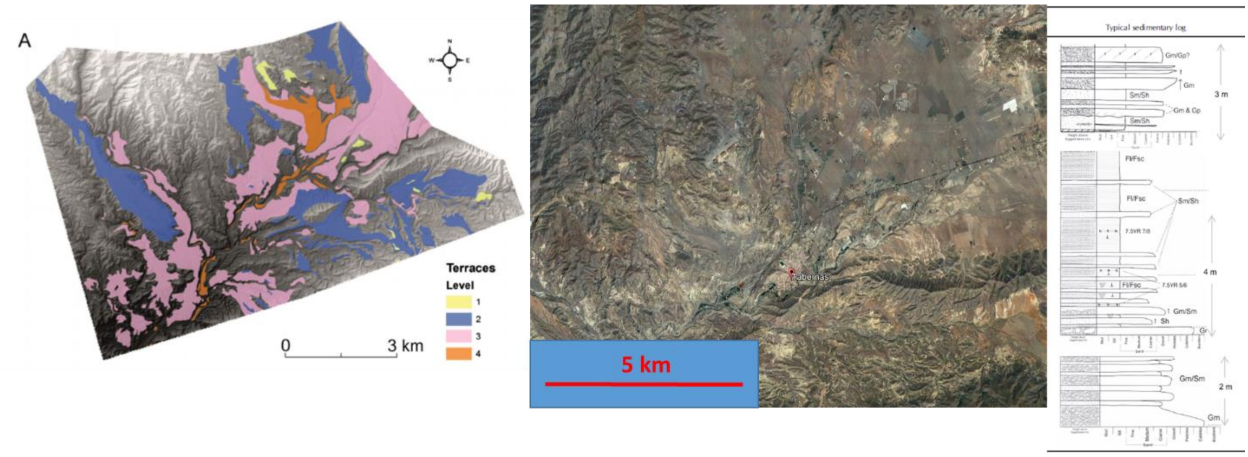

Figure 1. a) Quaternary terrace record of the Tabernas basin. Notice the position of the terraces and their level (Geach et al., 2015). b) Satellite view of the Tabernas Basin (Google earth). c) Section of the terrace pile showing the diversity of granulometry. Each terrace is dated by palynology (Geach et al., 2015).

2.2 Danakil depression – Dallol hydrothermal system

Location and geology: The Danakil Depression (Fig. 2) is part of the Oligocene-Recent Afro-Arabian rift systems. It is located in the northern part of the Afar triangle that connects the Red Sea with the Afar Triple Junction between the Gulf of Aden and the Main Ethiopian rifts (Oppenheimer et Francis, 1998; Mesfin et Yohannes, 2014). Since circa 30 Ma the area is submitted to extension with horst and graben systems with a NNW trend. The Dallol rift segment is located in the Northern part of the Danakil Depression in a low lying plain whose elevation reaches more than 125 below sea level with an average slope of less than 2% on both sides of the depression. The area is occupied respectively from the center to the edges, by a halite floored elongated salt pan lying on a wide gypsum bed, a marine reef rim that is evident in curvilinear outcrops on both of the sides of the basin, and different levels of terraced alluvial sediments and active wadis that underlie and crosscut the reef rim and the evaporitic pavements, and that show partial interfingering at the edges with the halite bed in the center.

The Northern part of the Dallol Rift system is occupied by a hydrothermal active dome which has a diameter of 3 km for an elevation of 40 m above the surrounding plain. The dome is composed mainly of salt deposits coming from uplifted primary halite beds controlled and derived halokinetic processes (Lopez Garcia et al., 2020). The top of the dome is a place of an intense geothermal activity which reworks the pre-existing deep hydrated salt layers. The Southern part of the area is occupied by basaltic lava flows which belong to the Erta Ale ridge. This ridge is active and includes at least 6 active volcanoes spaced at 10 km interval along a NNW-SSE trend.

Interest of the site: The Danakil depression is a hyper-arid area devoid of vegetation. It offers a large variety of lithologies from sedimentary to volcanic rocks. The Danakil depression offers thus all the characteristics to test the potential of FlyRadar system.

Logistical parameters: The Danakil depression (state of Afar) is accessible by road from the airport of Makele (State of Tigray). The Danakil desert is accessible for tourism and thus many good tracks permit

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transport of people and scientific equipment. It is possible to have accommodation in Hamadela. The geopolitical situation of the state of Tigray makes the access difficult for the moment in 2021-22.

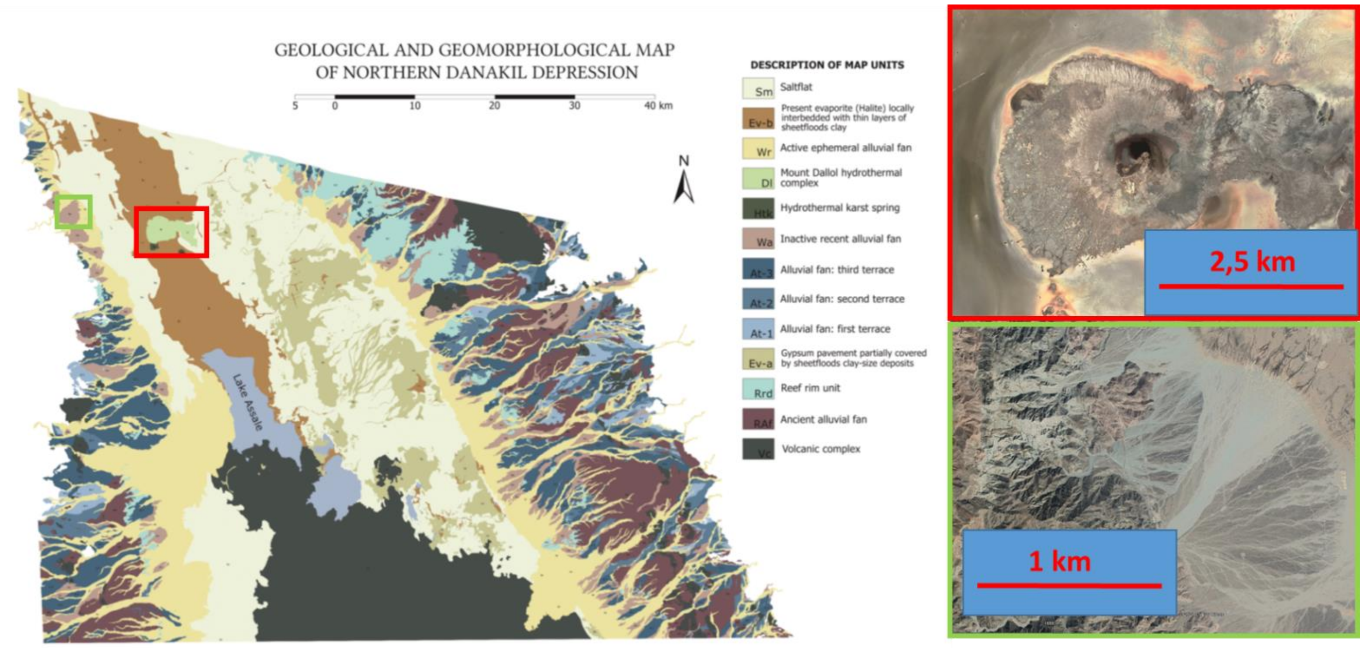

Figure 2: a) Map of the Danakill depression (from Garcia Lopez et al., 2018). Notice the diversity of lithologies. Colored rectangles show the position of b) and c). b) Dallol hydrothermal dome (Google Earth). c) Continental fan located on the border of the Danakil rift (Google Earth).

2.3. Port-Tarfaya - sand dunes

<u>*Location and geology:*</u> Port Tarfaya is located on the edge of the Atlantic Ocean in southern Morocco. It is located in a desert area subject to a prevailing NNE wind (fig. 3). The action of the wind has allowed the construction of many Barkhan-type dunes that line up along a corridor several tens of kilometers long. These dunes are formed from silica sand of homogeneous particle size. The dunes, however, present an internal structure in layers that are characteristic of their dynamics.

<u>*Scientific interest:*</u> Sand dunes are frequently observed on the surface of Mars (Gardin et al., 2012). The internal structure of a dune retains the signature of the winds that built it. They are therefore an excellent paleoclimatic indicator. The arid context of the Tarfaya region as well as the presence of siliceous sand dunes are particularly favorable for exploration by the Fly radar system.

<u>*Logistical parameters:*</u> Port Tarfaya is accessible by very good tracks and roads from Layoune airport. Accommodation is possible both in Port Tarfaya and Laayoune located 100km South. Flight authorization is required.

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Figure 3: Satellite image (Google Earth) of Port Tarfaya area. Notice the composite barkane dunes. The dominant wind that shapes the dunes comes from NNE.

2.4 Plio-Quaternary volcanoes of Azrou-Timahdite Plateau – Lava flow and geosite definition

Location and geology: The Plio-Quaternary volcanoes of Azrou-Timahdite plateau are localized in the middle Atlas. This volcanism is the most recent and the most extensive in Morocco (Baadi et al, 2021 – fig. 4). This alkaline volcanism has produced many volcanoes of decametric to kilometer size and many particularly well preserved volcanic flows which occupy the bottom of valleys.

Interest: The site presents analogies with Martian sites which show the presence of lava flows. In addition, the data collected would enrich the catalog of data relating to Moroccan geosites.

Logistical parameters: The site is located near the town of Azrou accessible by good roads from the Fez airport. Accommodation is possible in Azrou. The site of study is located 20 km South from Azrou. It is accessible by the road.

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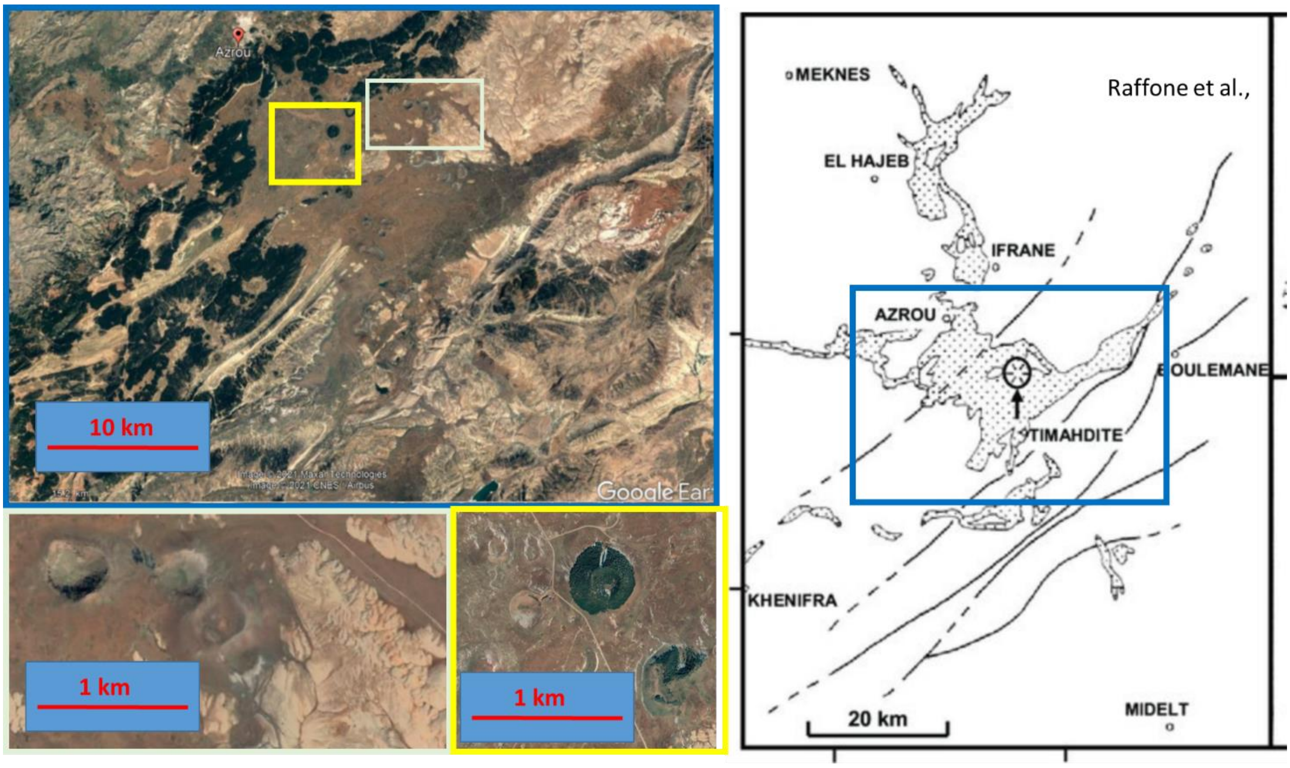

Figure 4: Right: Map of the volcanic flows around Azrou (Raffone et al., 2009). Left: Satellite images showing details about the volcanic constructions and lava flows. Notice that at least 5 geosites have been defined in this area. (Baadi et al., 2021)

2.5 Intrusion of Tichka – lithological contrast

Location and Geology: The Tichka massif is an emblematic area of the high Atlas mountain chain in Morocco (Lécuyer et al. 2017). It consists in 4 imbricated Variscan mafic to felsic plutons intruding a Lower Cambrian metamorphic volcano-sedimentary pile. The three southern plutons were emplaced sub-contemporaneously while the northern one was emplaced later. From North to South, the massif is composed by leucogranites, monzogranites, granodiorites-tonalites- diorites and finally by gabbros. The lithologies appear sometimes imbricated mainly for the most southern pluton where mafic rocks are closely associated and define a "zebra structure". The metamorphic basement is affected by at least 2 fold families of Variscan age.

Interest: The Tichka massif is an emblematic site for understanding the intrusion of diapiric plutons into a metamorphic pile. Beyond its great interest in terms of geosite, it provides a rich example of an assemblage of metamorphic and plutonic rocks, with a mineralogy and a cartography well characterized. As no plutonic rocks have been described on Mars, the site cannot be defined as an analog.

Logistical parameters: The Tichka massif is accessible by a very good road from Marrakech where an airport is available. A track allows the access to the study site. Accommodation can be done in the town of Taouma. Authorization for flight is required.

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Figure 5: Right: Map and cross section of the Tichka intrusion (Lécuyer et al., 2017) showing the internal structure of massif. From North to South: Leucogranites, Granodiorites, Diorite and Gabbro intruding a metamorphic sedimentary pile. Left: Google Earth images showing the entire massif and the contact between the massif and the metamorphic basement.

2.6 Foum Zabel carbonate turbidites

Location and geology: Foum Zabel is part of the central high Atlas chain, at the South of the town of Rich. The high Atlas (Skikra et al., 2021) is a Cenozoic mountain chain that result from the closure in transpression of a pull-apart active from Trias to Cretaceous in marine active environment that opened in a Variscan basement. The chain develops from the Atlantic Ocean. It crosses the Morocco in a ENE direction to the Algerian border where it takes a more NE direction to Tunisia where it ends close to the Mediterranean Sea. The tectonics of high Atlas is controlled by the rejuvenation of Variscan faults in extension during Mesozoic that closed with a strike slip component during Cenozoic. The High Atlas, that is a well-studied mountain chain, offers a wide varieties of lithology from the metamorphic basement to various sedimentary and volcanic rocks. The sedimentary pile located in Foum Zabel are turbidite carbonates (Quiquerez et al., 2013) was deposited in deep marine environment during the opening of the basin that occurred during Lias. It consists mainly of carbonate turbidite that originated from a carbonate platform located at South. The sedimentary succession contains also relics of bioconstructions of various sizes the biggest (the Tagount) reaching an elevation of 50 m above the paleo sea bottom. The Atlasic orogeny is characterized by a North-South shortening responsible of the development of thrusts, reverse faults and folds. The Foum Zabel deposits are now sub vertical at their boundary with the Tizi n'Firest reverse fault (fig. 5). The displacement associated to the Tizi n'Firest Fault remains discussed (Sarih et al., 2018)

Interest: The geometrical relations between the turbidite pile and the Tizi n'Firest could be determined using the data provided by the Fly Radar system in order to estimate the shortening associated to the fault. Moreover, the dip of the turbidite pile varies progressively from 90° close to the fault to 0° at 200 to 300m from the fault. The site is particularly well suited to test the response of the Fly Radar system to varying dips in a single lithology. This site is not a Martian Analog.

Logistical Parameters: Foum Zabel is located 10 km South of the city of Rich where accommodations can be

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found. The nearest airport is located in Fez. The site is accessible by a very good road and then by a track that cross the high Atlas toward the West. An authorization is required to investigate the area.

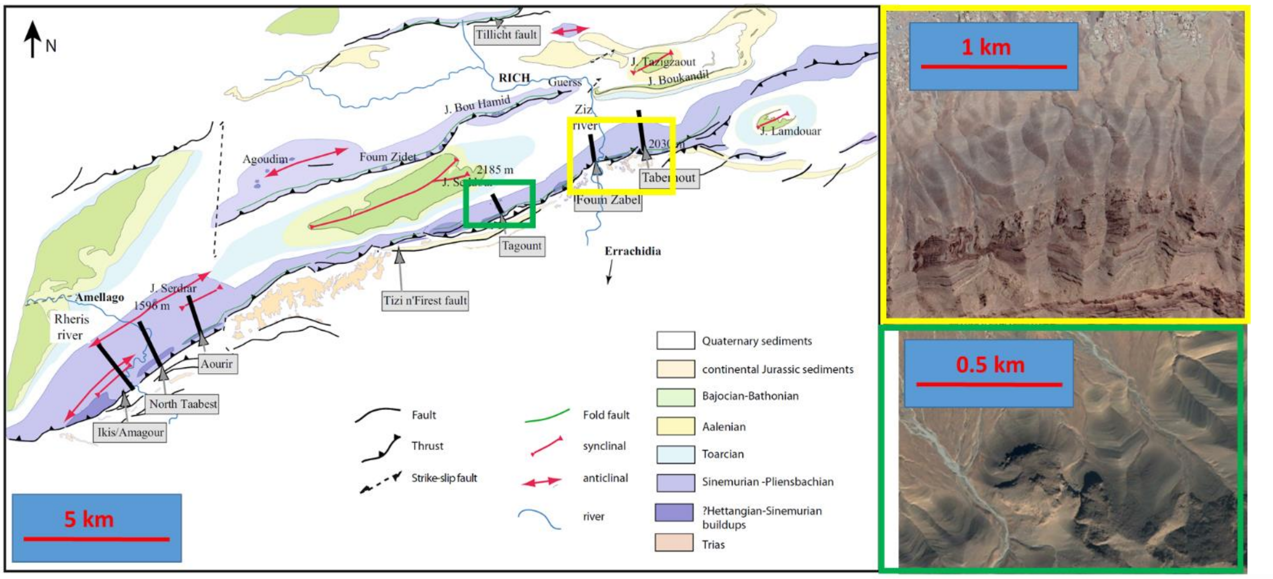

Figure 6: Right: Map of Foum Zabel (Quiquerez et al., 2013). Foum Zabel is located in the center of the high Altas chain South of the town of Rich. The Liassic deposits (in dark blue on the map) are mainly carbonate turbidites that were deposited from a Carbonate platform located at South. Upper Left: Google Earth images of the area showing details of the geometry of the deposits. Lower left: Google Earth image of the Tagount, two bio constructions of 40 to 50 m of elevation above sea bottom.

2.7 Djebel Bou Dahar

Location and geology: The southern High Atlas of Morocco offer exposures of relatively intact Lower and Middle Jurassic carbonate platforms which developed in a tectonically active rift-basin setting (Scheibner and Reijmer, 1999). Among these platforms the Djebel Bou Dahar is the most massive one. The platefom is located near the town of Bni Tadjite on the Eastern part of the Moroccan High Atlas. The Djebel Bou Dahar displays a well-preserved platform to basin morphology with no major tectonic disturbance.

Interest: The Djebel Bou Dahar offers the unique opportunity to study the underground geometry of the transition between a carbonate platform and the surrounding basin. Dykes of barityne are visible at the top of the platform. They provide interesting structure to test the detectability of vertical structures by the Fly Radar system. The Djebel Bou Dahar is not a Martian analog.

Logistical parameters: The Djebel Bou Dahar is located at 10 km East from the city of Beni Tadjit. It is accessible by a good rad and tracks are available to go to the top of the djebel. The nearest airport is Fez. Authorization for flight are required.

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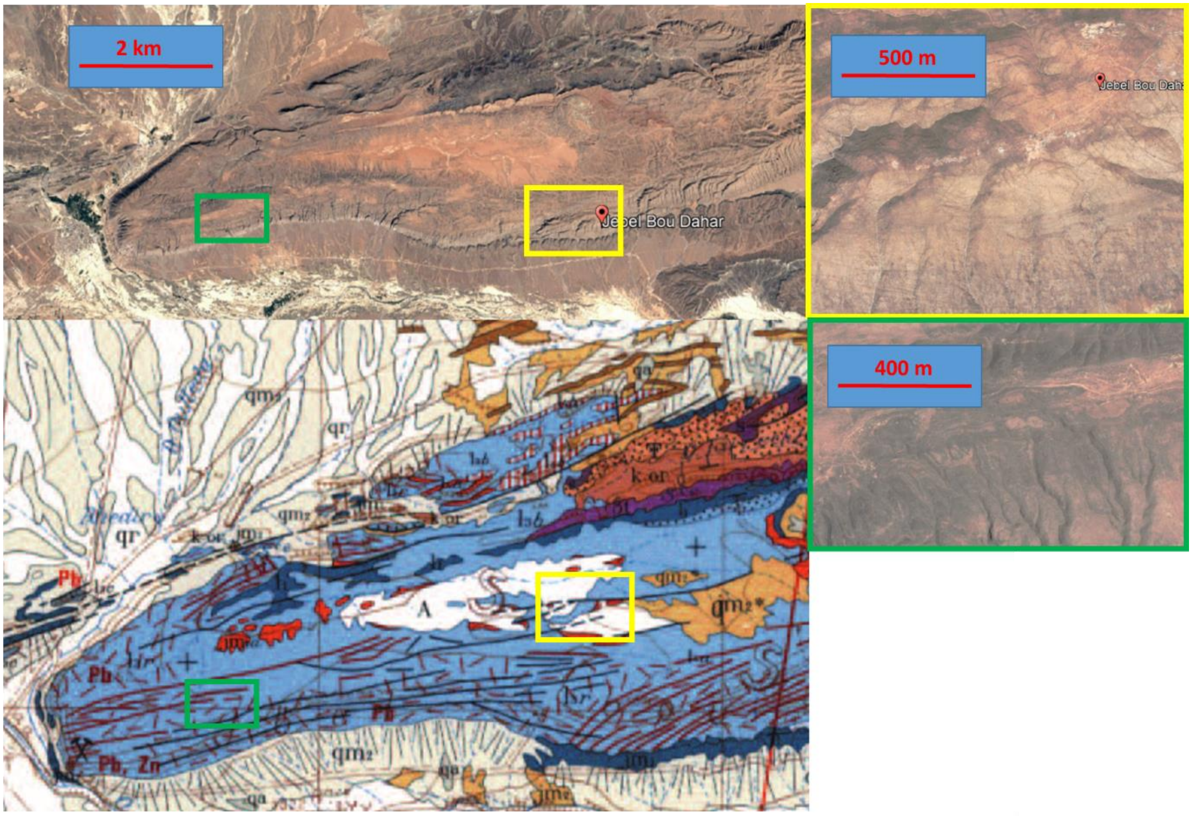

Figure 7: Google Earth images and map of the Djebel Bou Dahar located in the high Atlas of Morocco. The Djebel Bou Dahar is a Liassic bioconstruction that extend 10 km along an East West direction. The Djebel dominates the surrounding plain of about 80 m. It is composed of bio constructed carbonates intruded by dykes of barytine.

2.8 Erfoud

Location and geology: The city of Erfoud is localized between the High and Anti Atlas domains in a desertic environment. The Oasis of Tifilalet, located South of Erfoud is bounded by Oued Rheris at West and crossed by oued Ziz. The oasis is covered by a silt deposit which thickness varies from 1 to 5m. The Ground water table is under this deposits. (*Bouaamlat et al., 2016).*

Interest: Currently the thickness of the silt layer is estimated only from well data. It is necessary to have a better estimation of this thickness to manage groundwater in terms of sustainable development. Fly Radar system could be tested to provide a map of the thickness of the silt layer. This site cannot be strictly called a Martian Analog but it will be essential to provide map thickness of various capping layers that have been recently described on Mars.

Logistical parameters: The city of Erfoud is located South of the high Atlas at the beginning of Sahara. The city is accessible by the road from Marrakech or Fez where airports are available. Authorization for scientific investigations is required.

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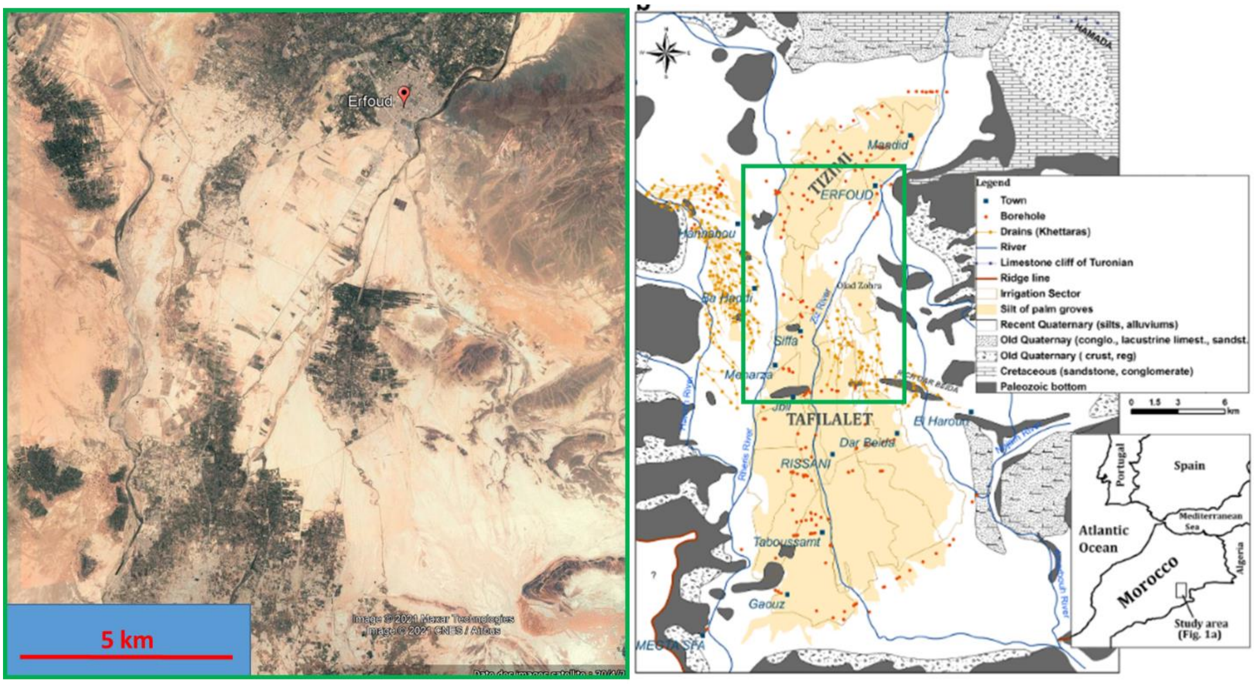

Figure 8: Erfoud area showing the extension of the silt deposited in Tafilalet Oasis between the Rheris and Ziz oueds. (map from Bouaamlat et al., 2016 – satellite image from Google Earth)

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Name of Site	Country	Coordinates		Lithology	Structure	Interest	Comments	Martian analog	References
		Lat	Lon						
Tabernas	Spain	37°03'N	2°23'W	Sediments	Flat Layers	Science	Active process	Yes	Canton et al., 2003
Dallol	Ethiopia	14°14'N	40°17'E	Volcanic deposit, salt layer, sediments		Science	Active process	Possibly	Lopez Garcia et al., 2020
Port Tarfaya	Morocco	27°38’N	13°02’W	Sand	Dunes	GeoSite*	Active process	Yes	Gardin et al., 2011
Azrou	Morocco	33°26'N	5°13'W	Volanic flows		GeoSite*	Very recent lava	Yes	Baadi etal., 2021
Tichka	Morocco	31°17'N	7°27'W	Plutonic rocks		Science	Fossil process	Possibly	Lécuyer et al., 2017
Foum Zabel	Morocco	32°10'N	4°22W	Carbonate layers		Science	Fossil process	No	Quiquerez et al., 2013
Bou Dahar	Morocco	37°17'N	3°25'W	Massive Carbonates		Science	Fossil process	No	Scheibner and Reijmer, 1999
Erfoud	Morocco	31°25'N	4°15'W	Silt cover		Science	Active process	Yes	*Bouaamlat et al., 2016*

Table 1: Selected sites for tests of the Fly Radar System.

***A “geosite” is a site of patrimonial interest that should be promoted for visit by the public*

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4. Logistical and technical constrains

For each site, some logistical parameters have been given. Subsequently, technical and logistical constraints linked to the place of maintenance and/or linked to the study sites are identified.

4.1. Constraints related to the service site

The Fly-Radar system will be transported from Italy and France to be deployed on the study sites selected for their scientific interests. Before the experiments, the system has to be assembled and tested. The first constraint is thus the availability of a clean workshop large enough to assemble the system (surface larger than 20 m^2). In this workshop, power will be available with at least 10 outlets on 220 V where tools will be plugged, where batteries of the UAV's and Radar will be put on charge, where computers will be put on charge. At least 2 workbenches will be available each with a surface of at least 3 m^2. The workshop will be equipped with storage system for tools. A network connected to the web will be also available, possibly with fast connection rate. The workshop will be located at less than 4 hours of a city where it will be possible to find consumable equipment that could be damaged during the test. The workshop will be located at less than 15 minutes of a test area where the system will be tested in a safe way after assembly or modification.

4.2. Constraints related to the study sites

The study sites selected by the scientists should be located in areas where it is legally possible to fly. It will be the responsibility of mission managers to obtain all the necessary authorizations for the flight. These authorizations depend on the country and may also vary depending on the study area (National Parcs, airports, military zones etc…).

The flight zones will be located on open ground, with low vegetation or without vegetation, far from any electrical, telephone or radar installation, far from any airport. It will be necessary to provide a flat area of 3 to 4 m^2 for the safest possible take-off and landing. The equipment will be transported in vehicles adapted to the terrain.

5. Conclusion

The main characteristics of the sites that have been selected to test and evaluate the Fly Radar system are given in Table 1. These sites cover the majority of the existing geological conditions on Earth and are, for some, analogues of Martian sites. Some of them offer a strong geopatrimonial interest. The complexity of the sites varies. Some sites are simple and can be studied first (Erfoud, Azrou, Djebel Bou Dahar, Port Tarfaya). Others have more complex geometry and less contrasting lithologies. They will have to be studied in a second step. One site has been selected in Europe. This is the Tabernas Desert site which has the advantage of proximity and geological simplicity. This site will make it possible to test the Fly Radar systems under simple logistical conditions. Finally, the Dallol site, initially planned, was described in the project. The current geopolitical conditions do not allow its exploration in the near future.

6. Appendix – Analog definition

A terrestrial site analogous to a Martian site is a terrestrial region which has experienced or is experiencing geological, environmental or biological conditions similar to Martian conditions. The study of analogous sites has always been important in planetology because it is a way of understanding terrestrial processes and extrapolating them to the environment of Mars. The study of these sites is also important in

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technological terms, as in the case of the Fly Radar project. It is about measuring the response of a particular probe on elements similar to those which we will be able to find on Mars. It is the latter type of study that will be carried out as part of the Fly Radar project.

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