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Ayyad University, Faculty des Sciences & Techniques
Marrakech, Morocco**

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Lahmidi

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**IGCP 653 Regional Workshop & Field Excursion
Cadi Ayyad University, Faculty des Sciences &
Techniques Marrakech, Morocco,**

Field trip Guidebook

**Middle Cambrian-Ordovician of the Central High Atlas and Anti-
Atlas Morocco**

October 21-23, 2022



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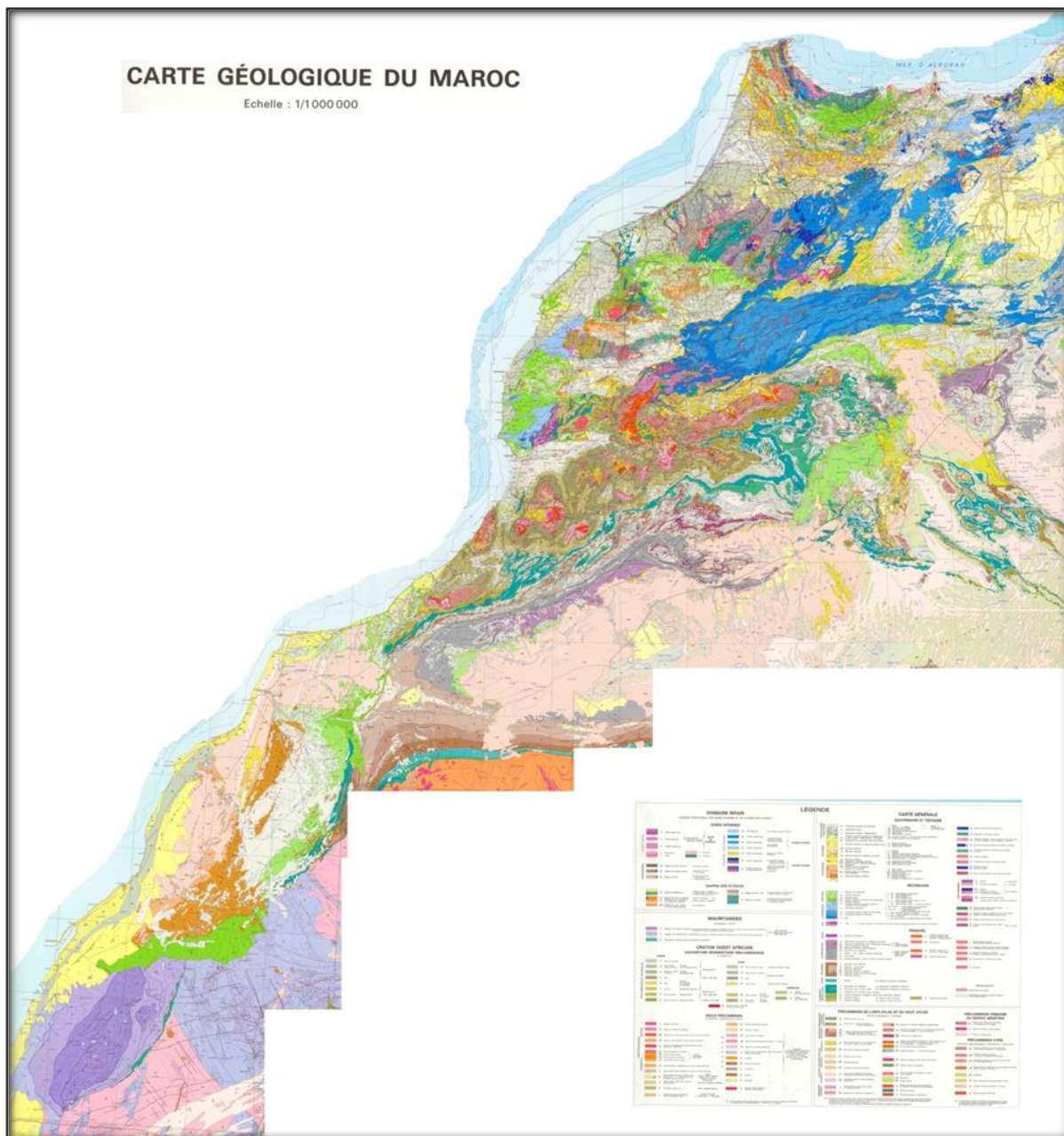


Figure 1: Geological map of Morocco (scale 1/1 000 000; NMSGM, N°260, 1985)

1. Presentation

The two-day trip itinerary was designed to study the Lower Ordovician outcrops along the well-known tourist transect through the Central alpine High Atlas and Central Anti-Atlas belts (*Fig. 2*).

The High Atlas intraplate chain is related to the Cenozoic African-European collision at the expense of the aborted Triassic-Jurassic rift that coincided with the opening of the Atlantic Ocean. In the Late Palaeozoic, the Anti-Atlas corresponded to the southern folded belt of the Hercynian (Variscan, Alleghanian) Mesetien-Mauritanian chains. It also includes large Precambrian inliers with a complex and protracted Eburnian and/or Pan-African history. The present-day topography of Anti-Atlas was also acquired during the Cenozoic Alpine orogeny.

Our goal is to present and discuss sedimentological and palaeontological features of the middle Cambrian to Lower Ordovician. The focus is on the Lower Ordovician Fezouata series, which have produced exquisite and well-preserved fossils.

The first day (J1) is devoted to observing the main geological features along the section of the Central High Atlas and the Anti-Atlas from Marrakech to Zagora. Due to the length of the trip, the focus is on the middle Cambrian-Lower Ordovician outcrops at the Tizi n'Tichka pass. The Aït Saouan inescapable stromatolite limestones of the Upper Ediacaran Ouarzazate Group and the scenic view of the Ordovician Jbel Kissane in the north of the Draa valley are the target stops in the Central Anti-Atlas.

The second day (J2) focuses on the Upper Ordovician glacial event recorded in the Second Bani Group at Oued Tarhbalt and the Lower Ordovician Fezouata series, which is famous for their very diverse and well preserved fossil faunas. A long stop is planned at Jbel Tizagzaouine, probably the most iconic site of the Fezouata Shale Lagerstätte, and recently listed within the 100 major international geosites by the IUGS.

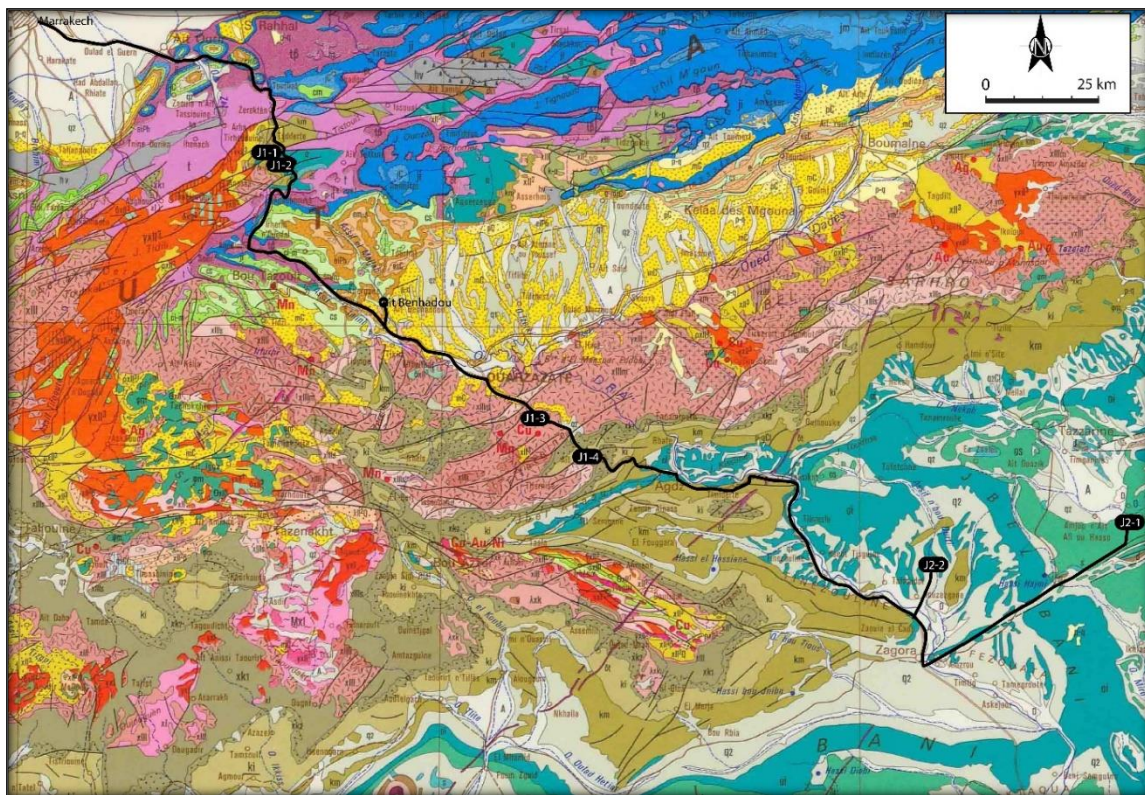


Figure. 2: Field trip itinerary and stops plotted on the geological map the Central High Atlas and the Anti-Atlas (extracted from Geological map of Morocco, scale 1/1 000 00).

2. Central High Atlas and Anti-Atlas geological survey

Morocco is located in northwestern Africa (Fig. 3), and its geological evolution has been significantly influenced by its location on the northwestern margin of the 2 Ga-stable West African Craton (WAC). In southern Morocco, the Reguibat shield in southern Morocco, is roughly bounded to the north by a series of mobile belts of decreasing age. Most of the Precambrian Eburnean and/or Pan-African events occurred in the extreme southernmost in the Anti-Atlas belt located between the Alpine Atlas Mountains and the intracratonic Palaeozoic Tindouf basin. The Late Palaeozoic Variscan overprints are unevenly expressed from the Oulad Dlim area in northern Mauritania in the South to Meseta in the North.

We present below a brief updated overview of this geological evolution.

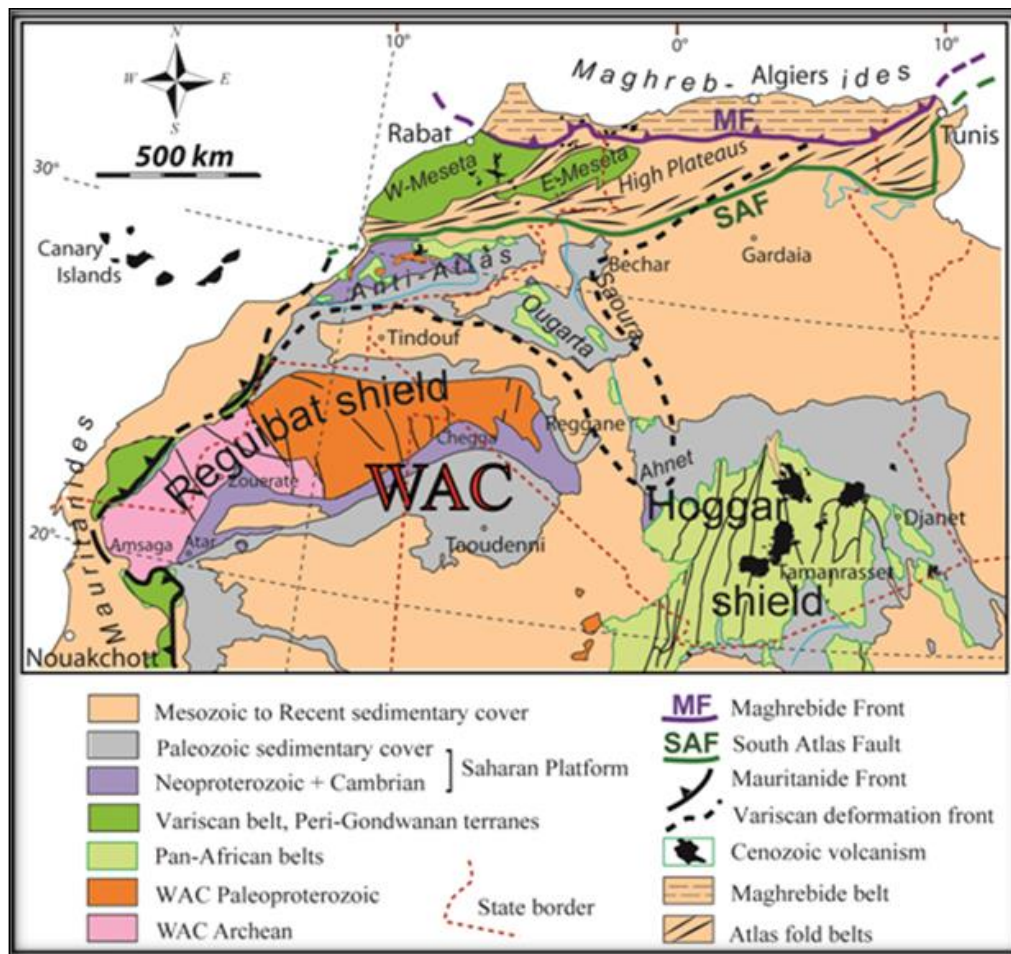


Figure 3: Main geological domains of Morocco and its neighbours in northwestern Africa (after Michard et al., 2008).

2.1. Precambrian basement

The oldest rocks in Morocco occur in the Archean Reguibat shield at the northwest of the West African Craton (WAC). Paleoproterozoic rocks crop out in the inliers of the central and western Anti-Atlas to the north, south of the Anti-Atlas Major Fault (AAMF) (Choubert, 1947). They consist of metamorphic rocks intruded by 2 Ga granitoids (Walsh et al., 2001; Thomas et al, 2002; Gasquet et al. 2008; Blein et al., 2022).

Except for a few mafic dykes (El Bahat et al. 2013; Kouyaté et al.; 2013; Youbi et al., 2013), Mesoproterozoic sediments are absent from the Anti-Atlas. Therefore, Neoproterozoic formations overlie directly the Paleoproterozoic basement. Globally, Neoproterozoic deposition is associated with three main stages of the Pan-African cycle: i) Early Neoproterozoic platform development, marked by the accumulation of quartzites and stromatolitic limestones succession (Tachdamt-Bleïda Group) (Bouougri et al., 2022), related to a rifting event coeval to the break-up of the Rodinia supercontinent. The Tachdamt-Bleïda platform coincides with oceanic accretion along the AAMF through the Bou Azzer-El Graara and Siroua (Bou Azzer Group) ophiolitic sequences (760 Ma), (Leblanc, 1975; Saquaque et al., 1989; Thomas et al., 2002; Hefferan et al., 2000; 2014); ii) The closure of the oceanic areas and subsequent Pan-African collision began at 750 Ma and peaked around 650 Ma (D'Lemos et al., 2006; El Hadi et al., 2010; Blein et al., 2014). They are associated with complex oceanic subduction and accretion of oceanic arc formations along the northern margin of the WAC (Hefferan et al., 2014); iii) During the Ediacaran waning stages of the Pan-African collision, the Late Pan-African transpressional to transtensional events were first recorded by thick sequences of folded Saghro Group turbidites and then by extended Ouarzazate Group volcanic and volcanoclastic records. The Cryogenian-Lower Ediacaran Saghro Group forms the basement of the Eastern Anti-Atlas and High Atlas.

2.2. Palaeozoic series and Variscan Orogeny

Seawater first invaded the northwestern regions where the Adoudounian "Série de base" was deposited, and then flooded the eastern Anti-Atlas basin (Choubert, 1963). The Precambrian-Cambrian transition (542 Ma) is thought to lie in the lower part of the Adoudounian limestones (Maloof et al., 2005), on the uppermost Ouarzazate Group or the gap between them (Karaoui et al., 2015). Cambrian marine sediments gradually evolved into thinner, more detrital sediments that developed eastward. On the entire Anti-Atlas scale, Upper Cambrian deposits are reduced or lacking.

During the Ordovician, a less subsident epicontinental sea occupied the Anti-Atlas domain and deposited clastic rocks from cratonic sources. At the end of the Ordovician, the southern high latitudes of the Anti-Atlas received periglacial sediments fed by icebergs from the Saharan domain.

The Silurian transgression caused by the melting of the Saharan inlandsis again invaded once more the entire Anti-Atlas. Graptolite black shales were deposited in shallower and less oxygenated seas and form the parent rocks for the Saharan oil. The Lower Devonian formations closely follow the Silurian strata and are represented by concordant bedded limestones and mudstones. At that time, the low latitude location of the Anti-Atlas domain allowed the installation of coral reefs associated with mud mounds that spread during the Middle Devonian. From the Famennian period, the sediments are no longer originating from the craton, but from the Anti-Atlas axis that has been uplifted. South of the Famennian Drâa plains, the Carboniferous series form impressive cuestas on the northern boundary of the Tindouf basin. (Jebel Tazout and Jebel Ouarkziz). Further south, the Upper Namurian to Stephanian continental deposits completed the cycle, and record the Variscan uplift of the Anti-Atlas.

In the Western Anti-Atlas, the 10 km-thick Palaeozoic series, accumulated over 200 Ma, correspond to the infilling of a large intracratonic basin, including the non-deformed Tindouf basin in its southern half (Burkhard et al., 2006; Soullaimani and Burkhard, 2008). Globally, the Anti-Atlas and Central High Atlas have experienced thick-skinned tectonic Variscan deformation with low intensity and significant heterogeneity. They differs markedly from the Variscan records north of the South Atlas Fault in the Meseta Block and the western High Atlas.

2.3. Mesozoic-Cenozoic series and Atlas-Alpine orogeny

The Mesozoic and Cenozoic evolution of the Central High Atlas and Anti-Atlas began with crustal extension processes associated with the dislocation of the Pangea supercontinent. Triassic rifts filled with detrital red beds sediments evolved along the High Atlas, while the Anti-Atlas area served as a

raised southern shoulder. Triassic synrift deposits are capped by widespread tholeiitic basalt flows (CAMP), dated around 200 Ma (Hailwood and Mitchell, 1971). From this period, only a few northeast-southwest mafic dikes remains in the Anti-Atlas, cutting Precambrian and Paleozoic rocks.

The Central-Eastern Atlas rift contrasts sharply with the western one that develops into the Atlantic Ocean. The postrift carbonates of the Lower Liassic platform seal the Triassic rifting. Thereafter, starting during the Middle Jurassic, the Central High Atlas gulf becomes an internal faulted trough, where the rhombic geometry of the present-day synclines and anticlines, and the intrusion of gabbro in the anticlines, would suggest a sinistral transcurrent motion (*Laville and Piqué, 1992*). In the High Atlas, Jurassic-Early Cretaceous continental deposits predominates. The geodynamic significance of Middle Jurassic-Early Cretaceous tectonic-magmatism remains controversial.

Beginning in the Albian, the African plate rotated counter-clockwise, approaching Eurasia when the Southern and Equatorial Atlantic opened up. Plate convergence will, from then on, guide Morocco's geodynamic evolution. Simultaneous intense activity of ocean ridges leads to global sea-level transgression. The Upper Cretaceous sediments constitute a marine cycle which begins with Aptian-Albian and Cenomanian-Turonian limestones and continues with Upper Cretaceous regressive facies. In the Western and Central High Atlas and Western Meseta, the Atlantic transgression continued into the Eocene, allowing the deposition of the famous Maastrichtian-Ypresian phosphate series. Confined marine environments existed in the High Atlas until the Middle Eocene. During the Late Eocene-Oligocene and the Neogene, compressive deformation occurred within the entire chain, but was particularly concentrated in the marginal zones. Two major pulses of detrital facies are recorded in the weakly subsident foredeep, indicating the uplift of the chain, first during the Oligocene, and second during the Miocene. Compressional deformation continues during the Miocene-Pliocene and Quaternary times, resulting in externally verging thrust faults along the northern and southern sides of the chain. Today's High Atlas and Anti-Atlas topography is not isostatically compensated as the existing root (34–39 kilometres) is poorly marked. Atlas crustal shortening by no more than 10 to 25% was added to asthenospheric uplift, evidenced also by high heat flux and the emplacement of the Miocene to Quaternary alkaline volcanism (Siroua - Middle Atlas province) (*Teixell et al., 2005; Missenard et al., 2007; Fullea et al., 2007, 2010*).

3. Lower Ordovician in Southern Morocco: An Overview

3.1. Introduction

During the Ordovician (488-444 Ma), most continents were gathered in the Southern Hemisphere, forming the Gondwana super-continent centred on the South Pole (Scotese *et al.*, 1999; Fortey and Cocks, 2003). Large siliciclastic deposits develop on large platforms along the Gondwana edges (Legrand, 1973; Destombes *et al.* 1985) (Fig. 4). These "giant" peri-Gondwanan platforms are considered to be the most important through the Phanerozoic.

Since 1952, the study of the Lower Palaeozoic series in the Anti-Atlas has benefited from the work of petroleum geologists (Petrofina-BRPM), who accurately logged cross-sections in the western Anti Atlas and discovered the first diverse Cambrian trilobite faunas studied by Hupé (1953). Following the discovery of trilobite in the green shales of the External Feijas (Agdz region, Central Anti-Atlas) by G. Choubert, P. Fallot J. Hinder-Meyer and H. Hollard in the early 1950s in the green shales of the External Feijas (Agdz region, Central Anti-Atlas), the Tremadocian, first stage of the Ordovician, was definitively evidenced in southern Morocco (Choubert *et al.* 1955)

The period from 1960 to 1990 was dominated by the intensive field activity of Jacques Destombes, who was responsible for studying the Lower Palaeozoic strata for the 1:200.000 geological mapping program. This prominent worker provided the first detailed biostratigraphic framework for the Anti-Atlas Lower Ordovician, collecting thousands of fossils that were subsequently described in a series of monographs (see Destombes *et al.*, 1985, and references therein).

Lower Ordovician sediments were deposited in peripheral intracratonic rifts on the western margin of Gondwana, often represented by shallow platform sediments (Babin, 1993; Destombes *et al.* 1985). These shallow shelf sediments are predominately siliciclastic interlayered with limestone or mixed siliciclastic/carbonate sediments, with horizons of oolitic ironstones and glauconites.

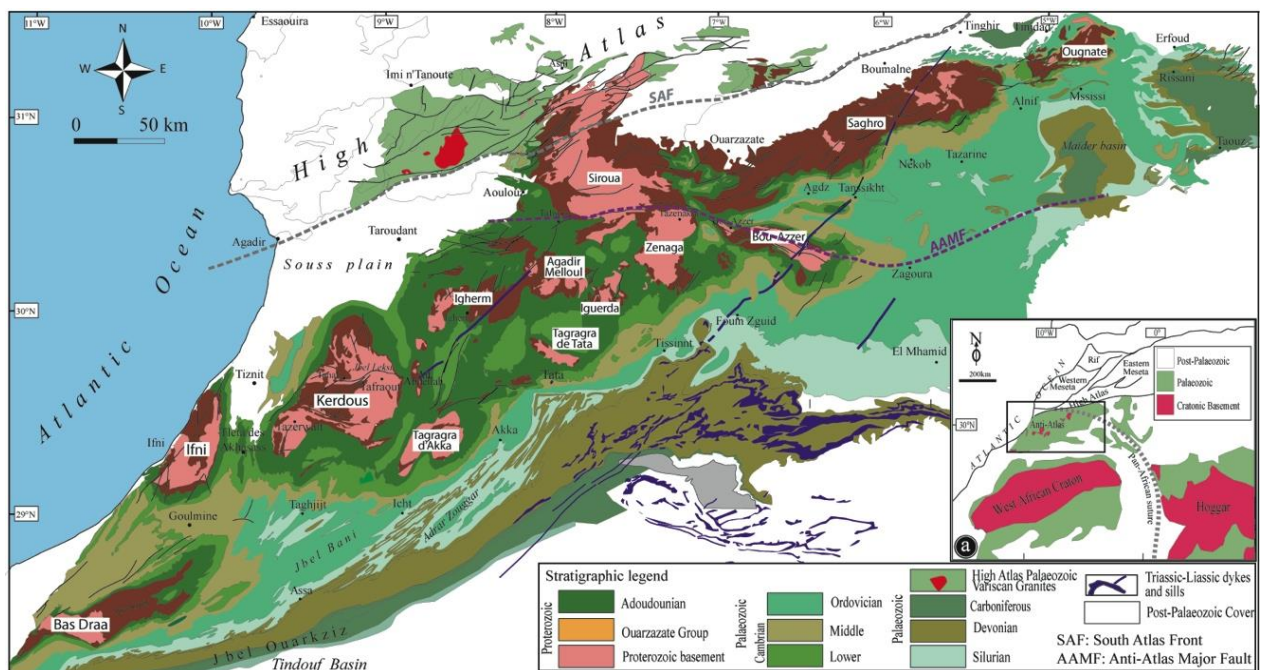


Figure 4: Generalized geological map of the Anti-Atlas, simplified from the Geological Map of Morocco, scale 1:1,000,000 (Service Géologique du Maroc, 1985); Insert (a): Location of the Anti-Atlas within the structural domains of NW Africa (in Soullaimani *et al.*, 2014).

3.2. The middle Cambrian and Cambrian-Ordovician transition:

The middle Cambrian formations are classically divided into two main lithological units: the Internal Feijas Shales (“Schistes à *Paradoxides*”; late Agdzian - early Languedocian) overlain by the Tabanit Sandstone (late Languedocian - Furongian). In the Anti-Atlas, the middle Cambrian succession shows significant variations in thickness from 1,200 to 1,300 m in the SW, to a thousand of meters in the region Fom-Zguid and only 300 to 400 m on the southern flank of Jbel Ougnat (eastern Anti-Atlas)

The Internal Feijas Shales lies over the Asrir Formation (“Grès terminaux”; Early Agdzian) and the famous “Brèche à Micmacca” (middle Agdzian, at the lower-middle Cambrian boundary). In fact, the lower–middle Cambrian boundary interval in Morocco is characterized by neritic siliciclastics with multiple intercalations of thin carbonate horizons developed as bioclastic limestone beds, originally termed “Brèche à Micmacca” by Bondon and Neltner (1933) (Stop J1-2). Near Agdz, the “Brèche à Micmacca” corresponds to a lenticular limestone horizon, rich in disjointed skeletal remains (*Bondon and Neltner, 1933*). Following this transgression, a considerable period of volcanic activity occurred in the western High Atlas and local emersions around the promontory of Ouzellarh and the country of Skoura area. These phenomena were considered by G. Choubert as distant influences of the Baikalian phase.

The upper Cambrian (Furongian) corresponds to a major stratigraphic gap in the Palaeozoic sedimentation throughout Morocco, except for some restricted areas of the western Anti-Atlas (*Destombes and Feist, 1987*) and the western High Atlas (*Cornée et al., 1987*). The scarcity of Furongian deposits is still debated, it may be due to the uplift of Central and Eastern Morocco as a tectonic shoulder of the spreading Iapetus (*Burkhard et al., 2006*). On the southern flank of Jbel Saghro, a small lumachellic limestone lens rich in middle Cambrian trilobites is overlain by red formations that yielded Furongian brachiopods (*Havlíček, 1971*).

3.3. The Ordovician:

The Ordovician series occur continuously over more than 600 km along the southern flank of the Anti-Atlas (*Fig. 4*). They consists of two morphological depressions (the External Feijas and the Ktaoua) separated by the quartzite cliffs of the First Bani, and is topped by the quartzitic cuestas of the Second Bani. This morphological subdivision, defined in the Central Anti-Atlas, is less clear in both the east and west where sandstone bars develop within shale units.

Lower and Middle Ordovician deposits consist of several hundred meter-thick shales and sandstones with frequent hiatuses, disconformities and shallow water iron oolites (*Destombes et al., 1985; Marante, 2008*). The maximum of subsidence of the Ordovician Saharan platform occurred in the western and central Anti-Atlas. By contrast, the eastern parts of the Anti-Atlas were less affected, and the Tremadocian deposits are completely absent in the Jbel Ougnat area (*Fig. 5*).

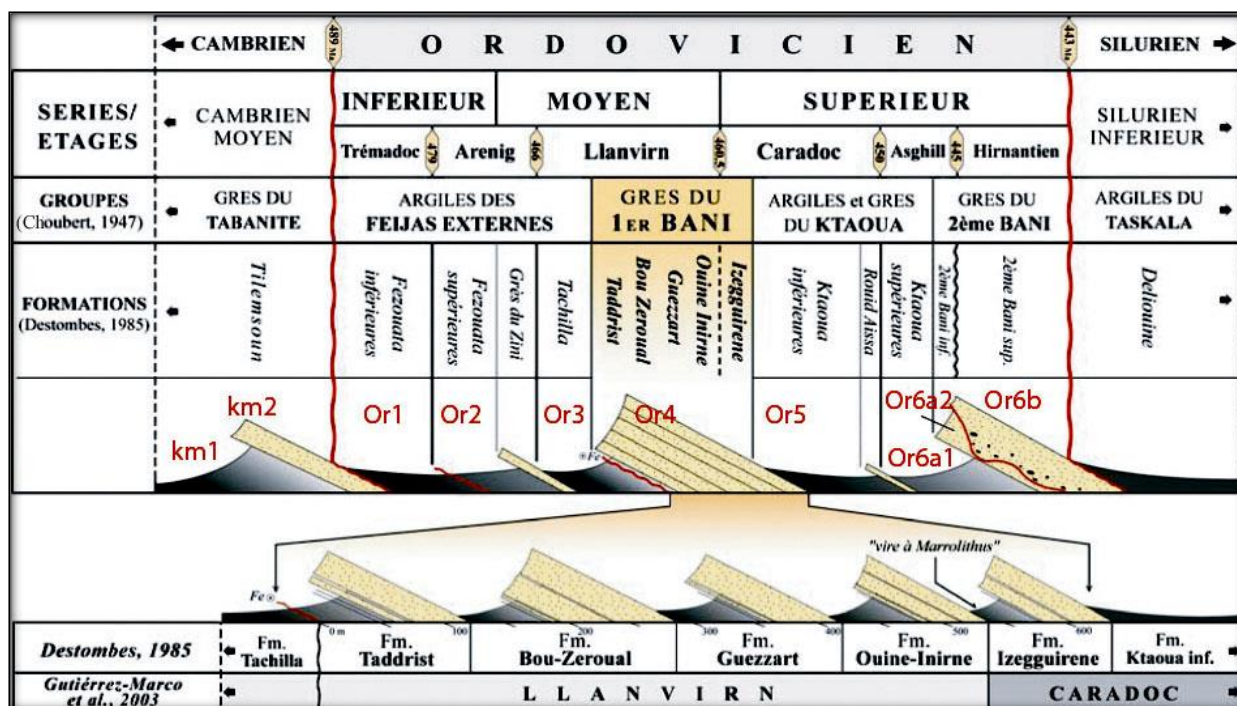


Figure 5: Middle Cambrian-Ordovician stratigraphic succession and details of the First Bani Group (according to Destombes et al., 1985, modified by Marrante, 2008). km and Or: abbreviations used in the 1/200 000 geological map, Zagora-Coude du Drâa sheet for Cambrian and Ordovician respectively.

The epicontinental Ordovician series were divided into four major lithological units (groups), first identified by Choubert (1942) in the Central Anti-Atlas.

3.3.1. External Feijas shales Group Formation (early Tremadocian to early Darriwilian),

This group is divided, from the bottom to the top, into three formations: i) the blue-green to beige **Fezouata Formation** transgressed on the middle Cambrian Tabanit sandstones, has its maximum thickness (~900 m) in the Draa valley. Since the early 2000s, the well-preserved levels in the middle part of the Fezouata Shale have yielded abundant remains of soft-bodied, previously unrecorded organisms (e.g., anomalocaridids, marrellomorphs, palaeoscolecoid worms, xiphosurans) (Stop J2-2 and 3); ii) the **Zini Formation** represents a lateral equivalent of the uppermost part of the Fezouata Shale, which is particularly thick in the western part of the Anti-Atlas, where it corresponds to 300 to 450 m of sandstones and quartzites (Jbel Zini); iii) the **Tachilla Formation** (early Darriwilian) represents a new cycle of bluish-grey transgressive shales deposits, extending widely in the Anti-Atlas belt, including the previously emerged Tiznit area, which in turn becomes the most subsident area with up to 1200 m of shales interbedded with sandstone levels. In the rest of Anti-Atlas, the 300 m thick Tachilla Formation typically begins with an oolitic ferruginous conglomerate level.

3.3.2. First Bani Group (late Darriwilian to early Sandbian)

The First Bani Group is composed of regularly and 300 to 400 m thick sandstones, forming a prominent landform feature along the southern flank of the Anti-Atlas. It corresponds to a regressive episode over the Tachilla Shale with a gradual enrichment of detrital elements in most of the Anti-Atlas, except for the Tafilalt-Maïder area, where the transition is marked by a discordant oolitic ferruginous horizon (Toughza), and in the south-western Anti-Atlas (Jbel Zini) where the sandstones of the First Bani may have been eroded.

3.3.3. Ketaoua Group

The facies of Ordovician rocks become again clayey in the Anti Atlas. The fauna is characteristic of the Upper Ordovician (Sandbian-mid Katian), and displays strong similarities to that of Bohemia. In the Tafilalt, several levels of the Ktaoua Group and of the underlying Izegguirene Formation (uppermost unit of the First Bani Group) have yielded exceptionally preserved assemblages comprising paropsonemid eldonioids, fully articulated machaeridians, lightly sclerotized arthropods (aglaspidids, cheloniellids), palaeoscolecoid worms, soft-bodied hydroids, and numerous echinoderm dense beds packed with crinoids, edrioasteroids, eocrinoids, ophiuroids, rhombiferans, solutans, starfish and/or stylophorans (Lefebvre *et al.*, 2008, 2022; Gutiérrez-Marco and Garcia-Bellido, 2015).

In the Tafilalt, the late Katian limestone biostrome with bryozoans (*Trematopora*, *Arthropora*, etc.) is the only Moroccan witness of the short but extensive development of bryozoan limestones and associated 'temperate' assemblages of brachiopods, echinoderms and trilobites (Alvaro *et al.*, 2022; Ernst, 2022; Villas and Colmenar, 2022). This marked shift from siliciclastic to carbonate sedimentation, which is recorded everywhere else in the whole Mediterranean Province during the late Katian (e.g. Armorican Massif, Carnic Alps, Corbières, Iberian Chains, Montagne Noire, Sardinia), is probably related to the Boda Event (short warming event before the onset of the Hirnantian glaciation; Fortey and Cocks, 2005)

3.3.4. Second Bani Group

The sandstone levels of the Second Bani constitute the last resistant bar forming a cuesta before the Draa lowland occupied by the Siluro-Devonian terrains. The lower formation lies conformably on the Ktaoua argillites, above a thin level of bryozoan limestones, and consists of about 160 m of light or dark quartzites, with oblique laminations, alternating with bioturbated argillites and sandstones. The fauna is rich in Hirnantian brachiopods. Abundant microconglomerate clays with exotic pebbles, as well as sedimentary figures both suggest a glacial environment, as evidenced by the presence of striated floors and submeridian paleovalleys.

The sedimentary records of the Second Bani Group are represented by the preglacial Lower Second Bani Formation which is truncated by the glacial erosion surface and overlaid by the subglacial Upper Second Bani Formation. This erosion surface constitutes an undulating surface showing variability in depth of the incision. Below the unconformity, the Lower Second Bani Formation corresponds to cross-bedded, hummocky cross-bedded or parallel laminated sandstones with a shell concentration of Hirnantian brachiopods, interpreted as shallow marine clastic deposits.

4. The Lower Ordovician Fezouata Shale Formation in the Central Anti-Atlas

4.1. Introduction

From the Zenaga inlier to the western part of the Saghro massif, the Central Anti-Atlas, including the Bou Azzer-El Graara inlier, has been an important geological area since the Precambrian. The Neoproterozoic Anti-Atlas Major Fault (Choubert, 1947) is considered as a major Pan-African suture on the northern margin of the West African Craton (WAC). Its current box-fold shape results from the complex reactivation of basement faults during the Variscan orogeny (Soulimani and Burkhard, 2008). Along the southeastern side of the Bou Azzer-El Graara Massif with an Ougartian orientation, the central Draa valley displays a distinctive succession of Cambrian-Ordovician outcrops. Discovered in the Lower Ordovician Fezouata Shale in the early 2000s, the Fezouata Biota has become an important source of information for understanding the biotic turnover that occurred across the Cambrian–Ordovician transition.

4.2. Ongoing works:

The Fezouata Biota is crucial because it fills the gap in the fossil record of non-biomineralized animals between the Cambrian Explosion and the Great Ordovician biodiversification. The recent

discovery of several Early Ordovician Lagerstätten in the Central Anti-Atlas provides new insights into the first animal biodiversity in Early Palaeozoic times (Martin *et al.* 2014; Lefebvre *et al.* 2016b; Saleh *et al.* 2021a) (Fig. 6).

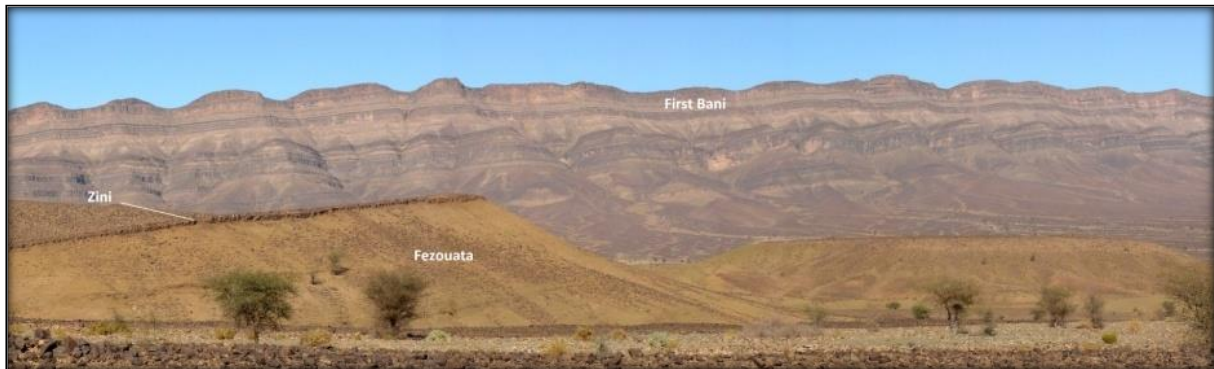


Figure 6: The Lower (Fezouata-Zini- Tachilla) and Middle Ordovician (1st Bani) in Zagora area.

In fact, the new Moroccan Lagerstätten are critical in unravelling the progressive settlement of marine ecosystems, shortly after the emergence of wildlife in the water column. Well-preserved soft-bodied faunas, from the external Feijas Group (Lower Ordovician) of Zagora area, partially fill this gap (Van Roy *et al.*, 2010, 2015; Lefebvre *et al.*, 2016b; Martin *et al.*, 2016; Saleh *et al.* 2021a). The co-existence of Burgess Shale-type organisms (such as demosponges, halkieriids, marrellomorphs, naraoids and anomalocaridids) with classical post-Cambrian faunal elements (such as cephalopods, crinoids, graptolites, ostracods and xiphosurids) suggests that the transition between the Cambrian and the Palaeozoic Evolutionary Faunas of Sepkoski (1979) was more complex and extended than previously thought. Exceptionally preserved soft-parts in fossils from the Fezouata Shale Lagerstätten have also yielded a wealth of new informations on the internal anatomy and zoological affinities of several enigmatic groups, such as machaeridians (now assigned to annelids; Vinther *et al.*, 2008; Parry *et al.*, 2019), halkieriids (re-interpreted as basal molluscs; Vinther *et al.*, 2017) and stylophorans (evidence of ambulacral podia, supporting their identification as derived echinoderms; Lefebvre *et al.*, 2019).

Since the discovery of Burgess Shale-type Lagerstätten in the Lower Ordovician of Morocco (Zagora area, Central Anti-Atlas), the Fezouata Shale has provided unexpected and unprecedented opportunity to gain insights into both the aftermath of the Cambrian explosion and the onset of the Ordovician radiation event (Van Roy *et al.* 2010, 2015; Martin 2014, 2016; Lefebvre *et al.* 2016b; Saleh *et al.* 2021a). Therefore, since 2012, the first challenge has been to clarify the palaeoenvironmental and stratigraphic contexts, with the aim of identifying the different horizons yielding exceptional preservation and specify their depositional environment. Extensive palaeontological excavations were initiated to collect as much information as possible about the composition and distribution of the Fezouata Biota assemblages in time and space. Excavation work began at Bou Izargane (see below) in January and February 2014, making it possible to investigate large areas (several tens of square meters) yielding several levels with exceptional preservation levels along a 18 m high section. These detailed field investigations have largely contributed to better elucidate the biostratigraphy (Lefebvre *et al.*, 2018), palaeoecology (Martin, 2016; Saleh *et al.* 2018, 2021b) and sedimentology (Vaucher *et al.* 2016, 2017) of the Fezouata Shale. They have also paved the way for new research on the geochemistry and taphonomy through the detailed analyses of several cores drilled through levels with exceptional preservation (Saleh *et al.* 2019, 2020a, 2021a, 2021b, 2022a).

4.3. Environmental setting

Sedimentological features indicate that the Fezouata Shale was deposited at, but mostly below storm wavebase, in a relatively shallow, open-marine environment (Vaucher *et al.* 2016, 2017; Saleh *et al.* 2018, 2019, 2021a, 2021b). Palaeodepth of the Fezouata Shale deposits range from 50 to 150 m, based on comparison with the depth of storm influence in modern oceans (Immenhauser, 2009),

The Fezouata Lagerstätte thus opens a unique and exceptional window into marine biodiversity in the Early Ordovician open-marine environment and allows for the first time an accurate correlation with the earlier well-documented open-marine exceptional Cambrian biotas. Many of them, such as the Burgess Shale (Canada; *Collom et al. 2009*), the Kaili (China; *Zhao et al., 2005*), the Sinsk (Russia; *Ivantsov et al., 2005*), and the Sirius Passet (Greenland; *Ineson et al., 2011*) Lagerstätten are associated with distal offshore environments, whereas the Emu Bay Shale Lagerstätte (Australia; *Gehling et al., 2011*) is characterised by a relative nearshore environment influenced by active margin tectonics.

In terms of environmental setting, the Fezouata Lagerstätte is more comparable to the Guanshan and Chengjiang Lagerstätten (*Hu, 2005; Hu et al., 2010; McKenzie et al., 2015*), although the prevailing environmental conditions in Chengjiang remain controversial (*Zhao et al., 2012*) and were probably slightly different from those in the Fezouata Shale. The most detailed and recent palaeoenvironmental analysis of the Chengjiang Lagerstätte suggests relatively shallow, unstable conditions in a deltaic environment, influenced both by storms and rivers floods (*Saleh et al. 2022b*). In contrast, the Fezouata Shale corresponds to a fully marine, shelf environment, without any fresh water (river) inputs (*Vaucher et al. 2016, 2017; Saleh et al. 2020a, 2021a*). Exceptional preservation in the Fezouata Shale results from the anoxia following smothering of distal environments (below storm wave base) by thin distal tempestites (*Vaucher et al. 2016, 2017; Saleh et al. 2020a, 2021a*). Such obrution deposits were not thick enough to bury and kill vagile elements of the benthos, which were generally able to escape. Consequently, the Fezouata Shale only preserves carcasses illustrating various stages of decay (*Saleh et al. 2020b*). This explains the rarity of entirely soft-bodied organisms (e.g. lobopodians) and external soft parts preserved (e.g. tentacles). Only internal soft parts (e.g. guts) are generally preserved in a wide range of organisms (e.g. halkieriid molluscs, hyolitids, machaeridian annelids, solutan and stylophoran echinoderms, trilobites), as well as lightly sclerotized organisms (e.g. aglaspidids, marrellomorphs). All in all, the Fezouata Biota preserves over 200 invertebrate taxa, encompassing a very wide range of modes of life: endobenthic (e.g. lingulid brachiopods, bivalves, numerous worms), epibenthic (conulariids, echinoderms, hyolithids, trilobites), nectobenthic/nectonic (e.g. anomalocaridids, naraoids), and pelagic (e.g. graptolites) (*Saleh et al. 2021c*).

Itinerary and stops

Day 1 (J1): Marrakech-Ouarzazate via Tizi n'Tichka (200 km)

Friday, October 21)

Themes : Marrakech High Atlas (MHA) and Central Anti-Atlas Agdz-Zagoura Transects: “Brèche à Micmaca” of the lower-middle Cambrian transition at Assanfou; Cambrian-Ordovician transition at the Tichka Pass; Late Neoproterozoic stromatolites at Aït Saoune; J Kissane Panorama north of Dra valley

Itinerary: (Figs. 1.1-1.4)

It is difficult to get to Zagora from Marrakech via the wonderful Tizi n'Tichka pass in one day. As a matter of fact, the beauty and geological diversity across the High Atlas and Central Anti-Atlas is worth spending more time, but given our goals, only a few stops are planned along the current Geotrail. To address this shortcoming, we have compiled below key geo-referenced geological features to assist participants during their journey between scheduled stops.

Route: The city of Marrakech and its palm grove remains were built on the Neogene and Quaternary of the Haouz plain. Many reliefs rise from the plain, corresponding to the Atlas uplift of Palaeozoic blocks (Jbel Gueliz and Jebilet massif to the north) (Figs 1 and 2).

From Marrakech, we drive southeast on the main road (R.P. 9) to Ouarzazate. The Haouz Plio-Quaternary plain is incised by intermittent streams or dry wadis, that are further northly tributaries of Oued Tensift and drain the High Atlas waters. One of the rivers (Oued Ghmat) crosses at km 20, just after the village of Chwiter.

The Haouz plain is traditionally considered as the Atlas foreland with relatively thin Neogene “molasses” (~200 m). The slope of the Quaternary alluvium increases imperceptibly towards the Atlas (glacis-terrace). Southward views allow the observation of various topographic levels of the Marrakech High Atlas. In the foreground, we see the mid-high hills of the Sub-Atlasic Zone, over-hanged in the background by the peaks of the High Atlas Mountains (Yagour Triassic plateau, Jbel Meltsen and Bou Ourhioul Proterozoic massifs, more than 3,500 m high). The mythical Jbel Toubkal, the highest peak of North Africa (4,165m), lies to the west.

The Mesozoic and Cenozoic Sub-Atlasic sequences are well exposed along the northern border of the High Atlas. The beautiful view in front of the village of Aït Ourir allows to discern from bottom to top thick Triassic-Liassic basalt flows, topped by Liassic reddish silts and dolomites (typical of the western tip of the Atlas Tethyan gulf), followed upward by Dogger marls passing to Lower Cretaceous pink silts, and finally a distinct cornice corresponding to Cenomanian-Turonian marine carbonates.

Then we start to cross the High Atlas chain from Aït Ourir. The road skirts first the Zat Valley for about 12 km, mainly on Triassic-Lias basalts. The cliff to the right (south) corresponds to the northern flank of the large Tidili syncline, an example of a series of supposedly detached synclines on the northern edge of the Marrakech High Atlas.

The road reaches the watershed between the Zat and Rdat valleys and begins climbing the Upper Triassic sandstones glacis. At GPS: N 31°30'14.52"; W7°27'49.20", we can observe the erosive slope on the western flank of Jebel Tagargoust on the left, showing red Triassic siltstones. We pass through the Triassic basalt outcrops, then reach the village of Toufliht in a beautiful pine forest, and get soon a wide view of the Oued Rdat valley, which deeply sinks within the thick red sandstones of the Triassic Oukaimeden Formation.

The road continues to climb, then slowly descends to the river. Two kilometers after Had Zrekten village, we cross both the Oued Tazlida (the western tributary of Oued Rdat) and the main branch of

the Zrekten-Meltsen fault zone, the north-eastern northern border of Proterozoic schists of the Ouzellarh Block (GPS: N 31°25'44.55" ; W 7°24'31.08") (Fig. 7; Ouanaimi and Petit, 1992).

The Proterozoic complex is composed of folded turbidites assigned to the Saghro Group of the Pan-African belt. Faulted granitoids stocks are intrusive in the Saghro Group with contact metamorphism zone (i.e. GPS: N31°25'10.21"; 7°24'21.31"W). One of these intrusive plutons assigned to the Ouarzazate Group constitutes the Ourgouz Mountain to the West (2424m).

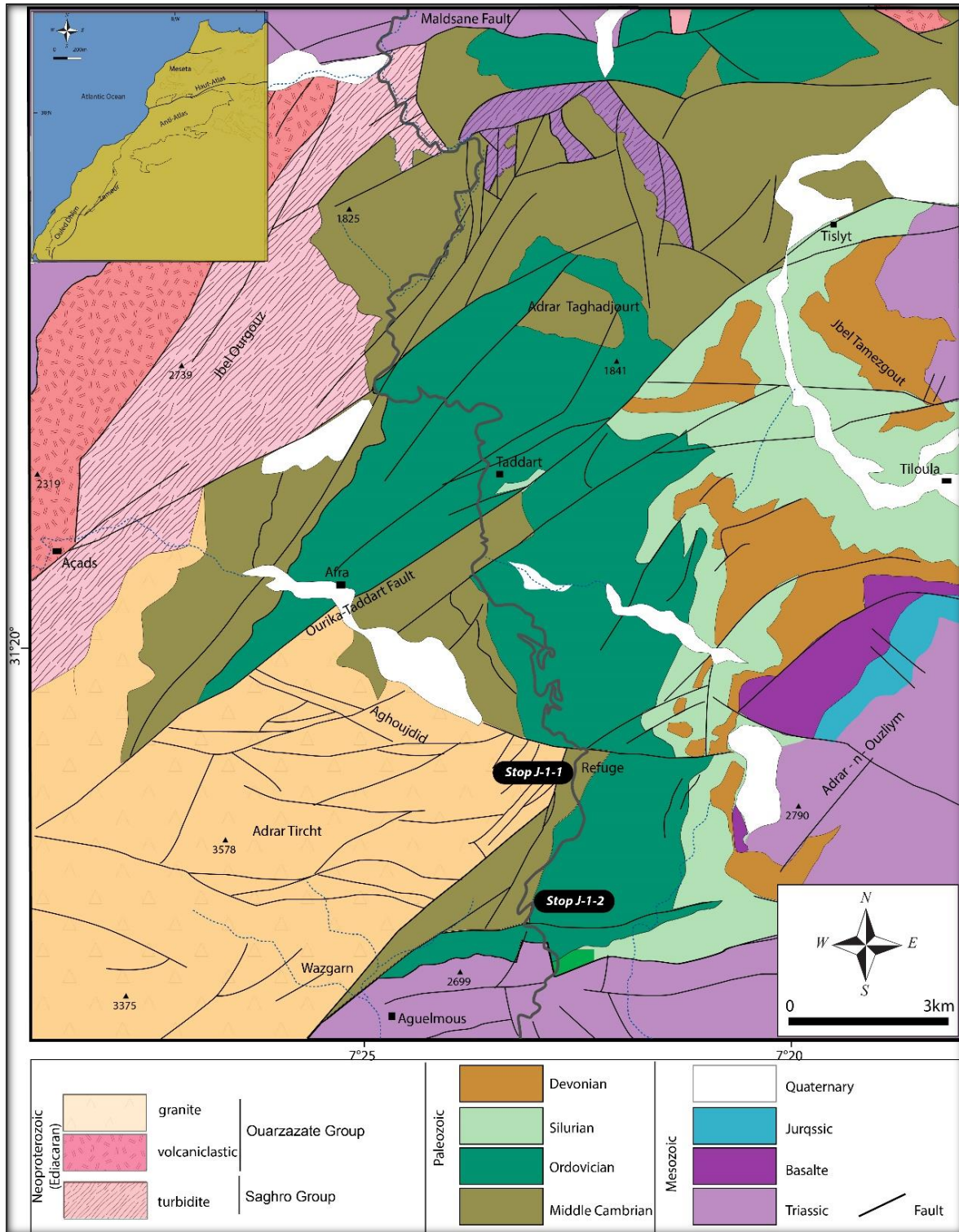


Figure 7: Geological map of the Tazlida-Tizi n'Tichka road, after Ouanaimi (1992).

To the south, the road passes through Cambrian formations (GPS: N31°24'49.22"; W7°23'52.62"), which dip gently to the South-east. Greenish middle Cambrian siltstones and greywackes unconformably overlay the Proterozoic basement. The middle Cambrian strata consist of greywacke with floated muscovite grains, devoid of tectonic cleavage. They yielded diverse trilobites, with the "Brèche à Micmacca" at the bottom, and *Paradoxides bohemicus* within the series. We are located south of the so called "Tizi n'Test Fault Zone-Atlas Palaeozoic Fault Zone" outside of the Variscan deformed areas that formed the Meseta Block. From a Variscan orogeny perspective, we are already in the less-deformed Anti-Atlas domain (Michard et al., 2010)

The road follows the "Assif Ghdat" (Assif=river in Berber) from GPS: N31°22'26.32"; W7°24'41.39", in the faulted, thick Ordovician pelites and sandstones, which display by place metre-size kink folds. About 5 km south of the village of Taddert, the road rises steeply to the Tichka Pass ("Tizi"). The highly crystalline massif of J. Bou Ourhioul appears to the southwest along the southern side of Assif n'Tichka.

In the western panorama, a large east-west fault separates the uplifted Bou Ourhioul basement (Late Neoproterozoic Ouarzazate Group) from the Cambrian-Ordovician formations to the north of the fault. Given the potential dangers of the Tichka pass, caution is advised.

After the first climb of about 7 km, the main road turns right and begins a slight drop slightly at the level of the "Refuge" (Assanfou Inn)

Stop J1.1: The lower-middle Cambrian transition "Brèche à Micmacca" at Assanfou Inn
(GPS: N31°18'21.07"N; W7°22'42.54")

Assanfou Inn welcomes you to rest after the hard climb of the Tichka Pass. Geologically, the area consists of a fault zone in which the middle Cambrian unconformably overlies the rhyolite blocks of the Bou Ourhioul massif of the upper Ediacaran Ouarzazate Group. It allows the observation of the lower part of the middle Cambrian, characterized by breccia level, rich in fragmented trilobites and brachiopods, called "Brèche à Micmacca". The outcrop can be reached after few hundred metres walk southwest of the Assanfou Inn. There are many places to reach the outcrop, the closest is at GPS: N31°18'21.07"N; W7°22'42.54" (Fig. 8).

The lower-middle Cambrian boundary interval in Morocco is characterized by neritic siliciclastics with multiple intercalations of thin carbonate layers, recording high-frequency sea-level changes. Large amount of these carbonates were developed as bioclastic limestone beds, originally called "Brèche à Micmacca" by Bondon and Neltner (1933). These limestone beds characterize the lower, Brèche à Micmacca Member of the High Atlas and Anti-Atlas Jbel Wawrmast Formation.

The Assanfou "Brèche à Micmacca" limestone beds are about five meters thick and lies above the upper Ediacaran rhyolite of the Ouarzazate Group. It is covered by blueish-greenish fine-grained greywackes of the middle Cambrian.

Little work was dedicated to the "Brèche à Micmacca" limestones. Its fossil composition shows an enormous range of species belonging to the trilobite, acrotretoid and articulate brachiopods, helcionelloids, hyoliths, different groups of echinoderms, cancelloriids and other systematic groups (Mghazli et al., 2021).



Figure 8 Google Earth oblique view of the Assanfou Inn with the localisation of the “Brèche à Micmacca”

We proceed to the Tizi n’Tichka pass (2260 m), which is no more than to 3 km away.

Stop J1.2: middle Cambrian-lower Ordovician transition in the Tizi n’Tichka pass
(GPS: N31°17'11.39"; W7°22'53.48").

Park at the Tizi n’Tichka car park. We start this stop by looking back toward the northeast. The Palaeozoic succession can be observed, from the middle Cambrian over the upper Ediacaran basement to Silurian black shales and Devonian carbonates, beneath the unconformable Triassic formations of Adrar n’Gout.

Right in front of us, on the lower slope, a fabulous cross-section allows us to look more closely at the transition from the middle Cambrian to the Lower Ordovician (Fig. 9). Along the eastern mid-depth monoclinical succession, the middle Cambrian “Schistes à *Paradoxides*” with a dip of about 40° are covered by a 2 m thick ferruginous conglomerate, followed by the uppermost levels of the Fezouata Shale (Floian). This transition is marked by a slight angular unconformity and the lack of the Tabanit sandstones that characterise the summit of the middle Cambrian and the lowest part of the Fezouata Shale (Tremadocian).



Figure 9: The middle Cambrian-Lower Ordovician transition at the Tizi n'Tichka Pass.

The ferruginous conglomerate can be closely observed along the road cutting, just behind us. Be cautious, due to the traffic on this narrow road, a high level of vigilance is required (stay on the road hard shoulders),

From Tizi n'Tichka pass, the southern flank of the High Atlas widens rapidly providing a scenic panorama to the south-east and the Mesozoic succession of the Telouet basin southward, in relation with the underlying northern branch of the South Atlas Fault. The Telouet depression is bounded to the South by the tilted Mesozoic-Cenozoic plateaux. This corresponds to the northern Sub-Atlasic zone of Ait Ourir, but here the series are virtually monoclinial, and only tilted by the uplift of the Ouzellarh Massif. The Liassic series are remarkably thin and rich in silts and argillites, while they gradually thicken to the east and become increasingly rich with carbonate levels, which can be observed in the far background in the east (Adrar M'Goun massif). From a palaeogeographic point of view, we are located at the southwestern border of the Atlas Tethyan gulf

Route: From Tizi n'Tichka pass, the road skirts the eastern border of the Adrar Assaoul (2686m), and then follows the Aguelmous valley. Triassic-Liassic basalts crop out extensively from GPS: N31°11'22.24"; W7°27'24.18". An impressive lava flow pile (with some coarse prismatic jointing) can be observed at the level of Agouim village in the northern flank of the Assif n-Tamnat valley. Much of the pile dates back to about 200 Ma, and was formed during the main magmatic event of the CAMP, coinciding with the catastrophic Triassic-Jurassic transition extinction. However, a recurrent basalt flow can be observed intercalated within the red siltites on top of the main volcanic pile. This ultimate lava flow has been dated at ~196 Ma, i.e. at the Hettangian-lower Sinemurian transition (Verati et al., 2007). It is overlain by lower Liassic reddish silts and carbonates on the western margin of the Atlas basin.

The road runs along the Assif Imini valley with beautiful countryside and kasbahs (ancient castles). The outcropping formations correspond to older stratigraphic levels as we approach the Imini anticline.

The road to Ouarzazate (ca. 40 km) runs through the reddish Senonian formations to Amerzgane. Then, pink-white hills of Mio-Pliocene silts can be observed on ridges of Late Proterozoic volcanic rocks. At the entrance of Ouarzazate (GPS: N30°56'25.18"; W6°59'7.61"), we turn right towards Agdz. From Ouarzazate to Zagora via Agdz, our route (road P 31) first follows the fault zone of Ouarzazate Group volcanoclastic series, which is filled locally with Neogene deposits.

Stop J1.3: late Neoproterozoic Amane n'Tourhart stromatolites
(GPS : N30°47'30.30"; W6°43'16.39")

About 25 km from Ouarzazate, this remarkable site is intended to offer the opportunity to observe stromatolite structures in the silicified carbonate sediments of the Ait Saoun-Tifernine antiform (Ouarzazate Group) (Fig. 10).

Park before the road, turn left and cross carefully to reach the outcrop on the left side.

Amane n'Tourhart stromatolites were first reported by *Choubert et al. (1952)*, who assigned them to *Conophyton*. They were subsequently revised by *Raaben (1980)*, who recognized some *Nucleela* structures and erected the parataxon *Conophyton amantourartensis*.

The Stromatolite limestones correspond to 3 m thick microbial constructions (biostromes), with undulating laminas at the bottom and evolving into domed structures to the top, more than 15 cm in diameter and 1 to 6 cm apart. These stromatolitic domes show polygonal circular sections. The spaces between the domes are filled by stromatolitic calcirudites and calcarenite. Laminas, 600 to 800 µm thick, formed by alternating levels of micrite-sparite levels and litharenitic siltstones.



Figure 10: A) Photographs of the Late Neoproterozoic Amane n'Tourhart stromatolitic limestones.

Route: Our route to Agdz reaches a faulted Cambrian anticline cored by the Ouarzazate Group basement at the village of Ait Saoun. Further north, the road crosses the lower Cambrian succession of

the southern flank of the Ait Saoun anticline. During the ascent to Tizi n-Tirifit (Tour Chardon) (GPS: N 30°43'34.31"; W 6°36'27.12"), the Precambrian-Cambrian transition is well-exposed on the southern flank of Tizi n-Tirifit, overhanging the Ait Saoun village.

After a pass at 1,665 m (GPS: N 30°42'57.08"; W 6°35'36.62") in the Adoudounian series, the valley on the right offers a great view of the deeply incised limestones layers, which dip gently to the southeast (optional stop at km-marker "Ouarzazate 52"). The "Lie-de-vin" series is well developed in the upper part of the upslope, but in contrast, the Adoudounian limestones are reduced (they are completely missing in the eastern Anti-Atlas).

After the pass, the descent to Agdz starts first on the "Calcaires supérieurs" then the "Grès Terminaux" of the lower Cambrian successions, where the last stop is planned.

Stop J1.4: the northern view of Jebel Kissane Ordovician
(GPS: N30°43'25.88"; W6°33'35.50")

The last stop of the first day's itinerary is intended to observe the famous northward view of Jbel Kissane, as it showcases the impressive Ordovician sandstone pile of the First Bani Group (late Darriwilian-early Sandbian) (Fig. 11). The Jbel Kissane forms the perched synclinal core of the East-trending synclinorium, which extends between the Bou Azzer and Saghro Precambrian antiforms. Younger Ordovician strata develop further eastward, up to the Second Bani (Hirnantian).

Route: The descent to Agdz (road P 31) follows successively the lower Cambrian "Grès Terminaux", the middle Cambrian pelites of Ourika n'Ourmast, the Tabanit Sandstones and Furongian Jbel Lmgaysmat sandstones. Finally, the Fezouata Shale forms the substrate of the Draa Valley, from Agdz to Zagora.

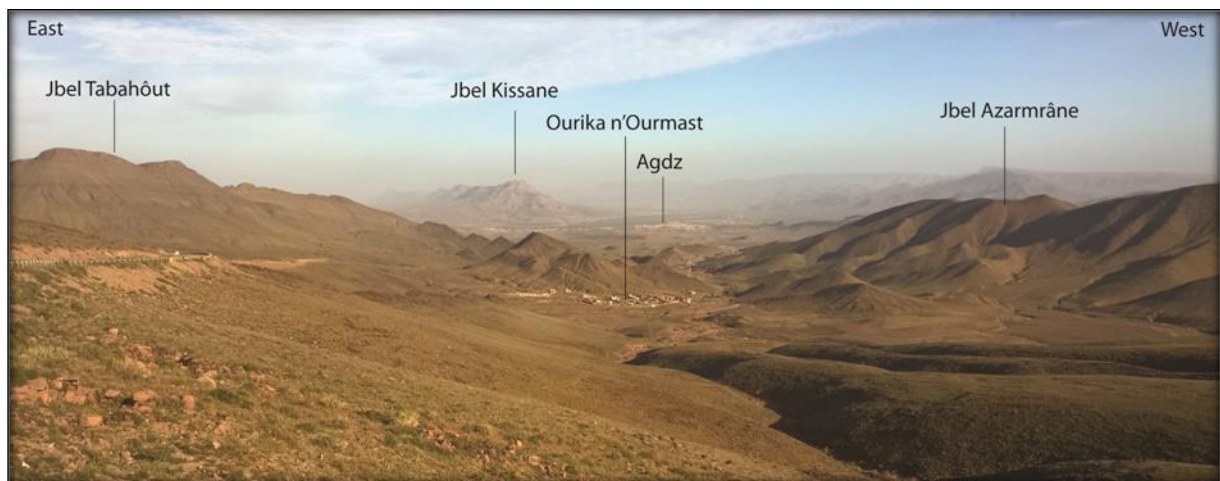


Figure 11: Southern view of the Cambrian Ourika n'Ourmast valley showing the Ordovician Jbel Kissane at the background.

End of Day 1 (J1).

First night in Zagora.

Day 2 (J2): Zagora-Tizoulina: Hirnantian tunnel valleys and Lower Ordovician Fezouata Shale

(Sunday, October 23)

Themes: Upper Ordovician Second Bani Group with glacial records at Oued Tarhbalt; Lower Ordovician Fezouata Shale at Jbel Tizagzaouine (Fezouata Lagerstätte- late Tremadocian), IUGS geological site.

The town of Zagora is located on the banks of Oued Drâa River, where the Fezouta plain is divided into the Ternata plain to the north and the Tagmout plain to the south by the Ordovician Jbel Bani-Adafane ridge. To the northwest, the middle Cambrian of Jbel Amergou, the south-eastern end of the El Graara-Bou Azzer inlier (Fig. 4), contributes to narrow the Drâa valley in no more than 2 km.

Geologically, the Zagora area is characterized by the prominent Zagora-Oum Jerane-Taouz zone fault (ZOTZF) that runs through the entire Central and Eastern Anti-Atlas. Jbel Adafane corresponds to the narrow ENE-WSW syncline of the Ordovician First Bani about 25km along this major fault. In the east, the ZOTZF reactivations lead to Silurian and Devonian collapses along the so-called “Zagora graben”. The precise age of the Zagora graben remains unknown. In the Fom Jerane area, this Fault zone likely controlled the Devonian sedimentation (Baidder et al., 2007). To the west, the ZOTZF appears to be connected to the WNW-ESE Anti-Atlas Major Fault (AAMF) of Choubert (1947). For this reason, some authors argue that the ZOTZF represents an eastern extension of the AAMF Pan-African suture (Hefferan et al., 2000 ; Samson et al., 2004, Inglis et al., 2004).

To sum up, the ZOTZF is considered to be the major long-lived crustal fault in the Central and Eastern Anti-Atlas, and played an important role during Precambrian times, Palaeozoic sedimentation, Variscan deformation and ultimately controlled the recent Atlas uplift (Soullaimani et al., 2014)

Late Ordovician glacial records at Oued Tarhbalt
(GPS : N30°32'58.93"; W5°19'54.93")

During the Hirnantian, the South Pole was positioned over the Gondwana supercontinent (Scotese et al., 1999; Evans, 2003) that was formed by the assembly of Africa, South America, Arabia and several peri-Gondwana terranes by Late Precambrian (Paris & Robardet, 1990; Evans, 2003). An ice sheet of 8000 km² was covering the Gondwana due to these high latitudes (Beuf et al., 1971; Veevers, 2005; Diaz-Martinez & Grahm, 2007; Ravier et al., 2014). This Hirnantian cold climate was examined through major erosion surfaces (Figs 12–13) and tunnel valleys as a result of the substratum erosion by subglacial meltwater-driven (Ravier et al., 2015).

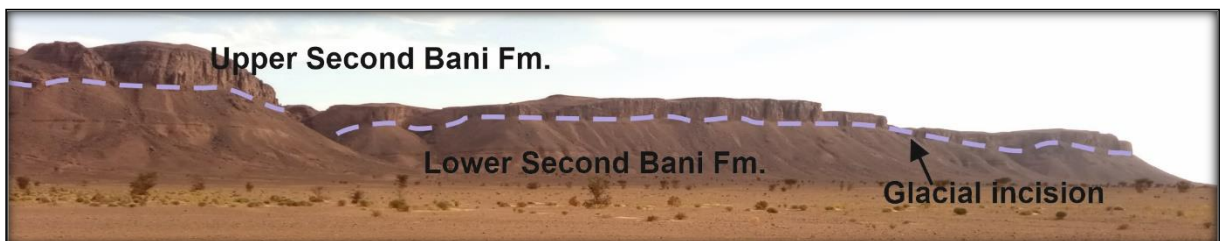


Figure 12: Panoramic views of the glacial incision surface, east of Tagounite village.

In the Anti-Atlas, the structure of tunnel valleys shows some morphological variations (Fig. 12). For example, in Alnif, two glacial incisions have affected the area and created a superimposed tunnel valleys system (Clerc et al., 2013), whereas Fom Larjamme exhibits one incision generation, and laterally truncates another tunnel valley in Tizi N'Tazzounghart, where it is attributed to a second episode of

tunnel valley (Le Héron, 2007). This difference in morphologies highlights the value of each location in the regional comparison of Hirnantian tunnel valleys, and therefore the processes responsible for their formation. Studies have evidenced a regional control of processes responsible for their formation, related to the distribution of palaeo-ice streams (Ravier et al., 2015). Accordingly, the generated network of tunnel valleys in Foug Larjamme is interpreted as having been cut between palaeo-ice stream pathways, while the Alnif tunnel valley is located in an inter-ice stream position.

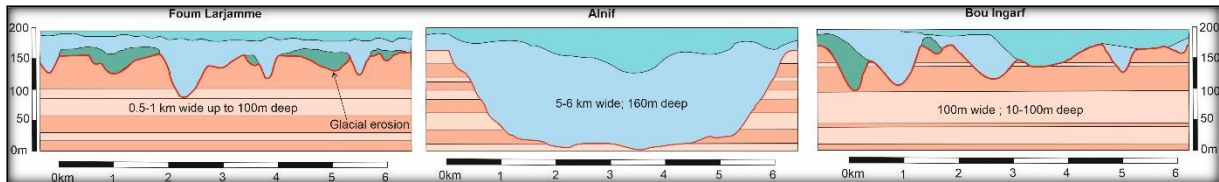


Figure 13: Variation of the Late Ordovician tunnel valley morphology in the Central Anti-Atlas (after Clerc, 2012)

From Zagora, after passing through Wadi Drâa, the N12 route runs to the ENE, parallel to the large folded corridor of Zagora. The sandstone columns of the First Bani Group block the horizon. The road takes advantage of the tectonic collapse and crosses a 600m cliff about 25km from Zagora. Then the huge cuestas that appear on either side of the road are composed of Upper Ordovician clay and sandstone (Fig. 14). In the lower part, green argillaceous rocks and some sandstone layers with storm deposits correspond to the Ktaoua Formation (Sandbian to upper Katian). At the top of the cuesta, the sudden appearance of sandstone on clay slopes was noted, reflecting a significant drop in the glacial-sea level origin of the Hirnantian era. In detail, the top sandstone level is divided into three units. The first, unit, includes strongly bioturbated tidal deposits; it is covered by the clay slope of the second unit, reflecting an interglacial period (sea level rise). The upper unit locally represents a very erosive base that cuts deeply into the lower subunit. These are subglacial channels cut during the Late Ordovician glacial maximum and filled with sand deposited on the surface of the retreating glaciers.

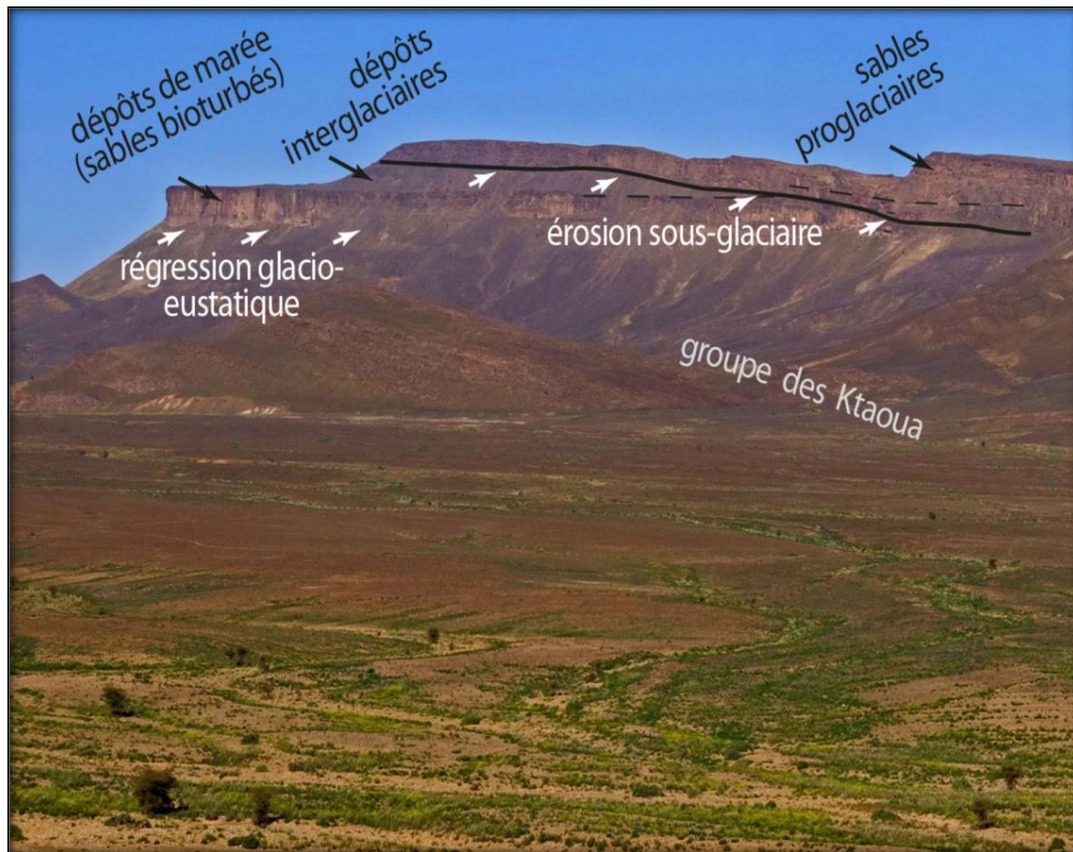


Figure 14: Second Bani group between Zagora and Tarhbalt (J.F. Ghienne).

After a few kilometres, the road climbs up the plateau and then crosses a vast and desolate surface that marks the foot of the Silurian crossing. Shortly before Tarhbalt and its destroyed ksar, the road juts into the eponymous dry river and then crosses the entire succession of the second Bani group.

Stop J2.2: Ordovician Fezouata Shale fossil site (late Tremadocian) at Jbel Tizagzaouine
(GPS: N30° 31.945', W5° 49.965')

Route: We leave Zagora and head north for about 15 km and turn right at GPS N30°25'22.36"; W5°54'32.12") and cross the Draa River and its magnificent palm groves. Continue on to the next stop on a remote hill about 20 km northeast of Zagora. The stop can be reached by relatively good quality track on the plain of Beni Zoli towards the village of Arroui (on the foothills of Jebel Bou Dehir, 8 km NE of Bou Izargane).

The Jbel Tizagzaouine (Fig. 15) represents one of the most complete and accessible sections through the main interval of exceptional preservation in the Fezouata Shale and contains some of the most important fossil discoveries. Its sedimentology is typical for the intermediate bathymetry inhabited by the Fezouata Biota, and the hill offers an excellent vantage point overlooking all the important geological features of the area.

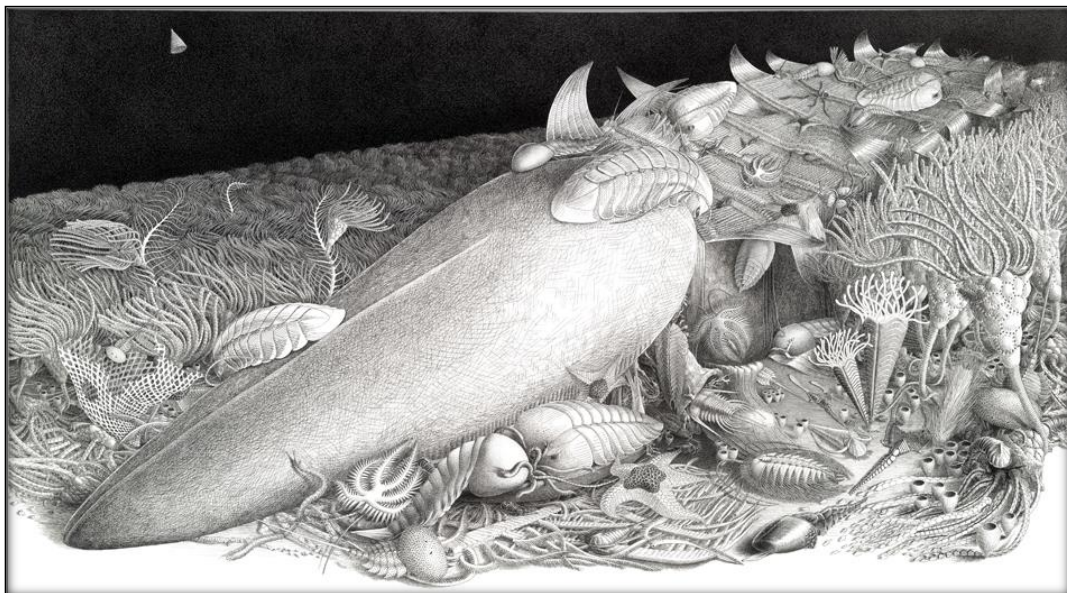
The Fezouata Biota is the only major Konservat-Lagerstätte displaying open Ordovician marine fauna, and critically documents the earliest stages of the Great Ordovician Biodiversification and enriches our understanding of the middle Cambrian and the Silurian marine ecosystems. From the over 185 taxa that have been identified so far, some belong to typical post-Cambrian groups (e.g. asterozoans, bivalves, cephalopods, crinoids), while others are iconic of exceptionally preserved Cambrian Burgess

Shale-type biotas (e.g. lobopodians, radiodonts, sachtids), which played a central role in providing insight into the origin and evolution of major animal groups. In addition, several Fezouata species represent the oldest occurrences in their group (e.g. cirriped crustaceans, eurypterids, xiphosurids). The sedimentology, stratigraphy, paleoenvironment and geological history of the Fezouata Shale are described in detail, and analyses of the Fezouata sediments greatly improve our understanding of soft-tissue taphonomy (see e.g. *Van Roy 2010, 2015; Martin et al. 2014, 2016; Lefebvre et al. 2016a, 2018; Vaucher et al. 2016, 2017; Saleh et al. 2018, 2019, 2020a, 2020b, 2021a, 2021b, 2022a*).



Figure: 15 Northward general view of the Jbel Tizagzaouine hill (in the foreground) and the Ternata Plain

The biodiversity, richness and quality of fossils preserved in the Fezouata Shale, especially the Jbel Tizagzaouine assemblage, provide unique insights into one of the most important evolutionary transitions in the history of Life on Earth and the establishment of the ecologically-modern marine biosphere. The geology and paleontology of the Fezouata Shale has produced seminal contributions in several disciplines including taphonomy, stratigraphy, and evolutionary biology, all due to the long history of geological exploration in the Anti-Atlas region and sustained efforts to characterize the fossil richness of the Fezouata Biota for the past two decades (Fig: 16).



*Figure 16: Madmeg's artistic reconstruction of the late Tremadocian idealized sea-floor, showing several typical taxa of the Fezouata Biota: numerous putative scavengers (e.g. aglaspidids, cheloniellids, eurypterids, machaeridians, marrellomorphs, palaeoscoleuids, somasteroids, trilobites) are shown attracted by the rotten carcass of a giant anomalocaridid (*Aegirocassis benmoulai*), decaying in a meadow of eocrinoids (*Rhopalocystis* sp.), in which were also thriving various conulariids, demosponges, and stylophorans (after Lefebvre et al., 2016a).*

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