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Key Points:

- The Tazoult salt wall shows composite halokinetic sequences on its flanks indicating its diapiric growth from Hettangian to Bajocian
- An allochthonous salt sheet formed during the passive growth coeval to higher deposition rates and salt withdrawal from minibasins
- The Tazoult salt wall represents a well-exposed analog for partially to completely buried diapirs along the Atlas System

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Diapiric growth within an Early Jurassic rift basin: The Tazoult salt wall (central High Atlas, Morocco)

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Abstract The central High Atlas (Morocco) constitutes a diapiric province that hosts a complex array of elongated diapirs and minibasins that formed during the Lower Jurassic rift of the Atlas Basin. This paper aims to study the structure and growth evolution of the Tazoult diapiric wall, located in the central High Atlas, by means of structural and sedimentological fieldwork integrated with remote sensing mapping. The Tazoult salt wall is a 20 km long × 3 km wide NE-SW trending ridge that exposes Upper Triassic red beds and basalts along its core. The succession flanking the salt wall ranges from Hettangian to Bajocian ages displaying spectacular sedimentary wedges in the SE and NW flanks. The Hettangian-early Sinemurian carbonates mainly crop out as blocks embedded in the core rocks. The ~1 km thick Pliensbachian platform carbonates display large subvertical flap structures along the flanks of the Tazoult salt wall with unconformities bounding tapered composite halokinetic sequences. In contrast, the ~2.5 km thick late Pliensbachian-Aalenian mixed deposits form tabular composite halokinetic sequences displaying small-scale hook halokinetic sequences. Passive diapirism resulted in the lateral extrusion of the evaporite-bearing rocks to form an allochthonous salt sheet toward the adjacent SE Amezrai minibasin. The Bajocian platform carbonates partially fossilized the Tazoult salt wall and thus constitute a key horizon to constrain the timing of diapir growth and discriminate diapirism from Alpine shortening. The Pliensbachian carbonate platform evolved as a long flap structure during the early growth of the Tazoult salt wall, well before the onset of the Alpine shortening.

1. Introduction

During Late Triassic to Early Jurassic times the Western Tethys was characterized by extensional tectonics related to the westward progression of the Tethys rift system that culminated with the multiphase breakup of Pangea [e.g., Ziegler, 1988; Dercourt et al., 1986; Ricou, 1994]. Permian (Zechstein) and Late Triassic (Keuper) evaporites and evaporite-bearing sediments were extensively deposited in the incipient Western Tethys rift systems (Figure 1) [e.g., Saura et al., 2015], precluding the formation of the Tethys-central Atlantic-northern Atlantic intersection. These ductile materials played a key role in the evolution of extensional and orogenic systems in western Europe (Apennines, Southern Alps, Jura and Southern North Sea), Iberia (Pyrenees, Iberian Ranges, and Betics), and North Africa (Rif, Atlas, and Tell), as well as in the evolution of the central and northern Atlantic margins. The conjugate margins of NW Morocco and Nova Scotia in the northern segment of the central Atlantic [Tari and Jabour, 2013; Loudon et al., 2013; Albertz and Beaumont, 2010] and of Iberia and Newfoundland in the southern segment of the North Atlantic [Alves et al., 2003; Rasmussen et al., 1998; Tucholke et al., 2007; Sibuet et al., 2007; Ramos et al., 2015] share a similar evolution that is characterized by the important role of the Triassic-Jurassic evaporites. Initially, these rocks controlled the extent and distribution of the Jurassic carbonate systems. During compression the evaporites controlled the location and style of the main tectonic structures (Figure 1).

In the central High Atlas of Morocco, the Upper Triassic rocks crop out along narrow and elongated SW-NE trending ridges [Dubar, 1938; Laville and Harmand, 1982; Laville, 1988; Jossen, 1990; Laville and Piqué, 1992; Fadile, 2003; Ettaki et al., 2007a; Michard et al., 2011] that are flanked by continuous successions of Lower to Middle Jurassic sediments forming wide synclines or plateaus between them [Warme, 1988; Poisson et al., 1998; Teixell et al., 2003; Frizon de Lamotte et al., 2008; Michard et al., 2011] (Figure 2). These Triassic-cored ridges were originally interpreted as related to strike-slip and transtensive tectonics that originated

Figure 1. Salt-related rift basins (orange) and passive margins (green) of the central and North Atlantic (based on *Hudec and Jackson [2007]*). AL, Atlas; AQ, Aquitaine; BE, Betic; CA, Carson; CB, Cuban; CT, Cantabrian-West Pyrenees; EA, East Alpine; FP, Flemish Pass; GB, Guinea-Bissau; GC, Gulf Coast; GE, Georges Bank; HS, Horseshoe; HT, Haitian; JA, Jeanne d' Arc; KQ, Kuqa; MN, Moesian; MT, Mauritania; NK, Nordkapp; OM, Offshore Moroccan basins; OR, Orpheus; PT, Petenchiapas; PY, Pripyat; RM, Rio Muni; SB, Sable; SE, Senegal; SF, Safi; SL, Salina-Sigsbee; SS, Scotian Slope; SU, Suriname; SV, Sverdrup; SW, South Whale; and WH, Whale.

during the early stages of rifting [*LaVigne and Harmand, 1982*]. However, it is accepted since the 1990s that the central High Atlas ridges, in fact, formed as Triassic salt diapirs that were later squeezed during the Tertiary inversion [*Canerot, 1990; Bouchouata, 1994; Ettaki et al., 2007b; Ibouh et al., 2011; Michard et al., 2011*].

Figure 2. (a) Synthetic map of NW Africa showing the location of the Atlas System (blue) and most important diapiric areas (pink). (b) Geological map of the central High Atlas showing the location of the Tazoult diapiric Ridge (Black Square). Minibasins are labeled as follows: Almghou (AL); Amezraï (AM); Demnate (DM); Ikassene (IK); Ikkou (IO); Lake Plateau (LP); Ouaouizaght (OU); and Tiloughite (TL). Based on *Saura et al. [2014]*.

Recently, *Saura et al.* [2014] described well-preserved growth strata geometries within the Lower and Middle Jurassic carbonates and siliciclastics over large areas of the central High Atlas, interpreting them as halokinetic sequences formed along Triassic salt walls (i.e., ridges; Figure 2). Halokinetic sequences are defined as “unconformity-bound packages of thinned and folded strata adjacent to passive diapirs” [Giles and Rowan, 2012]. According to these authors, hook- and wedge-type halokinetic sequences (HS), and their stacking tabular and tapered composite halokinetic sequences (CHS), are intimately related to the ratio of sedimentation rate to diapir rise rate and may alternate during the growth of a diapir. Therefore, the study of these sedimentary packages provides good understanding of the evolution of diapiric structures [e.g., Giles and Lawton, 2002; Ringenbach et al., 2013; Alsop et al., 2016; Poprawski et al., 2014]. Hook HS and tabular CHS form during episodes of low ratio of sediment-accumulation rate relative to diapir rise rate. On the contrary, wedge HS and tabular CHS form during episodes of high sedimentation rate relative to diapir rise rate. The systematic and widespread distribution of halokinetic sequences along the flanks of elongated minibasins confirms that the central High Atlas is a major diapiric province (i.e., salt basin). In the central High Atlas, key stratigraphic markers largely fossilize the diapiric structures, and these strata allow for ready discrimination between Jurassic diapirism and Alpine compressive inversion.

Despite clear evidence of Lower Jurassic synsedimentary diapirism in the central High Atlas, few salt-related structures have been described in detail, and very little has been published about the role of halokinesis in the development and deformation of synrift deposits [Bouchouata, 1994; Ettaki et al., 2007b; Ibouh et al., 2011; Michard et al., 2011]. In contrast, numerous case studies of Lias and Dogger carbonate platforms have been reported in the area, most of them closely associated with basement faulted blocks that developed during the early stages of rifting [e.g., Warme, 1988; Piqué et al., 2000; Souhel et al., 2000; Wilmsen and Neuweiler, 2008; Lachkar et al., 2009; Verwer et al., 2009; Merino-Tomé et al., 2012; Quiquerez et al., 2013]. Contrary to the central High Atlas, however, salt diapirs affecting the Jurassic and younger sediments have been widely reported from the Atlantic Atlas both onshore and offshore Morocco [e.g., Le Roy and Pique, 2001; Tari et al., 2003; Hafid et al., 2008; Tari and Jabour, 2013] and from the Atlas of Algeria and Tunisia [e.g., Courel et al., 2003; Turner and Sherif, 2007; Masrouhi et al., 2014]. Diapirism has been also reported along Morocco's conjugate margin of Nova Scotia [e.g., Ings and Shimeld, 2006; Albertz et al., 2010] and along the North Atlantic margins like in the Lusitanian Basin [e.g., Alves et al., 2003].

The Tazoult Ridge is a NE-SW trending elongated salt wall that crops out in a 20 km long and 0.6 to 3 km wide four-way closure in the middle of the central High Atlas (Figure 2). Despite the reported analysis of the sequential stratigraphy of the Jurassic depositional units around the Tazoult-Talmest region and their relation to rifting and diapirism [Bouchouata et al., 1995], the well-exposed halokinetic strata were not fully constrained and deserve a reinterpretation using modern salt tectonics concepts [e.g., Giles and Lawton, 2002; Giles and Rowan, 2012]. The study of the Tazoult diapir, therefore, provides a unique opportunity for the characterization of the Lower Jurassic diapirism as well as associated halokinetic sequences. The continuous exposure of the Tazoult salt wall structure and halokinetic strata, from core to fossilizing rocks, constitutes an excellent field analog for equivalent diapiric structures, especially in the Atlas System from Morocco to Tunisia. In addition, the size of the Tazoult diapir and the extent of the shallow marine carbonate platform developed on top (i.e., salt-diapir platforms after Bosence [2005]) allows comparison with similar structures that have recently been reported in the Red Sea [e.g., Purkis et al., 2012; Rowlands and Purkis, 2015]. Moreover, this new case study provides important insights for the understanding of diapiric structures of ancient rifted passive margins, as found along the North Atlantic conjugate margins [e.g., Ings and Shimeld, 2006; Albertz et al., 2010], as well as active examples such as in Yemen [Davison et al., 1996] or the Dead Sea [Alsop et al., 2015].

This paper focuses on the relationships between the superbly exposed and elongated Tazoult salt wall and the coeval Lower Jurassic carbonate and mixed carbonate-siliciclastic halokinetic sequences in the central High Atlas domain that have been revealed through extensive structural and sedimentological fieldwork. The aims of the paper are as follows: (1) to characterize the geometry and structure of the Tazoult salt wall; (2) to define prehalokinetic, synhalokinetic, and posthalokinetic strata and their geometries during Early and Middle Jurassic periods; (3) to reconstruct the geodynamic evolution of the Tazoult salt wall in six well-constrained steps; and (4) to compare this case study with published examples from both the Atlantic Atlas in Morocco and the Algerian and Tunisian Atlas.

Figure 3. Chart showing the age of the sedimentary record in the Tazoult diapir wall (red line) and most important geodynamic processes occurring in the central High Atlas [Based on Saura et al., 2014]. Data compiled from (1) Marzoli et al. [2011], (2) Ellouz et al. [2003], (3) Michard et al. [2011], (4) Baudon et al. [2012] and Domènech et al. [2015], (5) Moragas et al. [2016], (6) Charrière et al. [2009], and (7) Saura et al. [2014]. Absolute ages following Gradstein et al. [2012].

domain that is dominated by NE-SW striking structural highs or ridges separating elongated and wide synclines filled by Early and Middle Jurassic sediments [Poisson et al., 1998; Teixell et al., 2003; Frizon de Lamotte et al., 2008; Michard et al., 2011]. Subordinate NW-SE trending structural highs bounding equal-trend synclines are also present as in the Demnate area (i.e., DM in Figure 2). Cretaceous and later syntectonic Tertiary units are also locally present (e.g., Miocene-Pliocene La Cathédrale conglomerates and sandstones in Figure 2).

2.1. Triassic-Jurassic Sedimentary Record

During the Triassic, the central High Atlas extensional basin was characterized by the synrift deposition of red beds and localized evaporites capped by extensive basaltic lava flows [Frizon de Lamotte et al., 2008]. The

2. Jurassic Central High Atlas Diapiric Province

The Atlas Mountains define an ENE-WSW trending intracontinental belt that extends for more than 2000 km from the Atlantic coast of Morocco in the west to the Mediterranean coast of Tunisia in the east [Brechtbühler et al., 1988; Michard et al., 2008; Frizon de Lamotte et al., 2011] (Figure 2a). The Atlas mountain belt resulted from the tectonic inversion of the Late Triassic to Middle Jurassic rift basin during the Cenozoic convergence between Africa and Eurasia [Laville et al., 1977; Mattauer et al., 1977; Laville and Piqué, 1992; Piqué et al., 2000; Frizon de Lamotte et al., 2000; Teixell et al., 2003].

The Moroccan Atlas is formed by the ENE-WSW striking High Atlas and the NE-SW trending Middle Atlas. The former is divided into three segments named western, central, and eastern High Atlas. The western High Atlas was part of the Atlantic Jurassic passive margin and is separated from the central and eastern High Atlas by the Paleozoic Massif, an area of pre-Mesozoic basement exposures located south of Marrakesh [Brechtbühler et al., 1988] (Figure 2a). The central and eastern High Atlas basin developed as a multi-phase rift system opened toward the east by two major rift episodes occurring during Middle-Late Triassic and Early Jurassic (late Sinemurian and Pliensbachian) [Ellouz et al., 2003; Frizon de Lamotte et al., 2008; Wilmsen and Neuweiler, 2008; Lachkar et al., 2009; Moragas et al., 2016] (Figure 3). At present, the central High Atlas is characterized by a folded

Upper Triassic sediments, which unconformably cover folded and eroded Paleozoic rocks, were deposited in half-graben basins bounded by ENE-WSW trending normal faults [Laville, 1988; Piqué et al., 2000; Domènech et al., 2015], subparallel to the current tectonic grain of the central High Atlas. They consist of fluvial to lacustrine deposits made of clays, sandstones, and conglomerates that locally reach up to a few thousand meters of thickness [Courel et al., 2003; Baudon et al., 2009; Redfern et al., 2010; Baudon et al., 2012]. The Norian-Rhaetian deposits appear interbedded with variable amounts of evaporitic rocks, showing an increasing amount of salt eastward in the Atlas Rift System of Algeria and Tunisia. Based on the distribution of diapiric structures (i.e., Figure 2) and detailed structural reconstruction work [i.e., Saura et al., 2014], it is inferred that the mobile Upper Triassic-Lower Jurassic evaporitic successions were restricted to the center and half grabens within the central Atlas rift basin. Toward the top of the Upper Triassic sequence, basalt lava flows corresponding to the Central Atlantic Magmatic Province (CAMP) appear interbedded with silts and marls [Marzoli et al., 2004, 2011]. The latter authors defined several lava flows units (low, intermediate, upper, and recurrent), the age of which range between Late Triassic (200.9 Ma) and Early Jurassic (198.2 Ma).

Following the Triassic red bed deposition, marine conditions prevailed during the Early and Middle Jurassic resulting in the development of carbonate and mixed depositional systems [Warme, 1988; Souhel et al., 2000; Ellouz et al., 2003; Wilmsen and Neuweiler, 2008; Lachkar et al., 2009]. The Jurassic Atlas basin was open to the east (western Tethys realm) with Paleozoic provenance areas located toward the west and south [Souhel et al., 2000]. Liassic sedimentary systems evolved from extensive peritidal shallow water carbonate platforms (Hettangian-lower Sinemurian) that progressively backstepped toward the basin margins, to more localized platform development flanking the depocenters (Sinemurian) [Burgess and Lee, 1978; Warme, 1988; Souhel et al., 2000; Wilmsen and Neuweiler, 2008; Lachkar et al., 2009]. Normal faulting and block tilting increased notably during Pliensbachian times, resulting in north to south compartmentalization of the basin [Souhel et al., 2000; Ellouz et al., 2003; Merino-Tomé et al., 2012]. Pliensbachian carbonate platforms preferentially developed in the margins basin and in synsedimentary structural highs, promoting abrupt transitions in the marine sedimentary record from shallow water to basinal facies [e.g., Warme, 1988; Laville et al., 2004].

Global anoxia during the latest Pliensbachian and the earliest Toarcian occurred in close association with regional drowning of the lower Liassic platforms and localized deposition of basinal marls [Kenter and Campbell, 1991; Ettaki et al., 2000; Wilmsen and Neuweiler, 2008; Lachkar et al., 2009; Merino-Tomé et al., 2012]. From Toarcian times, carbonate platforms developed in the margins of the central High Atlas basin [Pierre et al., 2010; Amour et al., 2012], whereas the basin axis was occupied by a mixed carbonate-siliciclastic platform system prograding eastward to basinal deposits [Frizon de Lamotte et al., 2008]. This mixed system progressively graded to an extensive shallow water carbonate platform of Bajocian to lower Bathonian in age that is recognized throughout the central High Atlas [Ait Addi and Chafiki, 2013].

Finally, the middle Dogger to lower Cretaceous red beds record the sedimentation of continental to shallow marine transitional deposits that characterize the central High Atlas domain [Haddoumi et al., 2010; Bensalah et al., 2013]. Fully marine environmental conditions and platform carbonate deposits, which locally crop out in the margins of the Atlas System, dominated between Aptian and Cenomanian times [Frizon de Lamotte et al., 2008; Charrière et al., 2009; Haddoumi et al., 2010; Bensalah et al., 2013].

2.2. Diapirism

The central High Atlas is formed by a set of NE-SW trending and 15 to 80 km long narrow structural highs or ridges that are slightly oblique to the main tectonic boundaries of the range [Laville, 1988; Bouchouata, 1994; Bouchouata et al., 1995; Ettaki et al., 2007b; Michard et al., 2011] (Figure 2b). These highs are cored by Upper Triassic rocks and show growth successions on their flanks that are indicative of diapiric structures [i.e., Saura et al., 2014]. The cores of these elongated diapirs expose Upper Triassic red beds, evaporites, and basalts as well as Middle Jurassic magmatic rocks. The latter are frequently the dominant lithology in highly squeezed segments of the salt walls following Tertiary compression and basin inversion. In the western margin of the central High Atlas, subsidiary NW-SE trending diapiric ridges separate elliptical to subcircular minibasins <30 km wide forming a very well organized polygonal array (i.e., Figure 2). Toward the northeast (i.e., basinward), the distinctive Imilchil diapiric system comprises interrelated elongated diapir walls (Tassent, Ikkou, and Amagmag ridges among others) and elongated minibasins (Ikassene, Lake Plateau, Ikkou, and Almghou synclines among others) mildly deformed during Cenozoic shortening (Figure 2b). Minibasins borders are characterized by Lower to Middle Jurassic halokinetic deposits that reach thicknesses of >3–4 km,

showing diachronous sedimentation from one minibasin to the next [Saura *et al.*, 2014]. We note a significant east-west contrast in structure style within the diapiric province of the central High Atlas reflecting the change between shallow water (i.e., Azourki/Tazoult areas are the focus of this study) and basinal areas (i.e., the Imichil area).

The present-day lack of Triassic evaporitic rocks at surface is a common rule in most of the central High Atlas diapiric ridges and is a characteristic of most reported fossil diapiric examples [e.g., Rowan and Vendeville, 2006; Giles and Rowan, 2012; Kernen *et al.*, 2012; Harrison and Jackson, 2013]. In agreement with Saura *et al.* [2014], dissolution of the evaporites in the study area probably took place after extrusion to the seafloor or to subaerial exposures by marine or meteoric waters, respectively, or by hydrothermal fluids associated with the Middle Jurassic igneous intrusions, or a combination of them. In this regard, remnants of gypsum/anhydrite embedded within the Triassic deposits of the central High Atlas have been recognized in the Tassent [Michard *et al.*, 2011] and Ikerzi [Ettaki *et al.*, 2007b] salt walls. Furthermore, the presence of Triassic salt in the subsurface has been confirmed from Bouguer gravity anomaly data across the central High Atlas [Ayarza *et al.*, 2005], with the halite being presently mined from the core of the Toumliline and Ikerzi ridges (Figure 2). In the Tazoult diapir, rare gypsum fragments are observed at surface although larger amounts of evaporite rocks including salt are expected at the subsurface as is suggested through the presence of saline springs along the Ouhanal River gorge [Bouchouata, 1994].

3. Methods

The geology of the Tazoult Ridge has been characterized by a combination of remote sensing mapping (RSM) and extensive fieldwork. Remote sensing mapping has been performed using very high resolution Geoeye (0.5 m resolution) and QuickBird (0.6 m resolution) orthorectified satellite imagery and derived digital elevation models (DEM). QuickBird derived DEM has a spot resolution of 20 m $\times$ 20 m, and Geoeye derived DEM a spot resolution of 2 m $\times$ 2 m. Remote sensing mapping has been performed directly onto DEM data using ArcGis software, and the collection of RSM-derived strike and dip data is included (Figure 4).

Field mapping and geology have been used to quality control RSM and to collect systematic structural (strike and dip), lithostratigraphic (formations and thickness), and sedimentological (facies) data directly onto outcrops. The stratigraphic works include ~15 km of measured sections in the flanks of the Tazoult diapir and in the adjacent Amezraï minibasin (see Figure 4 for location). Detailed mapping also included systematic analysis of the stratigraphy of the carbonate located within the diapiric structure (dimensions, type, and orientation). RSM and field mapping have been supported by the mapping of stratal relationships onto photopanoramas and field maps. Field work has included the collection of samples for facies, biostratigraphy, radiometric dating (Sr-isotopy), and vitrinite reflectance work and basin modeling [i.e., Moragas *et al.*, 2016].

RSM and field data have been systematically integrated into modeling software enabling the creation of systematic serial 2-D section construction (using the 2-D kinematic modeling module in Move) and 3-D model construction (in GoCad software). The core of the structural analysis has been performed at the Jaume Almera Earth Science Institute (ICTJA-CSIC) of Barcelona (Spain), while the stratigraphic and sedimentological analyses have been performed at L'École d'Ingénieurs en Environnement, Géorressources et Ingénierie du Développement Durable of Bordeaux, France [Malaval, 2016; Joussiaume, 2016]. Sedimentary rates for the lithological formations involved in diapirism have been calculated for the NW and SE flanks based on the maximum thickness measured in the field [Malaval, 2016] and the corresponding ages according to foraminifera [Septfontaine, 1984; Jossen, 1990] and braquidopoda biozones [Bouchouata *et al.*, 1995].

4. Tazoult Lithostratigraphy

The sedimentary succession cropping out in the Tazoult Ridge ranges in age from Late Triassic to Middle Jurassic [Jossen, 1990; Bouchouata, 1994; Bouchouata *et al.*, 1995] (Figures 5 and 6). The core of the ridge structure comprises Upper Triassic-Lower Jurassic red beds and basalts that contain allochthonous blocks of Hettangian-early Sinemurian platform carbonates (Figure 7). Together, these strata are intruded by Middle Jurassic magmatic rocks. The succession flanking the ridge is typically arranged into two competent carbonate units separated by an intermediate weaker mixed unit [Bouchouata, 1994] (Figures 8–10): (a) competent Pliensbachian platform carbonates, (b) more ductile Late Pliensbachian-Aalenian mixed carbonate-siliciclastic platform deposits, and (c) competent Late Aalenian-Bajocian platform carbonates. The ages of

Figure 4. Geoeye satellite image showing the extension of the Tazoult salt wall and key boundaries of the remote sensing mapping. The semitransparent green lines represent field views in Figures 6–9. Yellow lines denote the stratigraphic sections logged in the area [Malaval, 2016].

the Jurassic marine deposits have been partially calibrated along the central High Atlas based on foraminifera [Septfontaine, 1984; Ettaki et al., 2000], and ammonites [Jossen, 1990; El Hariri et al., 1996; Ettaki et al., 2000, 2007a], and are enhanced locally through recent detailed work [Joussiaume, 2016; Malaval, 2016].

The Triassic sediments are made up of fluvial red to pink clays, siltstones, and fine-grained sandstones and green basalts [Jossen, 1990; Bouchouata, 1994] (Figures 5–7). The clays are highly deformed with the original bedding being poorly preserved, and they are frequently brecciated. In contrast to the clays, the siltstones (Tafilalt Fm) form a well-bedded package that is overlain by basaltic lava flows in the center of the Tazoult salt wall (Figures 7a and 7b). The Late Triassic-Early Jurassic Ait Aadel Fm is made up of very fine grained CAMP basalts ranging in color from green in fresh rock to brown in weathered exposures (Figure 7b).

The Hettangian-early Sinemurian platform carbonates of the Ait bou Oulli Fm consist of centimeter-thick beds of light to dark grey micritic limestones and dolostones with algal lamination and intraformational dolomitic breccias (Figure 5). The Hettangian-early Sinemurian carbonates form discontinuous outcrops (100 m to 3 km long) located next to the wall of the diapir, mostly in the NW flank, in apparent stratigraphic continuity with the flanking Pliensbachian carbonates (Figure 9b). However, the Hettangian-early Sinemurian carbonates dominantly form allochthonous blocks (<5 m to 3 km) that are embedded between Upper Triassic clays and basalts within the diapir core (Figures 7c, 8, and 9).

The Sinemurian-early Pliensbachian deposits of the Taguendouf Fm (Figure 5) do not crop out in the Tazoult diapir but form a thick succession (approximately 1000 m) of basinal hemipelagic facies approximately 20 km toward the north of the study area [i.e., Jossen, 1990]. These basinal facies are presumably equivalent, at least in part, to the shallow water Pliensbachian platform carbonates that crop out on the flanks of the Tazoult diapir as two distinct units (Jbel Choucht and Aganane formations; Figures 5 and 6).

The Pliensbachian Jbel Choucht Fm consists of well-bedded to massive inner platform limestones characterized by the presence of large bivalves (lithiotis type) together with gastropods and corals and minor oncolitic-rich facies (Figures 8 and 9). The Pliensbachian Jbel Choucht Fm is regionally characterized as platform margin

Figure 5. Chronostratigraphic and lithostratigraphic charts showing the sedimentary succession cropping out in the Tazoult Ridge based on field data and the literature [Jossen, 1990; Bouchouata et al., 1995]. Dashed lines bounding formations denote major unconformities and thick lines major depositional gaps. Maximum thickness measured in the field for each lithological formation [Malaval, 2016] and sedimentary rates (see section 3) noted for the NW (left) and SE (right) flanks. Note that the Sinemurian-lower Pliensbachian sediments (Taguendouf Fm), although included here, do not outcrop in the study area (see Figure 6). The colors in the representative section match those in all subsequent figures including maps (i.e., Figure 6). Absolute ages follow Gradstein et al. [2012].

facies [Jossen, 1990]. The top of the Jbel Choucht Fm, however, is typically karstified throughout the Tazoult diapir and is overlain by the red matrix carbonate breccias, red clays and siltstones, and grey marls of the Pliensbachian Talmezt-Tazoult Fm [Bouchouata, 1994] (Figures 9a–9c). These nonmarine rocks progressively pass laterally and upward into the Pliensbachian carbonates of the Aganane Fm, as recorded by an increase in carbonate content and the shift from marl to limestone lithology. The Aganane Fm consists of well-bedded oncolitic-rich lagoonal limestones, black mudstones, and marls (Figure 9c). Lithiotis bivalves are also frequent, occasionally forming relatively large biostromes toward the top [Lee, 1983; Fraser et al., 2004]. A mild karst surface is locally recognized at the top of the Aganane Fm suggesting an episode of subaerial exposure at top of the Pliensbachian carbonate platform.

The late Pliensbachian to Aalenian Zaouiat Ahançal Group comprises the Amezraï, Taфраout, and Aguerd-n'Tazoult formations (Figure 5) and represents a several hundreds of meter-thick mixed carbonate-siliciclastic systems dominated by shallow marine platform deposits [Jossen, 1990; Bouchouata, 1994] (Figures 8, 9d, and 10). Toward the west (Azilal area; Figure 2) the siliciclastic/carbonate ratio increases considerably denoting the proximity of the Paleozoic provenance area in the westernmost area of the central High Atlas. The late Pliensbachian-Toarcian (Amezraï Fm) consists of decimeter- to meter-thick beds of red to green clays and marls, ripple-bedded sandstones, and siltstones deposited in an intertidal environment [Souhel et al., 2000; Malaval, 2016]. The base of the formation is commonly characterized by the presence of lithiotis buildups. The Toarcian-Aalenian (Taфраout Fm) consists of marly limestones, green marls, and sandstones with corals deposited in a subtidal environment [Jossen, 1990; Malaval, 2016]. The Aalenian (Aguerd-n'Tazoult Fm) consists of yellow to red limestones, marls and sandstones, micritic limestones with algal lamination, oolitic grainstones, and dolostones deposited in an intertidal environment [Jossen, 1990]. The Aalenian Aguerd-n'Tazoult Fm progressively grades upward to the Bin el Ouidane Group (Figure 10d).

The Late Aalenian to Bajocian platform carbonates are represented by the Bin el Ouidane Group [Bouchouata, 1994; Jossen, 1990; Malaval, 2016] (Figures 8 and 10d). The Aalenian-Bajocian (Bin el Ouidane 1 Fm) consists of cross-bedded oolitic grainstones, bioclastic and oncolitic packstones to rudstones, and mudstones deposited in a platform margin to inner platform environment [Malaval, 2016]. Locally, red clays and sandstones, green

Figure 6. Geological map of the Tazoult Ridge showing the distribution of the diapir core rocks and the flanking sediments. Note that the Hettangian-early Sinemurian carbonates are systematically placed inside the diapir as blocks. Note that cross section through the Amezraï minibasin in Figure 11 continues ~3 km to the SE of this map (i.e., across the Jbel Azourki-Taghia weld as shown in Figure 2). A to D correspond to cross sections in Figure 12.

marls, and oolitic grainstones deposited in a restricted supratidal to intertidal environment form the base of the formation. The Bajocian (Bin el Ouidane 2 Fm) is made of grey mudstones and green to ochre-colored marls with brachiopods, and the Bajocian (Bin el Ouidane 3 Fm) of oncolitic limestones. The Bajocian carbonates are unconformably overlain by Miocene-Pliocene La Cathédrale alluvial siltstones, sandstones, and conglomerates in the NE margin of the Tazoult diapir (Figures 4 and 7a).

The Middle Jurassic magmatic rocks consist of fine- to coarse-grained gabbros, dolerites, and syenites [Jossen, 1990; Frizon de Lamotte et al., 2008] (Figures 7a, 10a, and 10b). These rocks occur as sills and dikes intruded within the Triassic core of the Tazoult diapir and as metric-scale dikes that crosscut the Lias to Dogger sedimentary succession in the surrounding of the Tazoult. Equivalent intrusions in the central High Atlas range

Figure 7. Field views of the core of the Tazoult diapir (see Figure 4 for location). (a) Panoramic view of the central diapir showing the characteristic red color of the Triassic rocks and the trace of an elongated Middle Jurassic magmatic intrusion. (b) Diapir core in the vicinity of Talmest made up of Triassic red beds capped by basalts (CAMP). These deposits are overlaid by the Hettangian-Lower Sinemurian carbonates (Aït bou Oulli Fm) in an apparent conformable relationship. (c) Triassic rocks forming the core of the diapir containing allochthonous blocks of the Hettangian-Lower Sinemurian carbonates (Aït bou Oulli Fm) at scales of tens of meters to 100 m. Note a kilometer-sized and folded block appearing in the background.

between ~165 and ~150 Ma indicating a Middle Jurassic Bathonian to Tithonian age of emplacement [Hailwood and Mitchell, 1971; Laville and Harmand, 1982].

5. Tazoult Ridge Structure

The Tazoult Ridge is a 20 km long and NE-SW trending diapir that is slightly oblique to the dominant ENE-WSW trending structural grain of the central High Atlas [Saura *et al.*, 2014] (Figures 2b and 6). The Tazoult Ridge is bounded by the Amezraï minibasin in the south and the Tiloughite minibasin in the north. The Amezraï minibasin, which is in turn bounded further to the south by the Jbel Azourki-Taghia-Tafrout diapiric structure (Figures 2 and 11), is filled with >3500 m of Pliensbachian to Bajocian sediments. The elongated Tazoult diapir plunges 15° at its NE termination and 12° at its SW termination and is highly asymmetric along strike with a narrow NE segment and a wider SW segment. The NE segment (~10 km long) is typified by a diapiric core that ranges between 600 and 1000 m in width, is dominantly made of Middle Jurassic magmatic rocks, and is bounded on its flanks by competent subvertically dipping Pliensbachian platform carbonates of the Jbel Choucht Fm (Figures 6, 8, and 12a). The salt wall significantly widens in its SW segment (~8.5 km long) where the core is up to 3 km wide at its maximum extent (Figures 6, 9a, and 12b). This SW segment configures a vast area of relatively low relief exposing red beds, basalts, and Middle Jurassic magmatic rocks and frequent decameter- to kilometer-sized allochthonous carbonates of the Hettangian-early Sinemurian Aït bou Oulli Fm. The latter commonly form the highest points in this segment of the salt wall (Figures 6 and 7c).

The sedimentary succession flanking the Tazoult diapir ranges in age from Hettangian-early Sinemurian (Aït bou Oulli Fm) to Bajocian (Bin el Ouidane 1 Fm) and typically dips toward the NW in the NW flank and toward the SE in the SE flank (Figure 12). The succession is commonly thicker in the SE flank compared to the NW flank, recording a stronger subsidence of the adjacent Amezraï minibasin. This increase in thickness in the

Figure 8. Field views and interpreted pairs of the NE segment of the Tazoult diapir along the Ouhançal River Gorge. (a and b) NW flank view showing the narrow diapir core and the overturned to north dipping flanking succession. Note the prominent Pliensbachian carbonate crests (Jbel Choucht Fm) bounding the diapir core and the Tertiary conglomerates in the right margin. (c and d) SE flank view showing the overturned to subvertical south dipping Pliensbachian carbonates (Jbel Choucht Fm) attached to the diapir wall and the less competent Pliensbachian (Aganane Fm) to Aalenian (Aguer-d-n 'Tazoult Fm) succession filling the Amezraï minibasin. Note the progressive onlap of the late Pliensbachian-Toarcian Amezraï Fm, first on the Pliensbachian (Aganane Fm) and later on the Jbel Choucht Fm toward the west.

SE flank is interpreted as corresponding to a southeast dipping basement normal fault, the Tazoult Fault, decoupled from the cover structure, and potentially there is a greater primary salt thickness in this depocenter (and subsequent salt withdrawal). Typically, the flanking sediments vary from overturned to subvertical

Figure 9. Panoramic views of the central Tazoult diapir. (a) NW flank succession in the vicinity of Taurirt showing the progressive dip variation from overturned next to the diapir wall (left) to north dipping away from the diapir (right). (b) Close view of the diapir margin (see location in Figure 9a) showing the boundary between the Upper Triassic clays forming the core rocks and the Pliensbachian carbonate platform. Note the presence of a decameter-scale block of the Hettangian-early Sinemurian carbonates (Aït bou Oulli Fm) at the diapir wall. (c) Close view of the top of the Pliensbachian platform carbonates of the Jbel Choucht Fm showing the intra-Pliensbachian karstic unconformity (see location in Figure 9a). (d) SE flank succession in the vicinity of Talmest showing progressive dip variation from subvertical in the Pliensbachian carbonates next to the diapir wall (left) to low angle and south dipping away from the diapir margin (right) in the Aalenian mixed deposits of the Aguerd-n'Tazoult Fm. Note the erosion of the Pliensbachian carbonate platform (bottom left) and the onlap of the late Pliensbachian-Aalenian mixed system directly in the allochthonous Triassic body (bottom center and right).

attitude in the strata attached directly to the diapir wall (i.e., Pliensbachian Jbel Choucht Fm) and decrease progressively to less-steep dips in the younger deposits away from the diapir wall (Figure 11). This bed faning, which is a combination of depositional wedges, truncations, and onlap geometries, is interpreted as have formed during the evolution of the minibasins in both sides of the Tazoult salt wall between the Pliensbachian and the Bajocian times (Early to earliest Middle Jurassic). Significantly, the flanking succession represents a stack of halokinetic composite sequences (in the sense of *Giles and Rowan* [2012]) abutting the diapir wall. These halokinetic sequences show significant variations both along strike and between the diapir flanks reflecting varying ratios of coeval salt wall rise and minibasin sediment accumulation (Figure 12).

5.1. NW Flank of Tazoult Ridge

The NW flank of the Tazoult diapir is superbly exposed north of Taurirt although it varies significantly along strike between the NE and SW segments (Figures 6, 9a–9c, 12b, and 12c). Here several meter-thick and decameter-long blocks of Hettangian-early Sinemurian carbonates of the Aït bou Oulli Fm, embedded

Figure 10. Panoramic views of the western and eastern closures of the Tazoult diapir. (a) SW segment showing the progressive onlap of the Late Pliensbachian-Aalenian mixed desposits of the Zaouiat Ahançal Group on the diapir margin (modified from *Saura et al.* [2014]). Note the gabbro dyke (green color) emplaced along the boundary between the flanking sediments and the diapir wall. The background is 5 km wide approximately. (b) Detail of Figure 10a (left square) showing the growth strata of the Pliensbachian to Toarcian sediments next to the diapir wall and the gabbro dyke. (c) Detail of Figure 10a (right square) showing the Late Aalenian-Bajocian carbonates of the Bin el Ouidane 1 Fm “floating” in the diapir core rocks, suggesting a roof collapse. (d) NE closure showing the angular relationship (i.e., former weld) between the Late Pliensbachian-Aalenian mixed desposits of the Zaouiat Ahançal Group and the Late Aalenian-Bajocian carbonates of the Bin el Ouidane 1 Fm. Note the small-scale thrusting (top right) and the monocline structure (top left) delineated by the Bin el Ouidane 1 Fm carbonates developed during the Alpine compression. The background is approximately 5 km wide.

between red clays and gabbros, are attached to the wall of the diapir. Nevertheless, these carbonates occasionally constitute the oldest stratigraphic unit along the flank of the salt wall (Figures 9a–9c). At this location, the succession flanking the diapir begins with the aforementioned thin and overturned Hettangian-early Sinemurian carbonates of the Aï bou Oulli Fm followed by overturned to subvertical Pliensbachian carbonates of the Jbel Choucht Fm. These latter carbonates are karstified at their top and form an abrupt angular subaerial unconformity with the north dipping Pliensbachian red breccia of the Talmest-Tazoult Fm (Figures 9a–9c and 12c). The unconformity indicates an important platform rotation episode during Pliensbachian times. The intra-Pliensbachian red breccias and conglomerates of the Tazoult-Talmest Fm, which mainly derived from the erosion of the underlying karstified Jbel Chouch Fm, constitute an unit up to 50 m thick that can be continuously traced more than 5 km toward the west along the SW segment of the diapir, and discontinuously traced for 5 km toward the east along the NE segment of the diapir (Figures 6 and 9a–9c). The red breccias progressively pass to the Pliensbachian Aganane Fm carbonates that in turn are followed by a progressive gentler north dipping succession consisting of the late Pliensbachian-Aalenian Zaouiat Ahançal Group mixed desposits and the late Aalenian-Bajocian Bin el Ouidane 1 Fm carbonates.

Figure 11. (a) Panoramic view of the SE margin of the Amezraï minibasin showing the compressed Jbel Azourki-Taghia diapir and the growth strata delineated by the late Pliensbachian-Aalenian mixed deposits of the Zaouiat Ahançal Group. The overlying late Aalenian-Bajocian carbonates of the Bin el Ouidane 1 Fm forms the subhorizontal top unit in the background. (b) Balanced cross section across the Amezraï minibasin and (c) restored pair showing the structure of the Amezraï minibasin, and the bounding Tazoult and Jbel Azourki-Taghia-Taфраout diapirs (see location in Figures 2 and 6). The subhorizontal Bin el Ouidane 1 Fm carbonates fossilize the Tazoult diapir and thus largely postdate diapiric movements. The southern extrusion of the Taфраout diapir is projected from the eastern continuation of this structure. Note that the sedimentary succession of the Amezraï minibasin in Figures 11b and 11c is conservative (i.e., it likely expands more than is shown) and that the Sinemurian Taguendouf Fm strata are not shown (i.e., they would increase thickness further into the minibasin center).

The fanning geometry (i.e., growth strata) delineated by the NW flank succession continues along the NE segment of the Tazoult salt wall, but the strata progressively show steeper dips toward the NE (Figures 8a, 8b, 12a, and 12b). At this position, the Pliensbachian carbonates (Jbel Choucht, Talmezt-Tazoult, and Aganane formations) are mainly overturned, the late Pliensbachian-Aalenian mixed deposits (Zaouiat Ahançal Group) are overturned to subvertical, and the Aalenian-Bajocian carbonates and marls of the Bin el Ouidane Group are subvertical to north dipping (Figure 12a). Approaching the Ouhançal River gorge, the Pliensbachian to Aalenian succession onlaps on a kilometer-sized block of overturned Hettangian-early Sinemurian carbonates of the Aït bou Oulli Fm. This block forms part of an extrusive overhang of the Tazoult diapir that slightly opens and expands its core toward the north (Figures 8a, 8b, and 12a). The uppermost strata of the Aalenian-Bajocian carbonates of the Bin el Ouidane 1 Fm, which show several small-scale internal compressive folding and thrusting, overpass the extrusive flange and fossilize the Tazoult diapir in the NE closure (Figures 6, 10d, and 12a). Toward the SW segment, the NW flank Pliensbachian platform

Figure 12. Balanced cross sections across the Tazoult Ridge showing the structure of the diapir along strike and the halokinetic strata delineated by the late Pliensbachian-Aalenian mixed deposits of the Zaouiat Ahançal Group on both flanks of the structure (see location in Figure 6). The late Aalenian-Bajocian carbonates of the Bin el Ouidane 1 Fm fossilize the halokinetic strata and are deformed by the Alpine compression. Note that (i) the thickness of the sedimentary succession in both flanks is conservative, (ii) the Sinemurian Taguendouf Fm strata are not shown in the subsurface, and (iii) the fault below the diapir is not necessarily the same in all cross sections. The cutoff of the truncation of the Pliensbachian Jbel Choucht Fm carbonates below the late Pliensbachian-Toarcian mixed deposits of the Amezrai Fm (orange line) underneath the southern salt extrusion is projected horizontally from its westernmost exposure (close to cross-section B). A SW plunging of this feature cannot be discarded, which would result in a deeper location.

carbonates (Jbel Choucht, Talmest-Tazoult, and Aganane formations) and the late Pliensbachian-Aalenian mixed deposits (Zaouiat Ahançal Group) thin toward and onlap the salt wall, revealing exceptionally exposed halokinetic strata relationships (see section 5; Figures 10a, 12c, and 12d). This bedding geometry has been projected above the topography on the cross sections of the SW segment of the diapir (Figures 11, 12c, and 12d). Here the SW segment is marked by a 100–200 m wide, and ~5 km long Middle Jurassic magmatic intrusion emplaced approximately adjacent to the contact between the salt wall and the flanking halokinetic sediments (Figures 10a, 10b, and 12d).

5.2. SE Flank of Tazoult Ridge

The SE flank of the Tazoult salt wall crops out with spectacular exposures of up to 1000 m relief along the Ouhançal River gorge (Figures 8c, 8d, and 12a). Here as on the NW flank, overturned to subvertical Pliensbachian carbonates of the Jbel Choucht Fm are truncated beneath a karstic surface with a well-developed angular unconformity separating them from the Pliensbachian red breccia of the Talmest-Tazoult Fm. The breccias pass to south dipping Pliensbachian carbonates of the Aganane Fm that in turn pass from late Pliensbachian to Aalenian mixed deposits of the Amezraï, Tafrout, and Aguerd-n'Tazoult formations, showing a progressive fanning and decreasing dip. This fanning succession is overlain by subhorizontal late Aalenian-Bajocian carbonates of the Bin el Ouidane 1 Fm toward the SE where it forms a high plateau of regional extension (Figures 6, 8c, 8d, and 12a).

The Pliensbachian Jbel Choucht Fm carbonates of the SE flank form a prominent crest that extent along the entire NE segment. North of Ighrem, approximately at the middle point between the NE and SW segments, the Pliensbachian carbonates of the Jbel Choucht Fm are erosionally truncated (i.e., karstified) and directly overlain by the upper strata of the late Pliensbachian-Toarcian Amezraï Fm, forming an angular unconformity (Figures 6, 9d, 12c, and 12d). Here the unconformity at top of the Jbel Choucht Fm carbonates represents a subaerial exposure of the diapir roof that expanded between upper Pliensbachian and lower Toarcian times. Farther west, the Jbel Choucht Fm carbonates are completely eroded, and the Amezraï Fm strata overstep the Pliensbachian carbonates and directly onlap the salt wall (Figure 9d). At this point, the salt wall forms an allochthonous body that is > 6 km wide and overrides the ~1500 m thick late Pliensbachian-Aalenian mixed deposits of the Zaouiat Ahançal Group that is interpreted as an extrusion of the diapir over its flank and adjacent seafloor (Figures 9d, 12b, and 12c). This Zaouiat Ahançal Group succession shows exceptionally well-preserved halokinetic geometries in the footwall of the overhang (Figures 12c and 12d). The uppermost beds of the Aalenian Aguerd-n'Tazoult Fm are subhorizontal and overstep the allochthonous body (Figures 12c and 12d). Farther SW, the SE flank of the Tazoult salt wall is characterized by a gently north dipping succession made of Aalenian to Bajocian sediments of the Aguerd-n'Tazoult and Bin el Ouidane 1 formations that defines a short wavelength (<1 km) anticline at the tip of the south directed diapir extrusion (Figure 12d).

5.3. SW and NE Closures of Tazoult Ridge

The Tazoult salt wall is fossilized on its SW closure by the uppermost beds of the Aalenian carbonate-siliciclastic mixed deposits of the Aguerd-n'Tazoult Fm that, in turn, are covered by the late Aalenian-Bajocian carbonates of the Bin el Ouidane 1 Fm (Figures 6 and 12d). The Aguerd-n'Tazoult Fm and Bin el Ouidane 1 Fm strata show minor folding and thrusting that indicate a post diapiric shortening related to the Alpine inversion.

In the NE closure of the Tazoult salt wall, the late Aalenian-Bajocian carbonates of the Bin el Ouidane 1 Fm delineate a northwest vergent monoclinial fold characterized by a steeply inclined northwest dipping flank displaying an inferred structural relief of approximately 2 km (Figures 6, 10d, and 12a). This structural step follows a WNW-ESE alignment, the WNW-ESE Azilal-Anergui Fault [see *Souhel et al.*, 2000], which is oblique to the Tazoult salt wall (NE-SW). The late Aalenian-Bajocian carbonates of the Bin el Ouidane 1 Fm are directly overlaying the salt wall in the monoclinial fold (Figures 6, 10d, and 12a) and are subparallel to the underlying Aalenian mixed deposits of the Aguerd-n'Tazoult Fm to the southeast of the monoclinial. The Aalenian mixed deposits show a sharp contact, abutting against the northwest dipping late Aalenian-Bajocian carbonates, which is interpreted as corresponding to a welded salt wall (see Figure 10d).

5.4. Tazoult Ridge Structural Synthesis

The observed stratal relationships suggests that the Tazoult salt wall represented a structural and sedimentary high, at least from Pliensbachian to Bajocian times as indicated by (i) the large-scale hook geometry delineated by the Pliensbachian carbonates of the Jbel Choucht Fm truncated by and in angular unconformity with the Pliensbachian breccia of the Talmest-Tazoult Fm (Figure 12); (ii) the overstep of the late Pliensbachian-Aalenian mixed deposits of the Zaouiat Ahançal Group successively onlapping onto the Pliensbachian carbonates of the Jbel Choucht Fm and the wall of the diapir; and (iii) the final overlap of the Aalenian mixed deposits of the Aguerd-n'Tazoult Fm and the late Aalenian-Bajocian carbonates of the Bin el Ouidane 1 Fm strata onto the roof of the salt wall. These halokinetic geometries developed from Pliensbachian to Bajocian times along the Tazoult Ridge indicates with precision the evolution of the

Tazoult salt wall. In this frame, the late Aalenian-Bajocian Bin el Ouidane 1 Fm constitutes a posthalokinetic succession in the two terminations of the Tazoult Ridge. The unfolding of this posthalokinetic unit indicates the amount of postdiapiric shortening in this area [Saura *et al.*, 2014] (Figures 11b and 11c).

The reconstruction of the Tazoult and Jbel Azourki ridges with restoration of the posthalokinetic late Aalenian-Bajocian Bin el Ouidane 1 Fm denotes that most of the Late Cretaceous-Tertiary Alpine shortening is concentrated within the diapiric structures as observed in Figure 11. In the Tazoult salt wall, the shortening is expressed by the inversion of the basement Azilal-Anergui and Tazoult extensional faults that converge below the NE closure of the Tazoult salt wall (Figure 12). The inversion of the Azilal-Anergui fault beyond the null point resulted in a monoclinical fold at the level of late Aalenian-Bajocian Bin el Ouidane 1 Fm (Figure 12a). Cross-section restoration indicates a total tectonic shortening of ~27% (3 km) across the NE closure (Figure 12a) and about ~16% in the SW closure (Figure 12d), an amount of deformation that contrasts with the lower deformation rate when including the Amezari minibasin (~10.4% and 3.2 km; Figure 11). The implication of the described geometries on the evolution of the Tazoult diapir is discussed in the next section.

6. Halokinetic Sequences Along the Tazoult Salt Wall

The Pliensbachian to Aalenian strata flanking the Tazoult salt wall are arranged in characteristic halokinetic sequences in the sense of Giles and Lawton [2002] and Rowan *et al.* [2003]. Accordingly, in the following paragraphs we describe most important characteristics of the halokinetic sequences recorded in both segments of the salt wall (Figures 13–15).

6.1. NE Segment of Tazoult Salt Wall

In the NE segment of the Tazoult diapir, the salt wall contact is subparallel to overturned carbonates of the Pliensbachian Jbel Choucht Fm forming a wedge halokinetic sequence. In contact with the diapir, the Pliensbachian carbonates are eroded by a major angular unconformity throughout the Tazoult salt wall. This sequence boundary records the faulting, rotation, and karstification of the Pliensbachian carbonate platform in the vicinity of the Tazoult salt wall, interpreted to result from an episode of diapir growth overpassing the sedimentary rates (0.15 and 0.16 mm yr^{-1} in the SE and NW flanks, respectively) (Figures 8c, 8d, 9a–9c, 12a, and 12b). Field observations show that the subaerial truncation (i.e., karst) extends for more than 1000 m down dip in the SW flank (Figures 8c, 8d, 12a, and 12b). It is assumed, however, that the unconformity between the Pliensbachian platform carbonates of the Jbel Choucht Fm and the overlain carbonates of the Aganane Fm pass to a conformable sedimentary contact away from the diapir and basinward.

The wedging and thinning of the Pliensbachian Aganane Fm against the Pliensbachian Jbel Choucht Fm carbonates and the diapir wall characterized a second carbonate-dominated halokinetic sequence (Figures 8c, 8d, 12a, and 12b). This onlap relationship indicates a relative decrease in the rate of diapir rise compared to the first sequence. The top bounding unconformity of this second sequence has been locally identified as a mild karstic surface in the SE flank adjacent to the wall of the diapir (~300 m away from the contact). At this point, the angular difference across the unconformity between the Aganane Fm carbonates and the above sediments is almost zero.

Above this sequence boundary, the geometry of the halokinetic sequences of the late Pliensbachian mixed deposits of the Zaouiat Ahançal Group against the salt wall is only recognized in the NE closure of the Tazoult Ridge. There, the abrupt contact between the gently SE dipping Zaouiat Ahançal Group and the strongly NW dipping late Aalenian-Bajocian carbonates of the Bin el Ouidane Fm is interpreted as a weld resulting from the salt wall closure. Equivalent halokinetic but uncompressed relationships are spectacularly well exposed in the SW segment of the Tazoult diapir and are described in the following paragraphs.

6.2. SW Segment of Tazoult Salt Wall

In the SE flank of the SW segment of the Tazoult diapir, the Pliensbachian Jbel Choucht carbonates are abutting against the SE directed extrusion of the Tazoult salt wall delineating the Talmest allochthonous salt sheet (Figures 6, 9d, and 13). In this area, the Jbel Choucht Fm carbonates are unconformably overlain by the late Pliensbachian-Toarcian Amezraï Fm (deposition rate of 0.05 mm yr^{-1}) that initiates with a 4 m thick unit of breccia containing meter-sized carbonate clasts overlain by red color conglomerates and cross-bedded sandstones. These coarse-grained deposits record the erosion and subaerial exposure of the Pliensbachian Jbel Choucht platform during the initial development of the Talmest allochthonous salt sheet. The late

Figure 13. (a) Satellite Geoeye image of the SW flank of the Tazoult diapir showing the allochthonous Triassic body and the late Pliensbachian-Aalenian halokinetic strata (see Figure 6 for location). Note the erosional truncation of the Pliensbachian carbonate platform (top center), the extrusion of the Triassic core rocks toward the SE (bottom left), and the thinning of the beds in the proximity of the diapir wall (center). (b) Field view of the late Pliensbachian-Toarcian Amezrai Fm strata onlapping onto the diapir wall. (c) Panoramic view of the Aalenian Aguerd-n Tazoult Fm strata folding and thinning in the proximity of the diapir wall. Note the intense deformation of the kilometer-sized Hettangian-early Sinemurian carbonate blocks located over the allochthonous body.

Figure 14. Geoeye satellite imagery of the SW segment of the Tazoult diapir NW flank showing halokinetic strata relationships delineated by the late Pliensbachian to Aalenian mixed sediments of the Amezrai, Tafrout, and Aguerd-n Tazoult formations in the proximity of the diapir wall (see Figure 6 for location). Hook halokinetic sequences are labeled #1 to #4 with extension denoted by dashed arrows.

Pliensbachian-Toarcian Amezrai Fm onlap the diapiric wall toward the west delineating several hook-type halokinetic sequences (Figures 13a and 13b). The Amezrai strata change from SE to east dipping or even overturned approaching the diapir, defining a set of low-amplitude drape folds (100 to 200 m from the diapir wall) with subhorizontal axis (Figures 13a and 13b). Typically, the strata grade to shallower facies toward the margin of the allochthonous salt sheet, being individual hook sequences bounded by local truncations, small cusps, or extrusive flanges that place the Triassic core rocks over the flanking sediments. The stack of hook-type sequences and associated structural-stratigraphic relationships delineated by the late Pliensbachian-Toarcian Amezrai Fm sediments are inferred to represent a period of intense diapir growth with a high ratio of diapir rise rate versus sedimentation rate (following insights of Giles and Rowan [2012]).

Above the Amezrai sediments, the Toarcian to Aalenian strata of the Tafrout Fm (deposition rate of 0.20 mm yr^{-1}) and Aguerd-n Tazoult Fm (deposition rate of 0.60 mm yr^{-1}) show a distinctive angular relationship with the diapir wall (Figures 6 and 13). Here the Toarcian to Aalenian strata thin toward the diapir and parallel the wall of the diapir for hundreds of meters, delineating low-amplitude drape folds (<225 m from the diapir wall) with NW subhorizontal axis. Typically, individual beds increase in dip from normal ($25\text{--}35^\circ$) SE dipping to normal ($60\text{--}80^\circ$) E dipping within 150–200 m of the diapir wall as they thin diapirward (Figure 13c). Locally, the beds become overturned ($75\text{--}85^\circ$) in the proximity (a few meters) of the diapir wall. These new hook-type sequences complete the stack mentioned above and confirm that this period of intense diapir growth (low ratio of sedimentation rate versus diapir rise rate) lasted until Aalenian times. The uppermost beds of the Aalenian mixed deposits overstep the allochthonous Triassic body, which is interpreted to mark a decrease in the diapiric activity with respect to the aforementioned halokinetic strata that finalize with the fossilization of the diapir by the late Aalenian-Bajocian carbonates of the Bin el Ouidane 1 Fm (Figures 6 and 12c).

Figure 15. Schematic evolutionary model of the Tazoult salt wall illustrating the most important stages of diapir growth and associated deformation of the flanking strata. The model is not to scale and does not represent any specific point across the diapir but a synthesis of the data observed along strike. Note that the Sinemurian-early Pliensbachian sediments (Taguendouf Fm), if present, are not represented in the subsurface. Grey dashed lines in stage 6 indicate the currently exposed structural levels along the Tazoult salt wall, and the black thick arrows extension and compression stages.

Similarly to the SE flank of the Tazoult diapir, the NW flank on its SW segment delineates spectacularly well exposed halokinetic relationships of the Pliensbachian to Bajocian sedimentary succession (Figures 6, 10a–10c, and 14). In this position, the Pliensbachian Jbel Chouch, Talmest-Tazoult, and Aganane formations thin toward the diapir indicating a diapiric sedimentary high toward the SW at that time. Despite the wedging and thinning of the Aganane Fm carbonates toward the diapir, its uppermost strata parallel the diapir wall for several hundred meters along the NW flank, confirming a low ratio of diapir rise rate versus sedimentation

rate (Figure 6). Above, the late Pliensbachian to Aalenian succession of the NW flank defines an exceptionally exposed stack of halokinetic strata. In this position, the late Pliensbachian-Toarcian mixed sediments of the Amezraï Fm (deposition rate of 0.02 mm yr^{-1}) dip between 35 and 45° toward the west and thus obliquely to the diapir wall (Figure 14). As these strata approach the diapir wall ($<100 \text{ m}$), the bedding changes to NW dipping and parallel the underlying Pliensbachian carbonates of the Aganane Fm for hundreds of meters prior to onlapping the Pliensbachian carbonates at a very low angle (Figures 10a–10c and 14). At that point the bedding varies in dip from subvertical $<65^\circ$ away from the diapir wall to 70 – 85° next to the diapir wall at a scale of tens of meters (Figures 10a and 10b). This stratigraphic wedging and thinning defines a high-amplitude drape fold ($>800 \text{ m}$) with NW steeply plunging axis, characterizing a wedge-type halokinetic sequence that is attributed to a period of moderate diapir growth (high ratio of sedimentation rate versus diapir rise rate) (Figure 14).

Above, the latest strata of the late Pliensbachian-Toarcian Amezraï Fm and the Toarcian to Aalenian mixed sediments of the Taфраout (deposition rate of 0.06 mm yr^{-1}) and Aguerd-n'Tazoult (0.43 mm yr^{-1}) formations delineate well-exposed hook geometries in the proximity of the diapir wall. Typically, individual beds within a hook sequence change from NW to SW and again to NW dipping in a range between $<100 \text{ m}$ in the lower hooks (#1 and #2 in Figure 14) and $<700 \text{ m}$ in the upper hooks (#3 and #4 in Figure 14). Next to the diapir wall (<10 – 50 m) the bedding is usually subvertical to overturned in attitude (90 – 85°). The reported succession forms a stack of hook-type halokinetic sequences characterized by narrow amplitude drape folds (40 – 200 m) with NW steeply plunging axis. This stack is attributed to a period of intense diapir growth (low ratio of sedimentation versus diapir rise rates). Toward the western end of the Tazoult diapir, the uppermost beds of the Aalenian mixed deposits of the Aguerd-n'Tazoult Fm and the late Aalenian-Bajocian carbonates of the Bin el Ouidane 1 Fm overpass the diapir and seal the extruded core rocks.

6.3. Synthesis of the Tazoult Halokinetic Sequences

The flanks of the Tazoult salt wall are composed of stacks of halokinetic sequences encompassing both carbonate and mixed carbonate/clastics deposits. The carbonates of the Pliensbachian Jbel Choucht and Aganane formations delineate large-scale (hundreds of meters to 1000 m) wedge halokinetic geometries in both flanks of the diapir that are well exposed along the River gorge (Figures 8, 12a, and 12b). By contrast, the late Pliensbachian-Aalenian Zaouiat Ahançal Group mixed carbonate and siliciclastic deposits (Amezraï, Taфраout and Aguerd-n'Tazoult formations) form small-scale (tens of meters to a few hundred meters) hook- and wedge-type halokinetic sequences in both flanks of the Tazoult diapir (Figures 6, 13, and 14). These are typically observed at less than 300 m from the diapir contact. While the upper and lower bounding unconformities of individual halokinetic sequences are primarily recognized from remote sensing mapping geometries, field observations indicate that breccias, conglomerates, and shallow marine carbonate facies including corals typically characterize the basal deposits of the sequences in the proximity of the diapir and that these deposits pass laterally into conformable deeper water facies. Detailed analyses of individual halokinetic sequences, which are beyond the scope of this paper, are provided in Malaval [2016]. The lithology of the sediments (i.e., carbonate versus mixed carbonate/clastics) is also a key point when defining the contact between the core rocks and the flanking sediments. The contact is typically steep and with high relief when contained within carbonates, whereas it is smooth and with low relief when contained within carbonate/siliciclastic mixed deposits.

7. Discussion

7.1. Central High Atlas Lower Jurassic Diapirism

Field and remote sensing data indicate that the growth of Tazoult salt wall took place, at least, between the Pliensbachian and the lowest Bajocian (~ 190 to 169 Ma). Therefore, the syndepositional deformation and facies change observed within the Pliensbachian to Bajocian flanking sediments are attributed to the rise of the evaporite-bearing Upper Triassic rocks (Figures 6 and 13–15). The case of the Tazoult Ridge constitutes a well-exposed example of the widespread synrift diapirism that took place in the central High Atlas during the Lower Jurassic [Saura et al., 2014; Moragas et al., 2016].

The NE-SW trending Tazoult salt wall (following Hudec and Jackson [2007]) strongly resembles other NE-SW trending diapiric structures reported in the central High Atlas like the Toumliline, Ikerzi, and Tassent ridges

[Michard *et al.*, 2011; Saura *et al.*, 2014] as well as from the western High Atlas on the Atlantic margin of Morocco [Hafid, 2000; Hafid *et al.*, 2000; Tari *et al.*, 2003; Hafid *et al.*, 2008; Tari and Jabour, 2013]. Of particular note is a comparison to Triassic salt diapirs associated with NE-SW trending Jurassic anticlines and faulted basement highs that are well documented in the Essaouira basin of Morocco [e.g., Le Roy and Pique, 2001]. In a broader context, similar diapiric salt walls have been described in other rift and postrift systems such as the Red Sea [e.g., Mohriak and Leroy, 2012; Jackson *et al.*, 2014] and the Dead Sea [e.g., Alsop *et al.*, 2015]. Active and surface salt walls have been also reported in compressive settings like the Kuqa fold-thrust belt [Li *et al.*, 2014].

Diapirism of the Upper Triassic evaporite-bearing deposits is thought to have been triggered by basement normal faulting related to the extensional-transensional tectonic regime dominating the central High Atlas rift basin between Late Triassic and Early Jurassic times [Bouchouata, 1994; McClay *et al.*, 2004; Saura *et al.*, 2014; Moragas *et al.*, 2016] (Figure 11). A similar association between extension and diapirism has been extensively reported in the literature based on outcrop data, seismics, and analog modeling [e.g., Mart and Ross, 1987; Koyi, 1991; Vendeville and Jackson, 1992; Koyi *et al.*, 1993; Dooley *et al.*, 2005; Hudec and Jackson, 2011; Burliga *et al.*, 2012]. In the study area, the presence of the basement Tazoult Fault at depth is inferred from the variation in thickness of the sedimentary succession between flanks, indicating an active SE dipping normal fault during deposition (Figure 12a). Additional data supporting a basement fault includes (a) the existence of Pliensbachian carbonate platforms in the central High Atlas that are typically developed in faulted blocks [e.g., Warme, 1988; Laville *et al.*, 2004; Merino-Tomé *et al.*, 2012] and (b) the abundant Middle Jurassic magmatic intrusions in the core of the diapiric ridges thought to be localized through plumbing into the extensional normal fault system and the mechanical contrast of the diapir and host rock interface (Figure 6).

Besides diapirism of the Triassic evaporite-bearing rocks, an active role of the Middle Jurassic intrusions in the deformation of the central High Atlas ridges was suggested during the 1980s and early 1990s [Laville and Harmand, 1982; Laville, 1988; Laville and Piqué, 1992]. However, the age of these intrusions range between Bathonian and Tithonian [Hailwood and Mitchell, 1971; Laville and Harmand, 1982] and thus fully postdate the halokinetic sediments flanking the Tazoult salt wall, a timing when the structure was still open and uncompressed. Field observations in the Tazoult salt wall, however, indicate that deformation of the strata due to postdiapiric magmatic intrusions is mostly local and only evident in the proximity of the igneous bodies (Figures 10a–10c). This is supported by the lack of significant along strike dip variations in the halokinetic strata between adjacent areas with and without igneous intrusions (Figure 6). Growth strata related to potential doming generated by igneous emplacement as has been reported in other areas [Schofield *et al.*, 2014] cannot be evaluated due to the current erosional level below synemplacement sediments.

7.2. Evolution of the Tazoult Salt Wall

We propose the initiation of the Tazoult salt wall by extension triggering reactive-active diapirism [see Vendeville and Jackson, 1992] followed by a long period of passive diapiric growth (stages 1 to 3), and ending with its fossilization (stage 4) as summarized in Figure 15. The evolutionary model also includes the intrusion of igneous rocks during the Bathonian (stage 5), and compression (stage 6).

7.2.1. Onset of Diapirism: Pre-Pliensbachian

The onset of diapirism, although not included in the evolutionary model of Figure 15, took place after the deposition of Hettangian-early Sinemurian carbonates of the Aït bou Oulli Fm as indicated by their inclusion as isolated allochthonous blocks floating within the salt wall core (Figure 7). The absence of younger Sinemurian sediments (e.g., Taguendouf Fm) cropping out in the area is taken to indicate that the Tazoult salt wall was already a sedimentary high at that time, supporting a pre-Pliensbachian irregular structural relief of salt. Disruption and faulting of the Hettangian-early Sinemurian platform carbonates is attributed to the late Sinemurian-Pliensbachian rifting extension [Ellouz *et al.*, 2003; Lachkar *et al.*, 2009; Moragas *et al.*, 2016]. In particular, we assume that the Hettangian-early Sinemurian carbonate platform were faulted above the Upper Triassic evaporites during basement faulting as suggested from analog modeling experiments [Dooley *et al.*, 2005]. Once faulted and fragmented, the Hettangian-early Sinemurian carbonates of the Aït bou Oulli Fm were entrained into the diapiric salt wall and carried upward as blocks together with Upper Triassic siltstones and basalt (Figures 7 and 12).

7.2.2. Stage 1: High Rate of Passive Diapir Growth and Platform Karstification (Pliensbachian)

The first stage of passive diapiric growth as recorded by the Tazoult flanking sediments took place during Pliensbachian times synchronously with the development of the shallow marine carbonate platform of the Jbel Choucht Fm (Figure 15). The rate of carbonate deposition was mostly compensated by the rate of diapir rise likely resulting in the updoming of the overburden carbonates, followed by the emergence and subaerial exposure of the platform at the salt wall crest. The karstification of the carbonate roof facilitated the subsequent erosion and destruction of the Jbel Choucht Fm platform (see stage 2). The reported subaerial exposure and karstification of the carbonates forming the diapir roof is rarely described in the literature [e.g., *Poprawski et al.*, 2016] and constitutes a clearly differentiate feature with respect to the original halokinetic sequences described by *Giles and Rowan* [2012].

The Pliensbachian carbonate platform pinches out toward the diapir margin in the SW segment of the NW flank suggesting that this area displayed a diapiric relief since late Sinemurian. This would indicate that passive diapirism in the Tazoult salt wall initiated in its SW segment and subsequently migrated along strike toward the NE. The rise of the NE-SW trending Tazoult salt wall was controlled by the activity of the Tazoult Fault. A strong intra-Pliensbachian synrift faulting and platform rotation is recorded by the angular unconformity with the overlaying sediments in the NW flank of the Tazoult (Figure 15). Interestingly, this time is coeval with a period of active normal faulting and block tilting in the central High Atlas [e.g., *Souhel et al.*, 2000; *Ellouz et al.*, 2003; *Wilmsen and Neuweiler*, 2008; *Lachkar et al.*, 2009].

7.2.3. Stage 2: Low Rate of Passive Diapir Growth (Pliensbachian)

The second stage of evolution comprises the deposition of the Pliensbachian carbonate breccias of the Talmezt-Tazoult Fm, the shallow marine carbonate platform of the Aganane Fm, and the lower part of the late Pliensbachian-Toarcian Amezraï Fm (Figure 15). The erosion of the karstified Jbel Choucht Fm carbonates (see stage 1) resulted in the deposition of the Talmezt-Tazoult breccias that pass laterally and basinward to the Aganane platform carbonates. The wedge shape of the Pliensbachian Aganane Fm strata against the rotated, fractured, eroded, and truncated Pliensbachian Jbel Choucht Fm carbonates first and the diapir wall later is attributed to a decrease in the rate of diapir growth compared to stage 1. Moreover, the Aganane Fm records an important change to shallower facies and final pinch out toward the SW segment of the Tazoult salt wall confirming a higher diapir relief and a decreasing water depth toward this area during the Pliensbachian. This stage of passive diapirism probably extended until Toarcian times as suggested by the wedging of the lower part of the Amezraï Fm toward the diapir wall in both flanks of the salt wall. A complete stop of the diapiric activity during the late Pliensbachian and before the stage 3 is not ruled out.

7.2.4. Stage 3: High Rate of Passive Diapir Growth and Salt Sheet Development (Late Pliensbachian-Aalenian)

The most intense period of diapiric passive growth occurred synchronously with the sedimentation of the late Pliensbachian to Aalenian thick mixed siliciclastic-carbonate deposits of the Zaouiat Ahançal Group (Amzraï, Tafraout, and Aguerd-n Tazoult formations) (Figure 15). The increase in the Tazoult salt wall rise was likely driven by the resume of the synrift extension in the central High Atlas realm since the late Pliensbachian [*Moragas et al.*, 2016] associated with higher sedimentation rates since the Aalenian [*Saura et al.*, 2014]. This is supported by the stack of tabular halokinetic sequences of the mixed deposits showing hook stratal geometries on both flanks of the Tazoult salt wall, indicating similar rates of sediment accumulation and diapir rise. It is likely that higher sedimentation rates in the adjacent Amezraï minibasin triggered salt withdrawal and inflation of the adjacent Tazoult and Azourki salt walls (e.g., Figures 2 and 11), locally forming the SE verging Talmezt allochthonous salt sheet. We interpret that the extrusion occurred toward the SE because of the higher regional slope and in the SW segment because of the thinner Pliensbachian carbonate succession (see section 7.2.2). Mapping and restoration work indicate that the weld observed in the NE closure (see section 5.3) represents the eastern continuation of the allochthonous salt sheet observed in the SW segment of the diapir (Figure 6), implying a salt extrusion extending along the entire SE flank of the Tazoult diapir. A superbly exposed composite halokinetic sequence (CHS) in the footwall of the Talmezt allochthonous salt sheet makes for an exceptional field example of hook- and wedge-type halokinetic sequences as described in the literature [e.g., *Davison et al.*, 1996; *Giles and Lawton*, 2002; *Rowan and Vendeville*, 2006; *Ringebach et al.*, 2013] (Figures 13–15). Moreover, this period of intense diapir growth is likely associated with the initial development of a megaflap structure constituted by the Pliensbachian platform carbonates of the Jbel Choucht Fm as recently discuss elsewhere [see *Rowan et al.*, 2016].

7.2.5. Stage 4: Salt Wall Fossilization (Late Aalenian-Bajocian)

The final stage of diapirism records the progressive diminution of the Tazoult salt wall growth and its subsequent fossilization. The decrease in the diapiric activity initiated during Aalenian times and is marked by the wedging of the uppermost strata of the Aguerd-n Tazoult Fm against the allochthonous salt sheet in the SE flank and against the lower strata of the late Aalenian-Bajocian platform carbonates of the Bin el Ouidane 1 Fm on the NE closure. Finally, the overstep of the Tazoult salt wall in both NE and SW closures by the platform carbonates of the Bin el Ouidane 1 Fm records the fossilization of large portions of the salt wall (Figure 15). However, tracing the Bin el Ouidane 1 Fm toward the Jbel Azourki-Taghia-Taфраout diapir system (see Figures 2 and 11) reveals that diapiric activity persisted after Bajocian times on nearby diapirs. At this position, the thick late Aalenian-Bajocian carbonates of the Bin el Ouidane 1 Fm display clear halokinetic stratal patterns that confirm the growth of localized diapirs in the area at that time. Therefore, a potential post-Bajocian diapiric growth of the Tazoult salt wall is not ruled out as discussed in section 7.3.

7.2.6. Stage 5: Intrusion of Igneous Rocks (Bathonian-Tithonian)

During Middle to Late Jurassic times (Bathonian-Tithonian), a considerable mass of posthalokinetic intrusive igneous rocks was emplaced along the core of the Tazoult salt wall and, in a minor extent, across the flanking sedimentary succession (Figure 15). The most important igneous bodies are concentrated in those areas representing lower structural levels (i.e., NE segment) and in the core of the Talmost allochthonous salt sheet (Figure 6), indicating that the magma was intruded upward through the salt wall and laterally through the salt sheet (Figure 15). A lateral emplacement of the magma might indicate that the composition of the evaporite rocks was dominated by hydrous salts like gypsum and carnalite as suggested elsewhere by *Schofield et al.* [2014]. Although not studied in detail in this work, field data indicate the existence of (i) differentiated igneous rock textures, and thus the occurrence of several intrusive events, and (ii) a contact aureole (metasomatic?) affecting the lithologies surrounding the intrusion. These igneous intrusive events are recorded in most central High Atlas ridges evidencing a regional-scale process.

7.2.7. Stage 6: Shortening and Diapir Squeeze (Late Cretaceous-Tertiary)

The tectonic contraction of the central High Atlas Basin between the Late Cretaceous and the Tertiary resulted in the deformation and squeezing of the Tazoult salt wall (Figures 12 and 15). A more pronounced shortening and squeezing of the diapir in the NE segment through the inversion of the Azilal-Anergui Fault resulted in a diapir core constituted almost exclusively by Triassic basalts and Middle Jurassic gabbros (i.e., hard rocks), which likely prevented the complete welding of the flanking Pliensbachian carbonates (Figure 12a). This feature is commonly observed in most of the salt walls of the central High Atlas [e.g., *Michard et al.*, 2011], in contrast to other salt provinces elsewhere where the lack of such intrusions facilitated the complete welding of the structure [Rowan and Vendeville, 2006; Rowan et al., 2012]. In contrast to the NE, the SW segment of the Tazoult salt wall above the hanging wall of the Tazoult fault was uplifted as a whole (Figures 12c and 12d). The compression of the Tazoult salt wall might be associated with (i) the generation of secondary diapirs and/or (ii) the downward movement of salt expelled from the diapir [see *Dooley et al.*, 2009]. Moreover, compression of the Tazoult salt wall resulted in the verticalization of the megaflap drawn by the Pliensbachian carbonate platform of the Jbel Chouch Fm [see *Rowan et al.*, 2016] (Figure 15).

7.3. Regional Comparisons

Elongated diapirs similar to the Tazoult salt wall have been reported from active rift basins like the Dead Sea [Alsop et al., 2015, 2016] and the Red Sea [e.g., *Mart and Ross*, 1987; *Davison et al.*, 1996; *Orszag-Sperber et al.*, 1998a, 1998b].

An exposed salt wall of comparable size (10 km × 1.5 km) to the Tazoult diapir and equally controlled by subsurface faults has been recently studied in the Dead Sea by *Alsop et al.* [2015]. The Sedom salt wall affects Miocene-Pliocene clastic sediments (conglomerates, sandstones, and shales) and its growth evolution includes the formation of a salt sheet that flowed toward the Dead Sea. Contrary to the Tazoult, however, the Sedom salt wall has not been affected by shortening, facilitating the study of the original angular relationships between the halokinetic strata and the salt diapir [Alsop et al., 2016].

Mart and Ross [1987] reported elongated diapirs up to 30 km × 4 km growing in the floor of the northern Red Sea that developed in close association with faults and penetrate relatively thin overburden sediments. These diapirs form a set of N-S to NNW-SSE trending ridges that are parallel or slightly oblique to the strike of the rift system and thus form a set very similar set to the current Triassic cored ridges (i.e., diapirs) of the central High

Figure 16. (a) Pliensbachian paleogeographic map of the central High Atlas showing the distribution of the shallow marine platform carbonates. Based on Poisson *et al.* [1998], Milhi *et al.* [2002], and Pierre *et al.* [2010]. See location in Figure 2. (b) Line drawing of the shallow marine deposits (up to 20 m of water depth in light blue) in the Red Sea Gubal Straits (upper) and Farasan (lower) areas [see Purkis *et al.*, 2012] illustrating a similar distribution pattern of platform carbonates to that reported from the central High Atlas in Figure 16a. Orange color represents emerged areas. Note that Figures 16a and 16b are at the same scale.

Atlas (Figures 2b and 16a). Similar salt walls located over basement blocks are described toward the north in the Gulf of Suez [Orszag-Sperber *et al.*, 1998b], occasionally topped by well-developed carbonate platforms as seen in seismic lines. Diapir structures and salt walls are also common in the southern Red Sea both offshore [Orszag-Sperber *et al.*, 1998a] and onshore [Davison *et al.*, 1996]. Late authors described an asymmetric salt wall in the coast of Yemen, bounded by faults and showing an overhang basinward, that is the continuation of offshore elongate diapirs as denoted from seismic lines.

In the Tazoult Ridge, the distribution of the Pliensbachian carbonates is almost continuous along the 15 km long crestal domain (Tazoult salt wall during Pliensbachian times). The width of the Pliensbachian Jbel Choucht carbonate platform is not constrained but rapid changes from shallow marine carbonates to platform margin carbonates in nearby areas (Jbel Azourki diapir; Figures 2 and 11b) suggest that these elongated platforms grew isolated on top of the salt walls. Equivalent carbonate platforms are reported from La Popa basin case study where Late Cretaceous (Maastrichtian) carbonate lentils grew on top of round diapirs and thus define rounded heterozoan carbonate platforms [Giles *et al.*, 2008]. In this regard, platform development and facies variations associated with growing structures have already been described in the literature [e.g., Bosence, 2005, Saura *et al.*, 2013]. The rifting scenario in the Atlas basin during the Early Jurassic times suggests that these Tazoult elongated and narrow carbonate platforms could be compared to similar sized shallow water carbonate platforms located along the borders of the Red Sea, especially in the Gubal Straits in Egypt and in the Farasan Banks along the coast of Saudi Arabia [Purkis *et al.*, 2012; Rowlands and Purkis, 2015] (Figure 16). Latter authors interpret the elongated and subparallel carbonate bodies of these two localities as directly growing above diapirically controlled highs, which in turn show an orientation consistent with the main Red Sea rifting system normal faults.

7.4. Implications for the Atlas Diapiric Province

The central High Atlas region is defined as an Early-Middle Jurassic diapiric basin by the widespread finding of halokinetic sequences flanking the diapiric ridges [Saura *et al.*, 2014]. Agreemently, diapirism of the Upper

Figure 17. Composite figure showing line drawings of seismic lines and cross sections at the same scale to compare diapiric evolution along the (a) Atlas Atlantic margin, the (b) central High Atlas (see Figure 11) and the (c and d) Saharan-Tunisian Atlas. Seismic-lines modified from Western Atlas (Figure 17a) [Tari and Jabour, 2013]; Tunisian Atlas (Figure 17c) [Hlaïem, 1999]; and Tunisian Atlas (Figure 17d) [Zouaghi et al., 2013]. Dashed lines indicate the equivalent structural relief outcropping in the central High Atlas exposing Lower-Middle Jurassic strata. Note that the Jurassic sedimentary pile reduces while the Cretaceous succession increases from the central High Atlas to the Tunisian Atlas.

Triassic-Lower Jurassic evaporites is well constrained in the Atlantic Atlas (western High Atlas), both onshore and offshore [Hafid, 2000; Hafid et al., 2000; Le Roy and Pique, 2001; Tari et al., 2003; Dunlap et al., 2010; Tari and Jabour, 2013] (Figure 17). Diapirism affecting strata up to Miocene and Pliocene ages is also well constrained by subsurface data in the Atlas of Algeria [e.g., Courel et al., 2003; Bracene et al., 2003; Turner and Sherif, 2007] and Tunisia [e.g., Hlaïem, 1999; Patriat et al., 2003; Zouaghi et al., 2005, 2011, 2013] (Figure 17).

All these occurrences may define a North African diapiric region included under the name of Maghreb Salt Province.

Across the Atlas Mountains, the description of diapirs has been hindered due to (i) the uneven distribution of Late Triassic evaporitic basins that has influenced the irregular development of diapiric structures and (ii) the difficult interpretation of such diapiric structures once tightened or even welded during the Alpine compression [e.g., *Hlaïem*, 1999; *Bracene et al.*, 2003; *Masrouhi and Koyi*, 2012; *Zouaghi et al.*, 2013]. In contrast, the Atlantic Atlas offshore Morocco shows a well-documented distribution of diapiric structures formed along the slope of the passive margin with extensional diapirs in the upper slope and compressional diapirs in the lower slope [e.g., *Hafid et al.*, 2008; *Frizon de Lamotte et al.*, 2008; *Tari and Jabour*, 2013]. However, the structures studied to date in the central High Atlas cored by Upper Triassic red beds (Figure 2) show a comparable Lower Jurassic diapiric origin to that recognized in the Tazoult salt wall, although they show important differences in terms of overall basin setting, facies and structural relationships, and overall timing/age.

In terms of subsurface data, we consider that the present-day outcrops of Jurassic halokinetic strata in the central High Atlas likely represent excellent analogs to the deepest parts of the Triassic-Jurassic succession revealed in published seismic lines (Figure 17). The comparison of the Tazoult-Azourki transect to these lines at the same scale reveals some striking similarities in terms of the age, size, and frequency of the observed halokinetic structures. The Algerian and Tunisian examples are buried at great depths. In the central High Atlas, however, vitrinite reflectance analyses [*Moragas et al.*, 2016] together with AFT and (U-Th)/He exhumation histories obtained from volcanic rocks intruding diapiric ridges of the Imilchil area [*Barbero et al.*, 2007] (Figure 2b) indicate that the Jurassic rocks in the study area could have been buried at depths of 2–3 km at the end of the Late Cretaceous, before Alpine compression, uplift, and erosion.

Assuming a 2–3 km thick Late Jurassic and Cretaceous overburden, two alternative evolutionary scenarios are envisaged for the Tazoult diapir during such burial. In the first scenario, diapirism became inactive by the early Middle Jurassic, and hence, the complete length of the Tazoult salt wall was fossilized by the Bajocian platform carbonates of the Bin el Ouidane 1 Fm. The salt welds preserved in both the NE and SW terminations of the Tazoult diapir may argue in favor of this hypothesis. In the second scenario, based on observed halokinetic geometries in the Bin el Ouidane 1 Fm in equivalent ridges, limited diapirism could persist during further burial of the Tazoult salt wall. This second scenario would imply a more prolonged evolution of the Tazoult salt wall with the remaining evaporites likely migrating upward and feeding smaller elliptical diapirs, after the Middle Jurassic and especially during Alpine compression, as observed in both the Atlantic margin of Morocco and the Tunisian Atlas (Figure 17).

8. Conclusions

The observed halokinetic stratal relationships indicate that the Tazoult Ridge (central High Atlas, Morocco) evolved as a salt wall forming a 20 km long NE-SW trending structural and sedimentary high for at least 20 Myr from Pliensbachian to Bajocian times.

The flanks of the Tazoult salt wall are composed of stacks of halokinetic sequences encompassing both carbonate and mixed carbonate/clastic deposits. The carbonates of the Pliensbachian Jbel Choucht and Aganane formations delineate large-scale (hundreds of meters to 1000 m) wedge halokinetic geometries on both flanks of the diapir that are well exposed along the Ouhancal River gorge. By contrast, the late Pliensbachian-Aalenian Zaouiat Group mixed carbonate and siliciclastic deposits (Amezraï, Tafraout, and Aguerd-n'Tazoult formations) form small-scale (tens of meters to a few hundred meters) hook- and wedge-type halokinetic sequences on both flanks of the Tazoult diapir indicating a change in the ratio between sediment accumulation and diapir rise.

We propose the initiation of the Tazoult salt wall by post-Hettangian extension triggering reactive-active diapirism (onset of diapirism) followed by a long period of passive diapiric growth. The passive diapirism stage initially controlled the development of the Pliensbachian carbonate platform capping the rising salt wall, which was karstified and subsequently eroded to form a 50 m thick unit of breccias around the salt wall. The most intense stage of passive diapirism occurred during the deposition of the late Pliensbachian-Aalenian mixed sediments that was characterized by salt wall inflation and the southeastward extrusion of an allochthonous salt sheet. The last stage of the salt wall evolution corresponds to its partial fossilization

by the late Aalenian-Bajocian carbonate platform observed along both terminations of the Tazoult ridge. However, the nearby Jbel Azourki salt wall records a late Aalenian-Bajocian halokinetic activity. The restoration of the cross section from the Tazoult to Jbel Azourki salt walls indicates that most of the Alpine shortening in the central High Atlas is concentrated above and around the diapiric structures, whereas the intervening Amezraï minibasin remains mostly undeformed.

The Tazoult salt wall was part of a widespread system of diapiric salt walls flanking minibasins during the Early-Middle Jurassic development of the Atlas rift basin. The diapirism of the central High Atlas province reported here is coeval with the earliest stages of diapirism in the Atlantic Atlas, both onshore and offshore, and in the Atlas of Algeria and Tunisia. These domains show ongoing diapirism up to Miocene and Pliocene times, which could also be the case in the central High Atlas.

The continuous exposure of the Tazoult salt wall structure and halokinetic strata constitutes an excellent field analog for equivalent structures in the aforementioned areas. In addition, the size of the Tazoult diapir and the extent of the shallow marine carbonate platform developed on top allow comparison with similar diapiric structures along active and ancient passive margins (Red Sea and North Atlantic province).

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