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1 **Evidence of Quaternary active folding near Utique (NE**
2 **Tunisia) from tectonic observations and a seismic profile**

3 **Plissement quaternaire d'Utique (NE Tunisie) mis en**
4 **évidence par des observations tectoniques et une ligne**
5 **sismique**

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16 **Abstract**

17 The present-day seismicity at northeastern Tunisia reported from permanent networks is of
18 low to moderate magnitude. However, earthquakes are mentioned in the literature, specially a
19 destructive one in the antique city of Utique. Geologic, seismic, and neotectonic
20 investigations in this area shows that Utique fold is closely related to the recent tectonic
21 activity in this region. Data show that Utique fold is built on an E-W fault, and we found
22 evidence of activity of this fault in the past 20 kyr. Seismic section and balanced cross section
23 shows that slip rate is of 0.38 mm.yr⁻¹. Our data show definitively the late Pleistocene–
24 Holocene activity of the Utique Fault; and we can predict the earthquake recurrence interval
25 which should be of ~10³-10⁴yr. This high seismic risk zone deserves to be taken into account
26 during the establishment of important regional development programs and in the application
27 of seismic building code.

28 **Keywords:** Atlas; Tunisia; active tectonics; fault-propagation folding; Utique; Quaternary;
29 Pliocene

30 **Introduction**

31

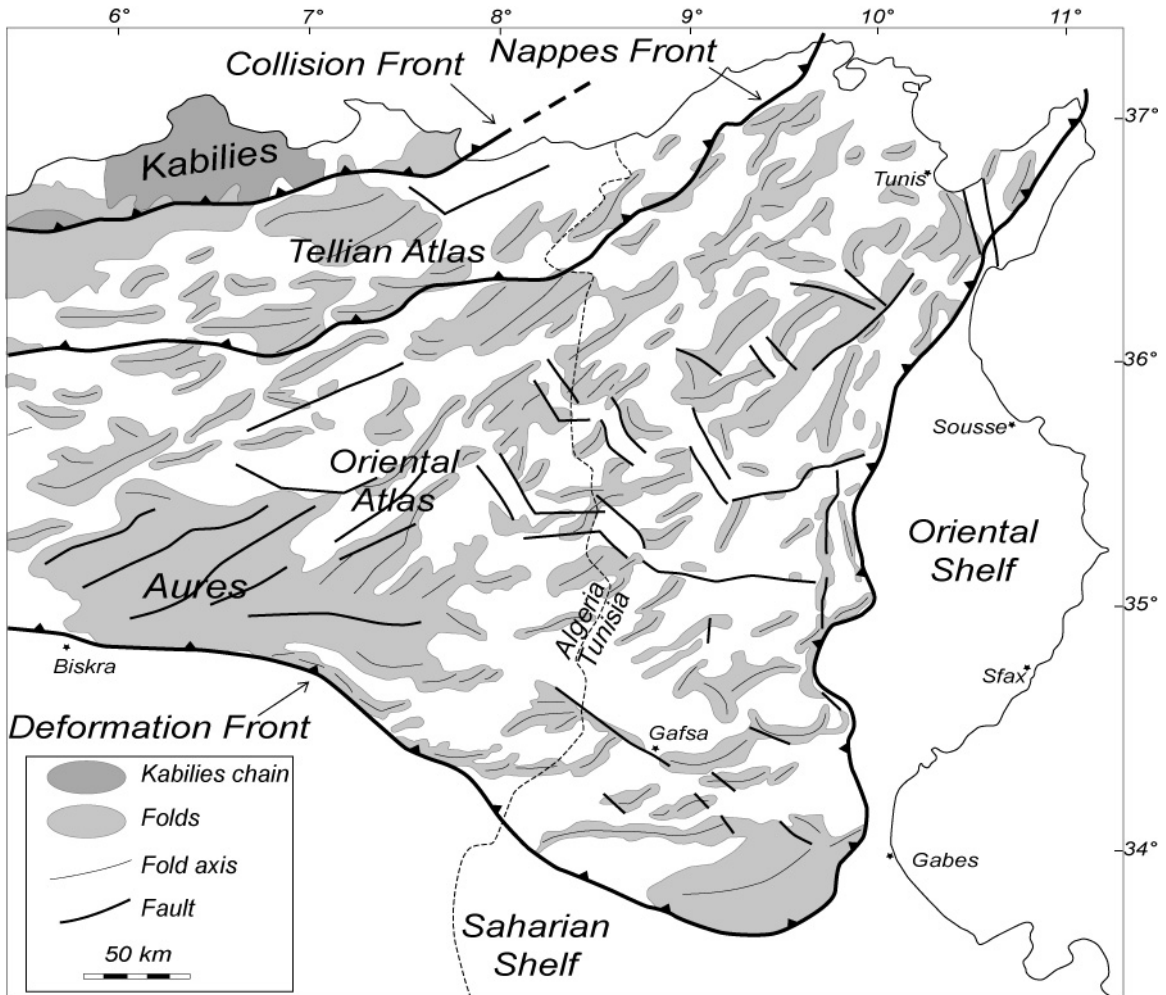
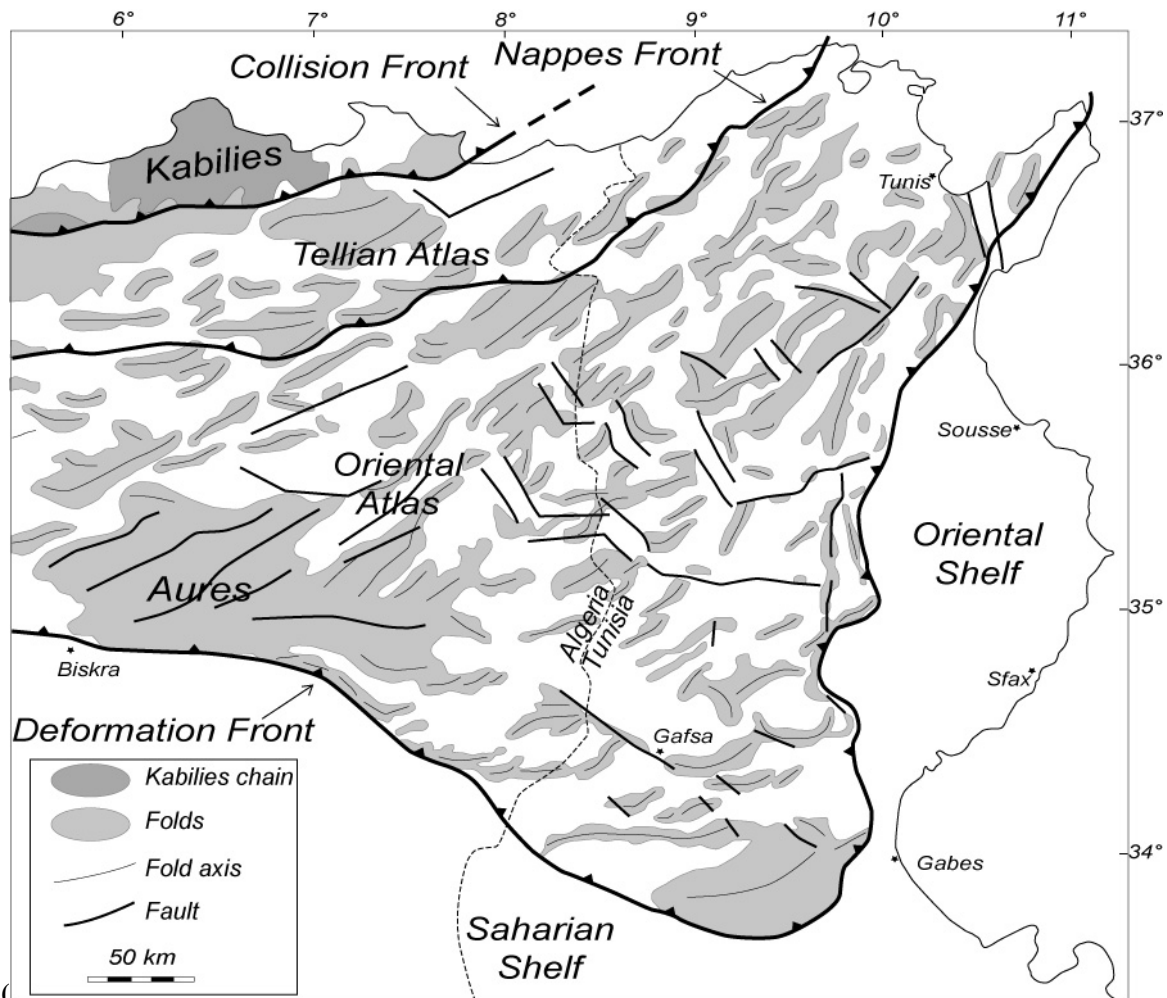


Figure 1. Structural map of Oriental Atlas (modified after Ahmadi, 2006 [1]).

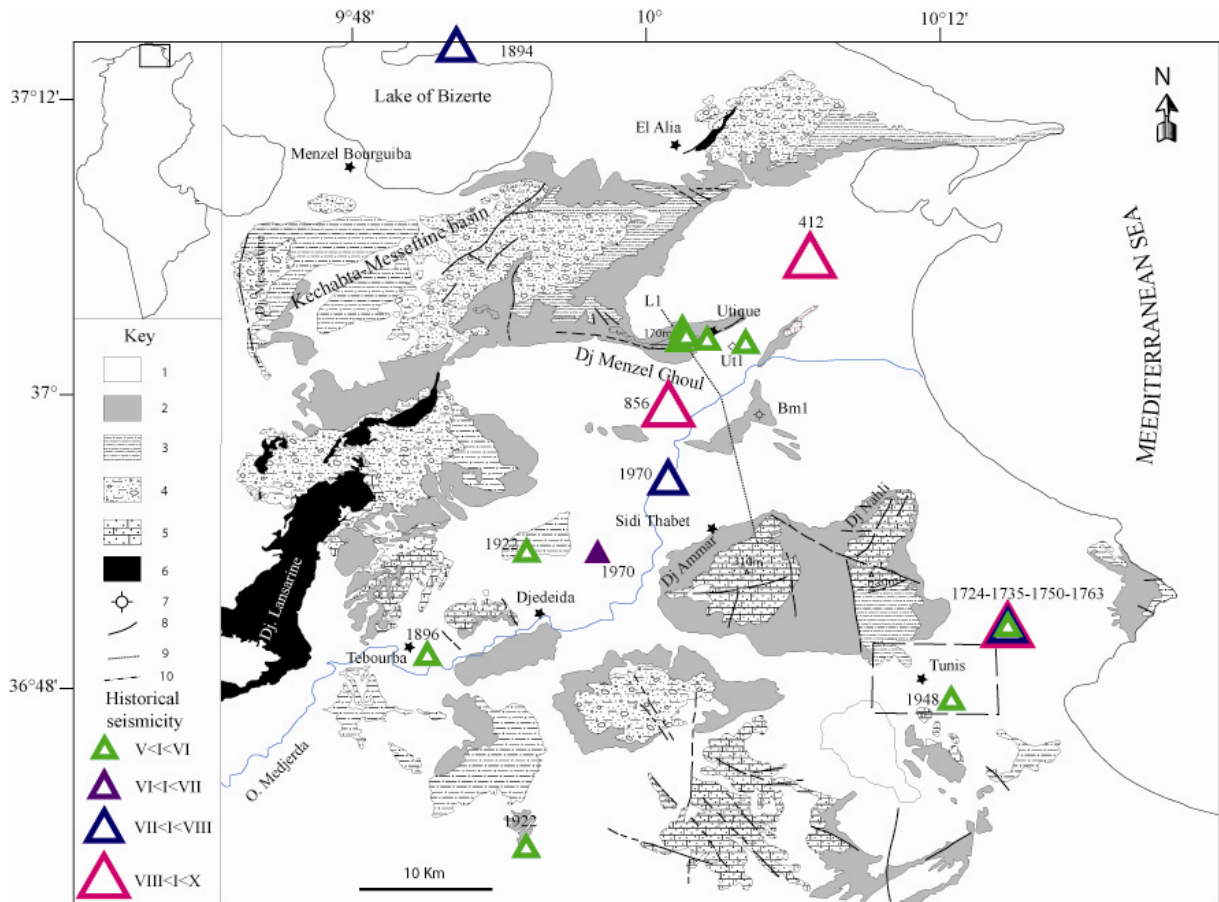
32 Northern and central Tunisia are dominated by the Tunisian Atlas, which is divided into several
33 structural zones, each characterized by faults and folds of variable magnitude



34
35 Figure 1). By its location at the northern African margin, northern Tunisia is strongly
36 influenced by the N135E-trending convergence of the African and Eurasian plates estimated
37 at about 5mm/yr [2-11]. In late Quaternary, seismological activity has been moderate to
38 locally intense; several earthquakes have been recorded in North East of Tunisia [e.g., 8, 12-
39 17]. This activity could take place in quaternary folds, reverse and strike slip faults which
40 deserve to be more studied to constrain modern rates of horizontal shortening and fold related
41 fault activity (as illustrated, for example, by the 1980 El Asnam earthquake in Algeria [18]).
42 The most active tectonic deformation is generally related to the reactivation of pre-existing
43 NW-SE, E-W and N-S trending strike slip faulting [15, 19]. One of the best examples of
44 active faulting is the destructive earthquake which ruined the antique city of Utique (35 km
45 north of modern Tunis) in 412 AD [20] and left surface deformation still visible [12]. It may
46 originate in the E-W-trending Utique fold structure, marked by both relief and seismicity

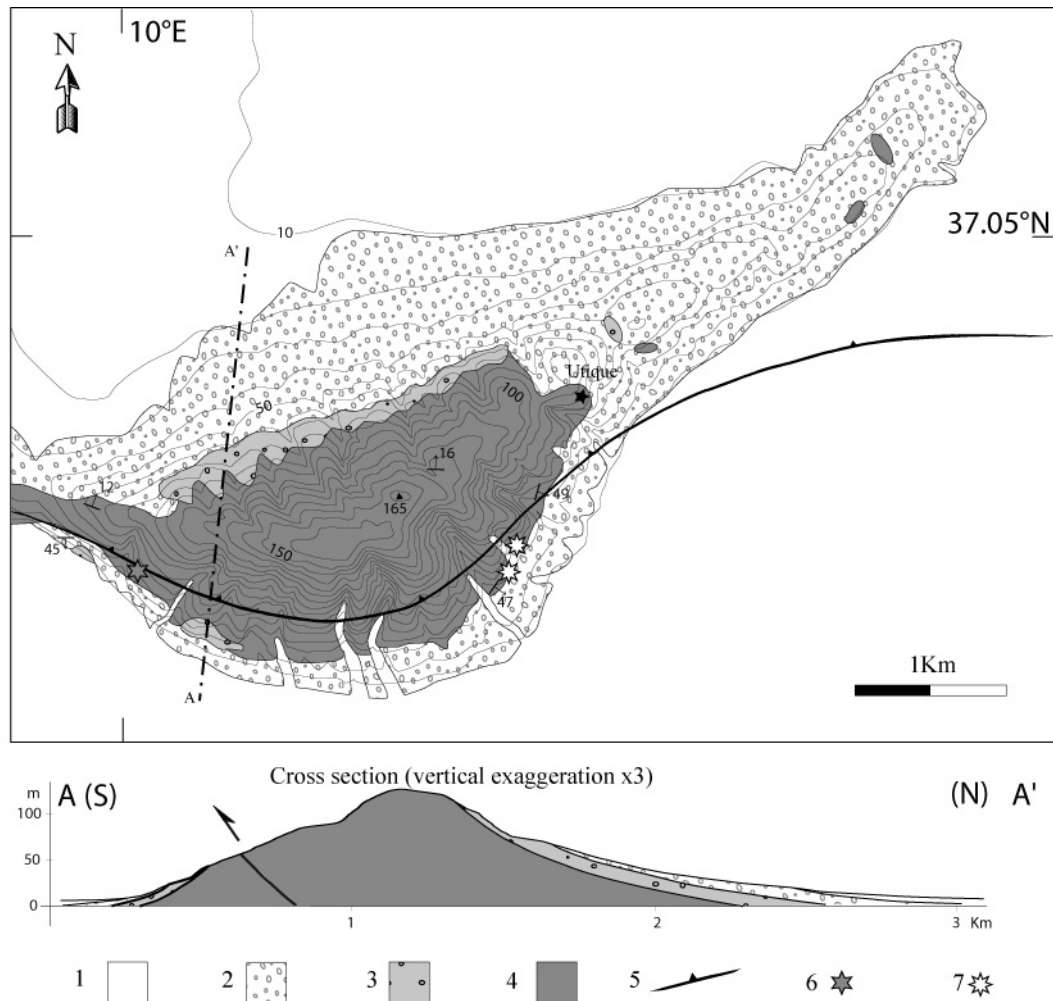
47 (Erreur ! Source du renvoi introuvable., and Figure 3) [15]: this structure is thus of major
48 importance in the seismic hazard assessment of the Tunis city surroundings.

49 The following study presents an integrated approach based on field observations, neotectonic
50 data, geological sections, seismic reflection data, and well logs to discuss the Utique fold
51 kinematics and estimate the Utique fold-related fault motion.



52

Figure 2. Geological map of northern Tunisia [21]. 1: late quaternary sediments, 2: lower quaternary, 3: Pliocene, 4: Miocene, 5: Cretaceous, 6: Trias, 7: Oil well, 8: Fault, 9: Seismic line, 10: Administrative boundary of Tunis City. Seismicity from the historical catalog covers the period between 412 AD and 1975 AD [20]; symbol size represents the intensity I.

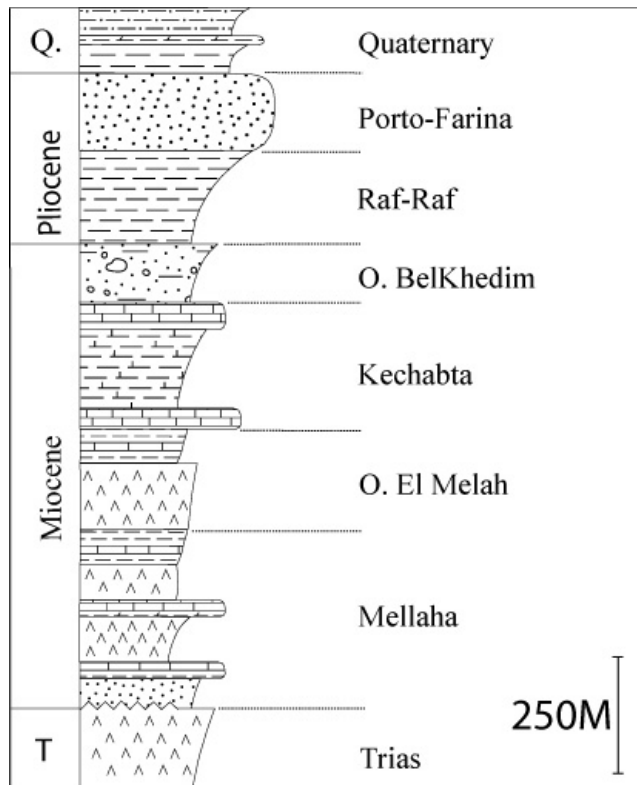


53

54 **Figure 3. Geological map and cross section of the Utique anticline. Legend: 1-modern**
 55 **alluvium; 2- Quaternary soils and colluvium; 3-upper Villafranchian; 4-Pliocene (Porto**
 56 **Farina Fm); 5-fault, as seen by geophysical methods [9]; 6-location of Figure 7; 7-**
 57 **location of Figure 6.**

58 ***Geological setting***

59 The Utique E-trending fold is located near the Utique village (about 35 km north of Tunis,
 60 **Erreur ! Source du renvoi introuvable.**). It bounds the Mio-Plio-Quaternary Kechabta-
 61 Messeftine continental shelf Basin to the southeast which is characterized by anticlines and
 62 lowlands [3, 22]. The fold emerges from a flat area made of Medjerdah river late quaternary
 63 (Holocene) alluvium. Seismic profiles indicate it is affected by an E-W-trending reverse fault
 64 (dip to the North) which outcrops in some places (see thereafter), but not yet clearly described
 65 [12, 15, 23]. The fold forms a topographic ridge about 3 km wide and 200 m high, and
 66 emerges from the lowlands for ~8 km.



67

68 **Figure 4. Stratigraphic log of the study area.**

69 The lithostratigraphical column is known after outcrops and well-logs [24]. Rocks from Trias
70 up to Quaternary outcrop in the area mainly in Anticlines (main relief constituted by the
71 “Jebels”) and plains, respectively [21, 25]. Additional stratigraphic information comes from
72 wells Ut1 and BM1 and from the transverse seismic line L1 (**Erreur ! Source du renvoi**
73 **introuvable.**). Ut1 well data, confirmed by the seismic profile L1, show mainly 1500 m-thick
74 Neogene units lying above thick chaotic Triassic evaporites. The 1000 m-thick-Upper
75 Miocene is composed of 4 formations (Mellaha, Oued El Melah, Kechabta and Oued Bel
76 Khedim, Figure 4). The Plio-Quaternary sedimentary pile is about 360 m thick. The lithologic
77 description of these sedimentary units is based on Ut1 well analysis and shows from the
78 surface downwards [24]:

79 - Quaternary rocks (up to 60 meters), predominantly continental to restricted lagoon shales,
80 sands conglomerates, calcareous crusts and alluvial deposits.

81 - The predominantly sandstone-made upper Pliocene Porto-Farina formation (up to 300 m)
82 lying above the lower Pliocene Raf-Raf formation (up to 300 m) which is constituted by
83 calcareous claystone and sand. This level appears only on Ut1 well log.

84 - Upper Miocene (Messinian) Oued Bel Khedim formation (up to 300 m) of littoral evaporitic
85 facies, lagoonal shales and local lacustrine limestones.

86 - The Kechabta formation (Tortonian) (up to 200 m) constituted lagoonal to continental shales
87 and sands.

88 - The Oued El Melah formation (Tortonian-upper Serravalian) (up to 150 m) showing
89 predominantly claystone, anhydrite (gypsum) with minor sand, dolomite and limestone.

90 - The Mellaha formation (Serravalian) (up to 350 m) evaporitic at its base, grading to
91 interbedded claystone, and anhydrite towards its top, with minor dolomite.

92 - Trias formations of dolomite and some pyrobitumen, with rare gypsum.

93 This stratigraphy reveals several incompetent evaporate and shale intervals that can be
94 considered as detachment horizons, as it will be shown in this work. These are the Oued El
95 Melah and Mellaha Formations (Tortonian-Upper Serravalian), and Oued Bel Khedim
96 (Messinian) Formations (Figure 4).

97 The Quaternary has been studied in details by Oueslati [23]. It is constituted by successive
98 clayish strata each one usually being cemented on top by a calcareous crust more or less thick
99 (calcrete). The number of strata varies from site to site, but the general trend is clay color
100 evolution from gray-green to red-pink towards. The succession could be related to
101 Quaternary glacial/interglacial alternation [23].

102 ***Seismological background***

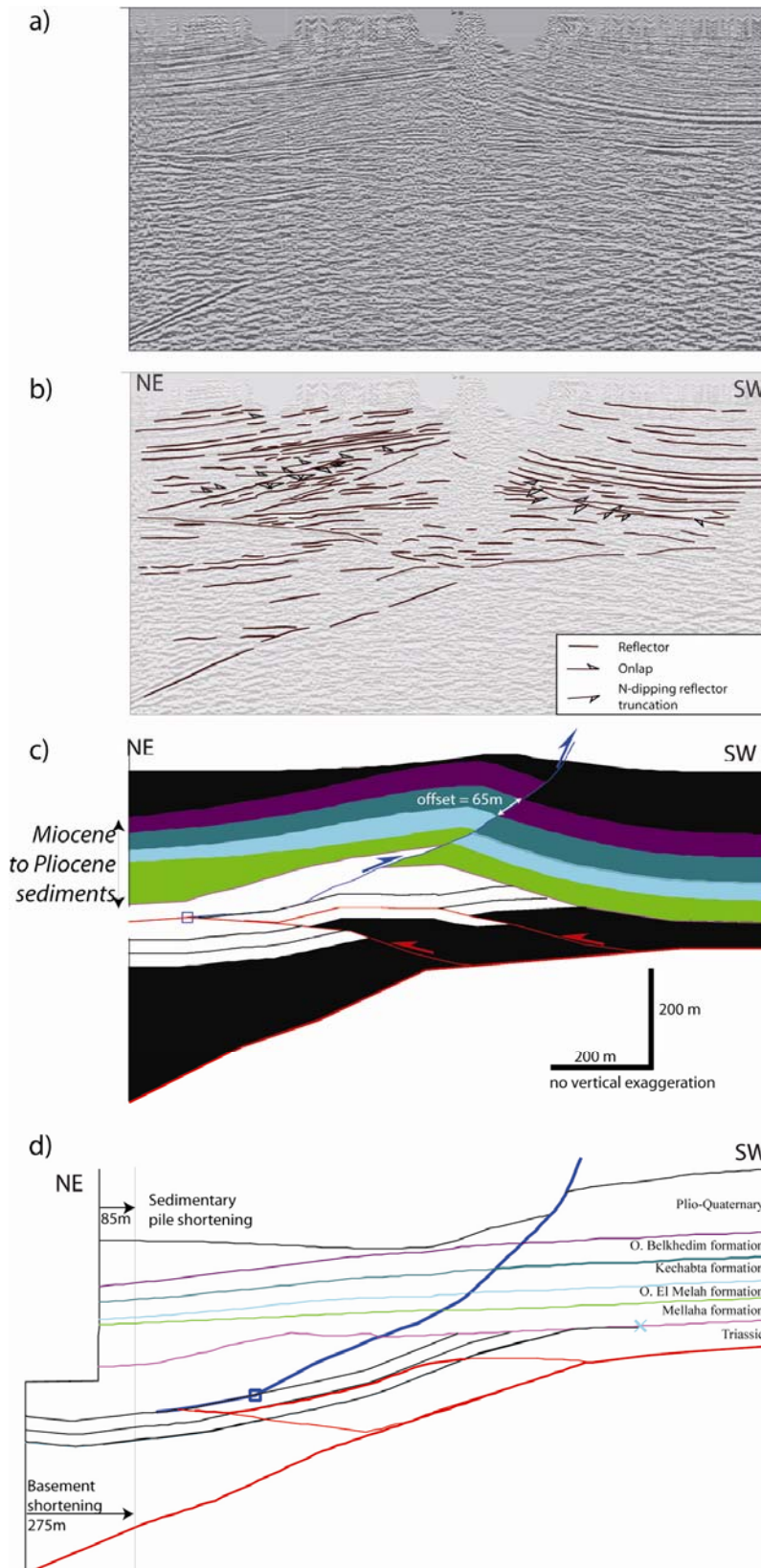
103 **Erreur ! Source du renvoi introuvable.** is presenting the historical seismicity. The historical
104 seismicity displayed comes from records of the historical catalog, spanning the period
105 408AD-1975AD [20] while instrumental seismicity is recorded since 1976 by the Tunisian
106 National Meteorological Institute. In northeastern Tunisia, the background seismicity is
107 important even if magnitudes are generally low, lower than 5. Moreover the earthquake
108 location figure is not informative about the seismogenic structures: no earthquake alignments
109 could be detected. Earthquakes located are always within the first 15 km of the crust.

110 Since destructive earthquakes have been recorded in the past, the two main ones being the
111 408AD in Utique and the 856AD in Tunis [20], studying the active structures in order to
112 better define the seismogenic character is of primary importance. It drove the way this study
113 was conducted.

114 ***New data and interpretation***

115 **Seismic Profiles**

116 The area of interest is well covered by 2D seismic survey acquired by the MAXUS LTD in
117 1983 and 1994. These seismic profiles are of moderate quality and some of them are not
118 migrated. Thus we present thereafter careful interpretations.



119

120 **Figure 5. a) seismic profile; b) interpretation (no vertical exaggeration); c) Cross-section**
 121 **in Utique structure drawn after seismic line L1 and slip rate measurement; c) Unfolding**
 122 **cross-section back to lowermost Miocene.**

123 We use the seismic profile L1 (with additional information from profile L2, **Erreur ! Source**
124 **du renvoi introuvable.**) trending N-S. This profile crosses the Utique fold and extends for
125 about 15 km from Northern Utique to Djebel Ammar to the South. The profile has been
126 depth-converted thanks to stratigraphic data coming from wells Utique1 and Bm1, closely
127 located (2.2 and 1.8 km, respectively; **Erreur ! Source du renvoi introuvable.**). The Ut1
128 well TD is 2500-m-deep.

129 The seismic profile L1 exhibits an erosional unconformity which separates two stratigraphic
130 packages (Figure 5). This unconformity is marked by the truncation of north-dipping
131 reflectors corresponding to a lower stratigraphic package and by the onlap of the upper
132 stratigraphic package. Ut1 well data indicates the lower package is made of mesozoic
133 sediments whose strata in the upper part could be seen, its base being probably made of
134 Triassic rocks. The overall Mesozoic sequence slightly dips to the north. A thick evaporitic
135 section of the Mellaha formation (Serravalian) seals the north-dipping Triassic strata. Such an
136 unconformity was previously reported by Brusset (1999) [26] and Khomsi et al. (2009) [27].
137 The Mellaha fm. is overlain by strata from upper Miocene upward which are merely isopach
138 and constitute the upper package. These are only deformed by a thrust branching at depth into
139 the Mellaha formation acting as a decollement level (see thereafter and Figure 5). The
140 structural style can be tracked on the seismic line. It consists obviously of a triangle zone
141 defined by a deep-seated fault-bend fold and a shallow fault-propagation anticline (Utique
142 anticline). Both folds are associated with south-verging thrusts which sole-out in Triassic and
143 Mellaha evaporites respectively (Figure 5). One must note that if the Mesozoic and the lower
144 Miocene formations are missing in the Utique structure, they are found at outcrop just 5 km to
145 the south in the Djebel Ammar [28, 29].

146

147 The seismic section has been analyzed using typical concepts of thrust tectonics [30-33] in
148 order to propose a balanced cross-section of the Utique fold, which gave important insights
149 into the fold history. The Utique fold developed reactivating a pre-Miocene structure. Slip
150 transfer is owing to an intermediate duplex developed in the lower stratigraphic package.

151 The cross-section was further analyzed by stepwise unfolding. This exercise is represented in
152 Figure 5. After a quiet period marked by upper Miocene deposition over previously folded
153 Mesozoic strata, the area has been shortened again. It is not possible to know when this
154 shortening stage began. Nor it is possible to be sure this shortening stage has continued up to
155 today, even if such a hypothesis is probable regarding to the background local seismicity.

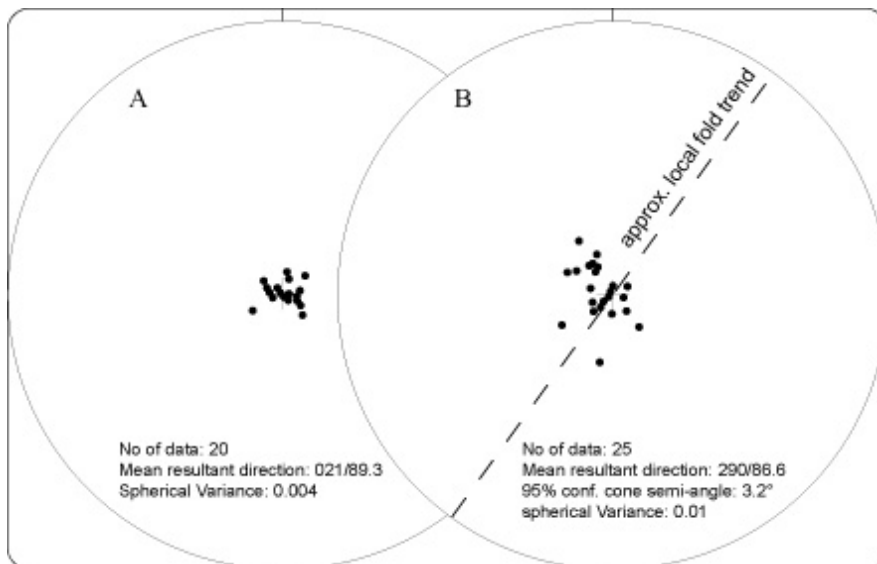
156 During this last deformation stage, deformation is accommodated at depth by the Mellaha
157 formation decollement (Figure 4 and Figure 5) and meanwhile by fault propagation folding in
158 the uppermost, from Miocene upward, formations. Interestingly, this scenario implies a
159 connection to deeper structures further south. It allows calculating a total shortening since the
160 Mio-Pliocene boundary of about 690 m (0.14 mm/yr on average) in the basal part and of
161 about 210 m in the uppermost formations (0.04 mm/yr). Note that individual formation offset
162 decreases upward, as predicted by the fault propagation geometry [34-36]. This implies that at
163 surface, the maximum offset observable is much less than these 690 m. Actually, it must be
164 less than the uppermost offset observed on the cross-section, which corresponds to the 170 m
165 Mio-Pliocene boundary offset.

166 **Geomorphology**

167 Geomorphic investigations from Utique anticline were conducted through satellite imagery
168 analysis, and by analysis of a digital elevation model (DEM) of the Utique fold (Figure 3).
169 The study of this DEM shows that the Utique anticline is trending E-W in the western part,
170 and its trend change to ENE-WSW in the eastern part. It is about 3 km wide and 200 m high.
171 It is characterized by a steeply dipping forelimb (reaching 45°) and a gently dipping backlimb
172 (not exceeding 30°). Both forelimb and backlimb exhibit a break in slope dividing them into
173 two slope segments separated by a short “flat” with gentle slope (usually used for farming). In
174 both limb the lower slope is shorter than the higher one, both slopes having close dip (Figure
175 3). Gullies developed in fold limbs in Quaternary and Upper Pliocene (Porto Farina fm) rocks
176 mantling the fold. In these gullies Quaternary rocks are discordant over the Pliocene ones.

177 **Neotectonic Markers**

178 On the south limb of the fold, at least two calcretes horizons are found, attributed to
179 Pleistocene and Holocene, respectively [23]. These horizons contain calcareous nodules
180 generated around plant roots. Originally, these nodules trend vertically; this is not necessarily
181 the case for the horizon itself, which could have mantled an inclined slope. A careful
182 measurement of calcareous concretion orientation has been carried in two locations on the
183 southeastern limb of the fold (Figure 6). They indicate a possible slight tilt (less than 5
184 degrees) with an axis perpendicular to the fold limb. If true, it would imply the tilt has
185 occurred since Pleistocene there.



186

187 **Figure 6. Wulf stereoplot of calcareous concretion data in two locations SE of the fold.**

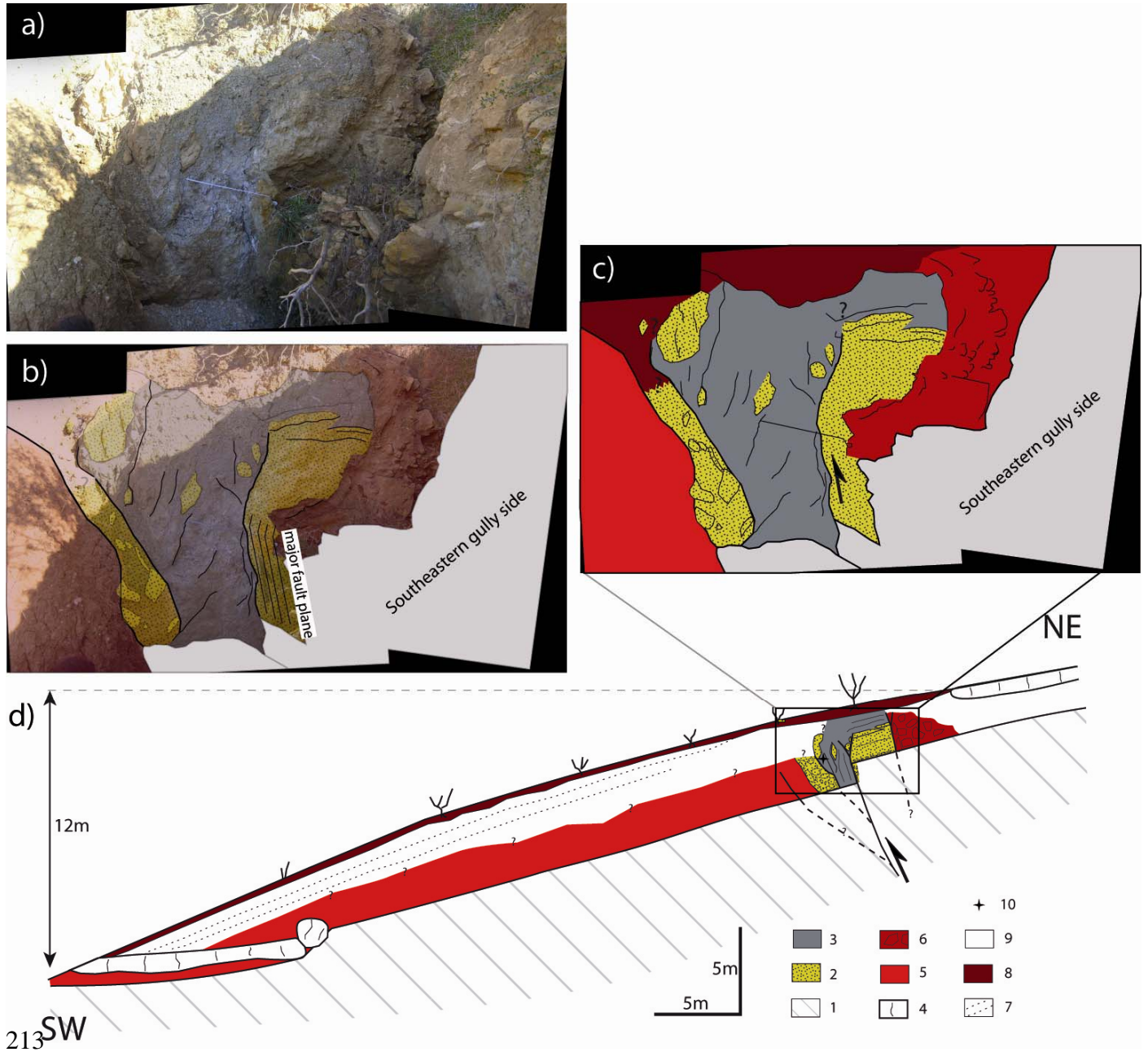
188 **In A, no tilt is indicated whereas in B, a slight tilt of 3° in a direction N290° is possible**

189 **(within 95% confidence), but not attested, this direction being roughly perpendicular to**

190 **the fold trend.**

191 A fault that can be associated with the fold has been observed along the Tunis-Bizerte
 192 motorway at the time of its building, but unfortunately the outcrop has never been described
 193 and is no more visible [12, 15, 19]. In turn, after careful exploration of the fold, another
 194 outcrop was found in a quarry now turned into a dump (37°01.80'N; 10°00.00'E). A fault
 195 outcrops in a gully ~5 m wide and ~5m deep (Figure 7). The gully seems to have experienced
 196 a complicated story with a first incision stage followed by recent filling and renewed incision
 197 that continues currently. This explains some strong differences observed on both sides of the
 198 gully; the southeastern side is the most representative and is schematized in Figure 3 in which
 199 were added some observations made in the northwestern side. A fault plane was found,
 200 displaying important variations in trend and dip; the average values being a N150°E trend and
 201 an 80°N dip, with uncertainties evaluated to be ~20°. It is accompanied by small faults that
 202 display an average N150°E-azimut and 60°N-dip. The fault offsets clearly some
 203 conglomerates made of Pliocene marine formation reworking and gray clay levels, observed
 204 elsewhere lying on top of calcrete. It is mantled by the recent gully infilling made of angular
 205 debris, which could have been affected by the fault (Figure 7). The major fault and its
 206 associated minor faults are affecting, with sometimes offsets observed, the following
 207 formations (Figure 7): some sandstones and conglomerates coming from Pliocene strata
 208 erosion (2 on Figure 7); grey clays (3 on Figure 7); red clays with calcrete remnants, typical
 209 form the Quaternary [23] (5 on Figure 7). A disturbed formation, that can be considered as a

210 fault gouge, made of clay and calcrete-derived sands, contains a piece of pottery, less than
 211 2000 years-old after archeologist expertise (Slim Khosrof, National Institute of Patrimony,
 212 Tunis, personal communication).



214 **Figure 7. Utique fold outcrop. a) Photography of the main fault plane; b) interpretation**
 215 **of the photo: faults (the main ones are in bold); c) interpretation of the photo; d) outcrop**
 216 **scheme. The photo (a,b,c) corresponds to a zoom of the fault zone. Main lithological**
 217 **formations, in likely stratigraphic order: (1) Gully basement; (2) Sandstones and**
 218 **conglomerates mainly made of Pliocene material (3) Gray clays; (4) Calcareous crust;**

219 **(5) Red clays with calcareous nodules; (6) Recent conglomerates; (7) Colluvial wedge;**
220 **(8) Soil; (9) Undetermined; (10) Approximative pottery location.**

221 In sum, the fault observed appears to have been active very recently, during the Holocene; it
222 has a clear reverse component.

223 Observations around this gully indicate that the calcrete underwent a total ~12 m vertical
224 offset (Figure 7). The calcrete often mantle the fold topography, but it is found faulted in
225 numerous places in the lower fold slope described in the previous section. One may
226 hypothesize that this lower slope corresponds to the total vertical calcrete offset, evaluated to
227 be ~40m, corresponding to ~45m of fault motion if fault dip is 60°.

228 ***Discussion***

229 The stepwise unfolding of the section including Utique structure shows that it was affected by
230 two phases of compressional deformation. The first one is occurred during Miocene (attested
231 by thickness variation of the Serravalian Mellaha formation) and caused folding over a
232 passive ramp in Triassic sediment. The timing of the second one is unclear because of low
233 definition of seismic data in its uppermost part: it clearly occurred after Serravalian. Tectonic
234 studies in neighboring areas (and all over Tunisia) clearly indicate that compression begun
235 early in Pleistocene after a Late Miocene to Late Pliocene extensional phase [e.g., 12, 28, 37,
236 38]. Field observations of surface faulting, debris of less than 2000 years old pottery reworked
237 and possibly tilted calcareous nodules at the fault zone suggest that the main compressional
238 phase continues up to present.

239 A total shortening of 690 m has been measured indicating an average shortening rate of 0.14
240 mm/yr since the beginning of Pliocene. As already mentioned, compression must have begun
241 early in Pleistocene (1.8 My); this leads to a most likely value for shortening rate of
242 0.38 mm/yr, corresponding to ~8% of the current shortening in Tunisia (~4.5 mm/yr in a
243 direction N145°E between stable Africa and Sardinia after a compilation of results from
244 D'Agostino and Selvaggi [39] and Hollenstein et al. [40]). Interestingly, Ahmadi [1, 2] made
245 a restoration of a section crossing the whole Tunisia from North to South. He found a rough
246 value for total shortening of 55 km which cannot be the result of the Quaternary shortening
247 alone (it would imply an average shortening velocity of ~3cm/yr). This does not contradict
248 our data which shows an older shortening phase (during Lower Miocene), even if it was less
249 marked in the study area.

250 We observed that the Utique structure must be seismogenic. Indeed, it displays clear
251 evidences of surface rupture. Historic (since roman era) displacements are meter-scale.
252 Speculatively we can use empirical relations from Wells and Coppersmith (1994)[41], with a
253 surface length of ~8 km, to evaluate the order of earthquake magnitude (~6) or typical surface
254 offset (~0.5 m); conversely earthquake recurrence interval should be of $\sim 10^3$ - 10^4 yr. These are
255 rough evaluations. Similar analysis should be extended to adjacent regions to give more
256 precision to fault segmentation.

257 **Conclusion**

258 We provide evidence of recent surface rupture along the Utique Fold. In addition, after
259 studying seismic cross-section we are able to evaluate a total shortening of 690 m during the
260 Quaternary. This corresponds to an average shortening rate of about 0.38 mm/yr, one tenth of
261 the total shortening accommodated over the whole country. This makes the Utique fault
262 propagation fold an important structure when regarding seismological hazard of the 1.5M
263 people Tunis City, located 35 km to the south.

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269 **References**

- 270 [1] R. Ahmadi, Utilisation des marqueurs morphologiques, sédimentologiques et
271 irostructuraux pour la validation des modèles cinématiques de plissement.
272 Application à l’Atlas méridional tunisien, Univ. Nantes, 2006.
- 273 [2] R. Ahmadi, J. Ouali, E. Mercier, J.-L. Mansy, B. Van-Vliet Lanoe, P. Launeau, F.
274 Rhekhiss, S. Rafini, The geomorphologic responses to hinge migration in the fault-
275 related folds in the Southern Tunisian Atlas, *Journal of Structural Geology* 28(2006)
276 721.
- 277 [3] P.F. Burollet, Etude géologique des bassins moi-pliocène du Nord est de la Tunisie,
278 *Ann. Mines et géologie de Tunisie*, Tunis, 1951.
- 279 [4] E. Calais, C. DeMets, J.M. Nocquet, Evidence for a post-3.16-Ma change in Nubia-
280 Eurasia-North America plate motions? *Earth Planet. Sci. Lett.* 216(2003) 81-92.
- 281 [5] A. Caire, M. Maamouri, Z. Stranik, Contribution à l’étude structurale de la région des
282 Hédil (Tunisie septentrionale) et comparaison avec le Tell Algérien, *Notes du Service*
283 *Géologique de la Tunisie* 36(1971) 1-30.
- 284 [6] G. Castany, Etude géologique de l’Atlas tunisien oriental. Thèse Doctorat ès Sciences,
285 Paris, *Annales Mines et Géologie*, Tunis, 1951, 632 pp.

- 286 [7] M. Durand-Delga, J.M. Fonboté, Le cadre structural de la Méditerranée occidentale,
287 26ème Congrès géol. inter. Paris, les chaînes alpines issues de la Téthys, mém.
288 BRGM, 1980, pp. 67-85.
- 289 [8] M. Hfaiedh, Etude sismotectonique de la Tunisie nord-orientale, Univ. Paris VI, 1983.
- 290 [9] J. Kacem, Etude sismotectonique et évaluation de l'aléa sismique régional du Nord-
291 est de la Tunisie apport de la sismique réflexion dans l'identification des sources
292 sismogéniques, Univ. Tunis, 2004.
- 293 [10] J.M. Nocquet, E. Calais, Geodetic measurements of crustal deformation in the
294 Western Mediterranean and Europe, Pure And Applied Geophysics 161(2004) 661-
295 681.
- 296 [11] A. Piqué, P. Tricart, R. Guiraud, E. Laville, S. Bouaziz, M. Amrhar, R. Ait Ouali, The
297 Mesozoic-Cenozoic Atlas belt (North Africa): an overview, Geodinamica Acta
298 15(2002) 185-208.
- 299 [12] N. Ben Ayed, Evolution tectonique de l'avant-pays de la chaîne alpine de Tunisie du
300 début du Mésozoïque à l'Actuel, Université de Tunis II, 1986.
- 301 [13] G. Castany, Essai de synthèse géologique du territoire Tunisie-Sicile, Ann. Mines et
302 Géol., Tunis, 1956.
- 303 [14] L. Boutib, F. Zargouni, F. Melki, Tectonique récente et sismotectonique de la région
304 du grand Tunis: apport télé-analytique et données de terrains, Africa Geoscience
305 Review 4(1997) 395-403.
- 306 [15] M. Dlala, Evolution géodynamique et tectonique superposées en Tunisie implications
307 sur la tectonique récente et la sismicité, Tunis II, 1995.
- 308 [16] Y. Kammoun, Etude néotectonique de la région de Monastir-Mahdia (Tunisie
309 orientale): géologie structurale, Univ. Paris XI, 1981.
- 310 [17] R. Vaufrey, Le plissement Acheulo-Moustérien des environs de Gafsa, Rev. Géol.
311 Dyn. Géogr. Phys. 1(1932) 209-325.
- 312 [18] H. Philip, M. Meghraoui, Structural-Analysis And Interpretation Of The Surface
313 Deformations Of The El-Asnam Earthquake Of October 10, 1980, Tectonics 2(1983)
314 17-49.
- 315 [19] M. Dlala, S. Rebai, Relation compression extension miocène supérieur à quaternaire
316 en Tunisie, C. R. Acad. Sci. Paris 39(1994) 945-950.
- 317 [20] J. Vogt, Further research on the historical seismicity of Tunisia, Terra Nova 5(1993)
318 475-476.
- 319 [21] Office National des Mines de Tunisie, Carte géologique de la Tunisie 1/500000,
320 Office National des Mines de Tunisie, Tunis, 1987.
- 321 [22] N. Ben Ayed, Le rôle des décrochements E-W dans l'évolution structurale de l'Atlas
322 tunisien, C.R. Somm. Soc. Géol. France 290(1980) 29-32.
- 323 [23] A. Oueslati, Les côtes de la Tunisie, recherches sur leur évolution au Quaternaire,
324 Publications de la faculté des sciences humaines et sociales de Tunis. Série 2:
325 Géographie, 1993, 402 pp.
- 326 [24] ETAP, well report, Ut1 and Bm1 well log, ETAP (Entreprise Tunisienne des Activités
327 Pétrolières).
- 328 [25] F. Melki, Tectonique de l'extrémité Nord- Est de la Tunisie (Bizerte-Menzel
329 Bourguiba-Mateur), évolution tectonique de blocs structuraux du Crétacé supérieur au
330 Quaternaire, Université Tunis II, 1997.
- 331 [26] S. Brusset, Dyanmique des bassins d'avant-pays: signatures tectoniques et
332 sédimentaires de l'évolution de chaînes de montagnes (exemples de la chaîne de
333 Taiwan et de la chaîne des Maghrébides-Bétides), Université Paul Sabatier, Toulouse
334 III, 1999.

- 335 [27] S. Khomsi, M. Soussi, C. Mahersi, M. Bedir, H.F.B. Jemia, S. Riahi, K.B. Khalfa,
336 New insights on the structural style of the subsurface of the Tell units in north-western
337 Tunisia issued from seismic imaging: Geodynamic implications, *Comptes Rendus*
338 *Geoscience* 341(2009) 347-356.
- 339 [28] J.J. Devolvé, G. Martin, G. Menant, Le Djebel Amar de l'Ariana. Esquisse structurale
340 issue de données stratigraphiques nouvelles, *Trav. Geol. Tun.*, note n°46 14(1980).
- 341 [29] S. Pini, C.A. De Jauzein, F. Kchouk, Carte géologique de la Tunisie au 1/50000,
342 feuille n°13: Ariana, Publ. Serv. Géolo. Tunisie, 1971.
- 343 [30] C.D.A. Dahlstrom, Balanced cross sections, *Can. J. Earth Sci.* 6(1969) 743-757.
- 344 [31] C.D.A. Dahlstrom, Geometric constraints derived from the law of conservation of
345 volume and applied to evolutionary models of detachment folding, *AAPG Bull.*
346 74(1990) 336-344.
- 347 [32] L.U. De Sitter, *Structural Geology* (2nd edition), McGraw-Hill, New York, 1964, 551
348 pp.
- 349 [33] W.R. Jamison, Geometric analysis of fold development in overthrust terranes, *J.*
350 *Struct. Geol.* 9(1987) 207-219.
- 351 [34] J.G. Ramsay, M.I. Huber, *Modern structural geology; tome 2: Folds and Fractures*,
352 Academic Press (London), 1987, 700 pp.
- 353 [35] H. Rouvier, *Géologie de l'extrême Nord tunisien*, 1985, 417 pp.
- 354 [36] J. Suppe, D.A. Medwedeff, Geometry and kinematics of fault-propagation folding,
355 *Eclogae Geologicae Helveticae* 83(1990) 409-454.
- 356 [37] N. Boukadi, Structuration de l'Atlas de Tunisie; signification géométrique et
357 cinématique des noeuds et des zones d'interférences structurales au contact de grands
358 couloirs tectoniques, Univ. Tunis II, 1994.
- 359 [38] F. Zargouni, Tectonique de l'Atlas méridional de Tunisie. Évolution géométrique et
360 cinématique des structures en zone de cisaillement, université Louis-Pasteur, 1985.
- 361 [39] N. D'Agostino, G. Selvaggi, Crustal motion along the Eurasia-Nubia plate boundary in
362 the Calabrian Arc and Sicily and active extension in the Messina Straits from GPS
363 measurements, *Journal Of Geophysical Research-Solid Earth* 109(2004) B11402.
- 364 [40] C. Hollenstein, H.G. Kahle, A. Geiger, S. Jenny, S. Goes, D. Giardini, New GPS
365 constraints on the Africa-Eurasia plate boundary zone in southern Italy, *Geophysical*
366 *Research Letters* 30(2003).
- 367 [41] D.L. Wells, K.J. Coppersmith, New empirical relationships among magnitude, rupture
368 length, rupture width, rupture area, and surface displacement, *Bull. Seis. Soc. Am.*
369 84(1994) 974-1002.
- 370