Title: Diachronous folding and cleavage in an intraplate setting (Central High Atlas, Morocco) determined through the study of remagnetizations

Abstract: Remagnetizations are common in intraplate basins. When remagnetizations occur at an intermediate stage between different tectonic processes, they can be used for paleo-geometrical reconstructions and relative dating of different structures. This has a particular interest in geological frameworks where other geological markers are absent. In order to apply this methodology, it is necessary to calculate the regional remagnetization direction and subsequently to use this reference direction to restore the attitude of the beds at the moment of remagnetization acquisition. In this work, we use this methodology for dating a pervasive cleavage (whose time of formation is controversial) and the associated structures in the Central High Atlas. Paleomagnetic directions from 64 sites were used to calculate the regional remagnetization direction D= 330.6° / I= 36.1° that is coincident with the Albian-Cenomanian expected direction for NW Africa. This direction was used to restore the Mesozoic paleo-geometry of beds allowing us to analyse bedding orientation, cleavage and folding relationships between the present day and the Cretaceous geometry. After restoration we conclude that the development of cleavage postdates remagnetization, being in relation with Cenozoic basin inversion. However, the paleo-geometry shows incipient folds at Cretaceous times, which can be related to an intra-Mesozoic compressional event.

Novel approach for dating cleavage in inverted basins using widespread remagnetizations

Regional paleomagnetic direction of the Cretaceous remagnetization (100 Ma.)

Present-day and restored at 100 Ma. geological cross-sections

Better constraints about deformational history of the Central High Atlas basin

Cleavage in the High Atlas developed during the Cenozoic inversion

1   **Diachronous folding and cleavage in an intraplate setting (Central High Atlas, Morocco)**

2   **determined through the study of remagnetizations**

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21   Abstract

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23   Remagnetizations are common in intraplate basins. When remagnetizations occur at an intermediate

24   stage between different tectonic processes, they can be used for paleo-geometrical reconstructions and

25   relative dating of different structures. This has a particular interest in geological frameworks where

26   other geological markers are absent. In order to apply this methodology, it is necessary to calculate the

27   regional remagnetization direction and subsequently to use this reference direction to restore the

28   attitude of the beds at the moment of remagnetization acquisition. In this work, we use this

29   methodology for dating a pervasive cleavage (whose time of formation is controversial) and the

30   associated structures in the Central High Atlas. Paleomagnetic directions from 64 sites were used to

31   calculate the regional remagnetization direction D= 330.6º / I= 36.1º that is coincident with the Albian-

32   Cenomanian expected direction for NW Africa. This direction was used to restore the Mesozoic paleo-

33   geometry of beds allowing us to analyse bedding orientation, cleavage and folding relationships

34   between the present day and the Cretaceous geometry. After restoration we conclude that the

35   development of cleavage postdates remagnetization, being in relation with Cenozoic basin inversion.

36   However, the paleo-geometry shows incipient folds at Cretaceous times, which can be related to an

37   intra-Mesozoic compressional event.

38

39   **1. Introduction**

40

41   Defining the relationships between cleavage and folding is a classical ~~tool~~ in structural geology,

42   helping to decipher the tectonic evolution of orogenic areas (see e.g. Séguret, 1972; Mattauer, 1973;

43   Williams, 1985; Mitra and Yonkee, 1985; Ramsay and Huber, 1987; Marshak and Mitra, 1988;

44 Lüneburg and Lebit, 1998). This task requires the definition of the relative age of cleavage with respect

45 ~~to folding and their geometrical relationships in large-scale and small-scale folds.~~ Relative and absolute

46 dating of cleavage in partially inverted intracratonic basins containing rocks which underwent very low

47 to low metarmophic ~~evolution~~ is sometimes a difficult task. This is in relation with the generally weak

48 deformation ~~and~~ the lack of significant thermal events and/or the absence of syntectonic sediments

49 associated with particular tectonic phases.

50   Intracratonic Mesozoic basins of the western Tethys domain (Fig. 1; Iberian Peninsula and NW

51 Africa) show several examples of this problematic. In an overall view, these basins had a similar

52 evolution during Mesozoic-Cenozoic times. They are characterized by a first rifting phase during the

53 Early Triassic ~~followed by a post-rift phase in the Middle-Upper Triassic,~~ a second rifting phase during

54 the Jurassic or Early Cretaceous (having different timing in different basins), both followed by thermal

55 relaxation, post-rift stages. Finally a general event of inversion took place during the Cenozoic in all

56 these basins as the result of Africa, Iberia and Europe convergence (Gibbons and Moreno, 2002; Frizon

57 de Lamotte et al., 2008). Most of these basins, both in the Iberian and African plates, show a Mesozoic

58 remagnetization (e.g. Galdeano et al., 1989; Moreau et al., 1992; Juárez et al, 1998; Villalaín et al.,

59 2003; Soto et al., 2008; Torres-López et al., 2014; Moussaid et al., 2015; Calvín et al., in review) and

60 some of them developed cleavage to varying degrees. A particularly interesting stage in the evolution of

61 these basins is ~~the~~ Mesozoic compression and cleavage formation stage (as an intermediate

62 compressional stage within the overall extensional evolution), that has been clearly assessed in the

63 Cameros basin (Casas-Sainz and Gil-Imaz, 1998; García-Lasanta et al., 2014), and proposed in the

64 High Atlas (Laville, 1985; Laville and Piqué, 1992), having important implications in plate kinematics.

65 This Mesozoic compression event, but without cleavage development, also was recognized by Soto et

66 al. (2011) in the Basque-Cantabrian basin (N Spain).

67   Cleavage in the Cameros basin (westernmost sector of Iberian Range, N Spain) has a

3

68 widespread development and is related (both in time and in space) to a metamorphic event (Gil-Imaz

69 and Pocoví-Juan, 1994; Casas-Sainz and Gil-Imaz, 1998; Mata et al., 2001) as assessed from the

70 presence and relationships between pre-, syn-, and post-cleavage metamorphic minerals. The thermal

71 metamorphic peak has been dated at 99.5 ± 2.2 M.a. by Ar-Ar isotope analyses in authigenic phengite

72 (Golberg et al., 1988). However, cleavage in the Basque-Cantabrian basin seems to ~~be associated with~~

73 ~~Cenozoic inversion~~ (Álvaro, 1976; Cámara, 1977; Gómez et al. 2002); for example, Oliva-Urcía et al.

74 (2013) reported a vertical cleavage in this area related to buttressing processes against an extensional

75 fault, during the Cenozoic inversion, although in this case deformation was attributed to this stage

76 based only upon geometrical criteria. A similar origin was proposed for cleavage appearing in the

77 Galve basin (central Iberian range, NE Spain), also related to buttressing against steeply-dipping

78 normal faults (Liesa et al., 2004). ~~Finaly,~~ other examples of cleavage-related folds were reported in the

79 western Iberian range (Gutiérrez-Elorza and Pedraza-Gilsanz, 1974; Gual-Pérez et al., 2012; García-

80 Lasanta et al., 2015) where they appear to be related to Cenozoic basin inversion.

81   Controversy about timing of cleavage formation in relation to other structures is a long-term

82 issue in the geological literature about the Central High Atlas (CHA; NW Morocco), which constitutes

83 the target of this work. A sinistral transpression phase during Late Jurassic times, coeval with intrusion

84 of magmatic bodies and an associated hydrothermal metamorphic event, has been invoked to explain

85 anomalous thermal gradients favoring cleavage development (Laville and Piqué, 1992; Laville et al.,

86 1994). Strong uplift of the Mesozoic basin associated with Jurassic compression proposed by these

87 authors was contradicted by Charrière et al. (2009), ~~dating~~ as Paleocene the supposed Callovian-Lower

88 Cretaceous sediments that lie uncomformably on the igneous intrusions and host rocks. ~~Furthermore,~~

89 Barbero et al. (2007) by means of fission tracks indicated that the main uplift of these igneous rocks

90 occurred during Cenozoic times. However, although these ~~arguments~~ are in support of the absence of

91 total basin inversion during Mesozoic times, cleavage-related folding could have been generated during

92   the Mesozoic, as it occurs in the Cameros basin, without an important uplift of the basin.

93   In this paper we propose a methodological approach using paleomagnetism and the analysis of

94   remagnetization directions to the relative dating of folds and cleavage and, consequently,

95   compressional phases occurring during the evolution of inverted extensional basins. A pervasive

96   widespread remagnetization, dated around 100 M.a., has been observed in the CHA (Torres-López et

97   al., 2014; Moussaid et al., 2015). From the application of the above-mentioned method to this

98   remagnetization, we demonstrate that cleavage in the CHA was generated during the Cenozoic

99   compression, after the remagnetization stage, although some Mesozoic compressional folds formed in

100   the area before remagnetization times. Moreover, since remagnetizations are common in intraplate

101   extensional basins where a minimum thickness of sediments was accumulated (e.g. Villalaín et al.,

102   2003, Moreau et al., 2005; Elmore et al., 2012; Van der Voo and Torsvik, 2012; Torres-López et al.,

103   2014 and references therein), it can be used for resolving tectonic and structural problems related to the

104   evolution of sedimentary basins as proposed here.

105

106   **2.   Regional geological background**

107

108   The Atlas system is an intracontinental chain located in the foreland of the southernmost sector

109   of the Mediterranean Alpine System, formed as the result of the inversion of extensional Mesozoic

110   basins during the Cenozoic convergence between African and European plates (Mattauer et al., 1977;

111   Gomez et al., 2000). The Mesozoic sedimentation in the CHA began with Triassic continental clastic

112   sediments and evaporites during the first stage of rifting, which are intercalated by Triassic-Jurassic

113   basalts. During the Early-Middle Jurassic, normal faults were reactivated in a second stage of rifting

114   and more than 5000 m of marine carbonates and fluvial red beds were accumulated (Frizon de Lamotte

115   et al., 2008). During this stage, NE-SW normal faults were generated in addition to ENE-WSW faults

116   related to ~~the~~ NW-SE extension, and an important diapiric activity began, forming salt-walls limiting

117   sub-basins (Saura et al., 2014). During the Late Jurassic-Early Cretaceous, the axial zone of the CHA

118   emerged, and rocks related to the basinal stage younger than the Upper Jurassic are not preserved in

119   this area.

120   The extensional stage ended with an alkaline to transitional magmatic event, characterized by

121   mafic intrusive rocks dated with K-Ar in biotite at 160 ± 3 M.a. to 152 ± 3 M.a. (Hailwood and

122   Mitchell, 1971) and with Ar-Ar in biotite at 151.3 ± 0.5 M.a. to 146 ± 0.5 M.a. (Armando, 1999).

123   The alpine compression imprinted relatively weak deformation in the CHA, with values of

124   shortening ranging between 15% and 24% (Teixell et al., 2003) in a NW-SE direction (without

125   considering internal deformation associated with cleavage). The structure of the CHA is characterized

126   by tight anticlines with steeply-dipping limbs parallel to the ENE-WSW general trend of the chain,

127   cored by Triassic shales and basalts and Jurassic gabbros, which limit wide, gentle synclines. These

128   anticlines were partially developed during the Mesozoic (Torres-López et al., 2016) primarily because

129   of diapiric processes (Bouchouata et al., 1995; Ettaki et al., 2007; Michard et al., 2011; Saura et al.,

130   2014) and also enhanced by Jurassic igneous intrusions (Calvín et al., in review). In the central sector

131   of the CHA, a pervasive foliation appears (Fig. 1) showing varying attitudes along and across the main

132   structural trends (Laville and Piqué, 1992).

133   Torres-López et al., (2014) described the presence in the CHA of an Albian-Cenomanian ($\approx$ 100

134   M.a.) widespread remagnetization affecting the Jurassic carbonate rocks and red beds of the central part

135   of the chain. This event is responsible for the particular magnetic behavior of rocks both in the

136   demagnetization processes and in rock magnetic experiments. Because remagnetization in carbonate

137   rocks can be linked both to burial depth and regional thermal anomalies, it is restricted to the central

138   part of the High Atlas, along the basin depocenter(s) and cannot be recognized in marginal areas

139 (northern and southern margins of the CHA) of the Atlasic basin (Torres-López et al., 2014). Torres-

140 López et al. (2016) used this remagnetization to restore the attitude of the beds at the moment of its

141 acquisition.

142

3. Geometry of cleavage and folding

144

145 The study area covers a large part of the CHA characterized by (i) tabular areas without

146 significant structures and (ii) trains of plurikilometric folds with a constant NE-SW trend (Fig. 2). The

147 central sector of the study area is characterized by folds that can be followed along trend up to 100 km,

148 although most of them show lengths between 20 and 50 km. Many of the anticlines are cut by

149 extensional faults inherited from the rift stage and show large amounts of gabbros in their cores. These

150 faults are linked in many cases to complications of the structure and are the main responsible for the

151 interruptions of fold axes along trend. Cleavage shows an uneven distribution throughout the study area

152 (Laville and Piqué, 1992; Laville et al., 2004), probably conditioned by the sedimentary load, since it is

153 more pervasive approaching the sectors with thicker syn-rift Jurassic series. This area coincides with

154 the Mesozoic basin ~~center,~~ as stated from illite crystallinity studies (Schaer and Persoz, 1976; Schaer,

155 1987). Although having many complications in detail, as will be described below (see also Laville and

156 Piqué, 1992; Schaer, 1987), cleavage shows in general steep dips and runs parallel to the structures.

157 The study area can be divided into two structural domains: a central domain (Ikkou-Amouguer sector),

158 where tight anticlines are the dominant structures, and a SW domain (Timarirhine sector), a ~~tabular~~

159 region without significant structures and axial-plane cleavage associated with moderately-dipping beds

160 and doubly-vergent box folds (Figs. 3 and 4).

161

162 The present-day geometry of the Timarirhine sector is characterized by a tabular, subhorizontal

163   ~~disposition~~ interrupted by (i) large-scale folds with gentle limb dips, showing amplitudes of hundreds

164   of meters and wavelengths of ~~a~~ few kilometers (e.g. Timarirhine anticline) and (ii) deca- to hectometric

165   structures, mainly folds and thrusts. ~~These~~ include doubly-vergent box anticlines having angular hinges

166   (Fig. 3a) and limbs dipping about 50º. Amplitude of these anticlines rarely exceeds 100 m. Some

167   thrusts appear in the area, either in relation with the cores of the folds or involving individual beds or

168   groups of beds with subhorizontal attitude (Fig. 3b), favored by the existence of many incompetent

169   levels within the Jurassic series. A pervasive cleavage can be recognized in soft and hard lithologies,

170   showing pressure-solution features in calcareous rocks (Fig. 4a, b and Fig. 5) whereas slaty cleavage

171   dominates in marls and shales (Fig. 4c, d). Cleavage shows in general steep dips, and high or low

172   angles to bedding, depending on the dip of beds (Fig. 5). Cleavage refraction is common at the

173   transition between marly and calcareous units (Fig. 4e). Folds do not show a dominant vergence,

174   although a prevalent southward dip of cleavage can be interpreted from the complete dataset (Fig. 6).

175   The Tissila-Amouguer sector is characterized by tight, kilometer-scale anticlines (Fig. 3c)

176   separated by wider synclines (Fig. 3d), sometimes with angular hinges (Fig. 3e), in whose cores Middle

177   Jurassic red beds crop out. Although fold trend ~~orientation~~ is relatively constant, numerous changes of

178   strike of beds, linked to re-activation of extensional normal faults, periclines and relays between fold

179   axes can be observed in the geological map (Fig. 2). Some of these changes, especially those regarding

180   E-W striking beds have been classically attributed to interference between NE-SW and E-W folding

181   stages (De Sitter, 1976). In some of the synclines, a kink-fold geometry, with straight limbs having

182   homogenous dips, and angular hinges, can be observed (Fig. 3e). Rounded hinges are more common

183   near the periclinal termination of folds. In general, a combination of both kink and flexural geometries

184   can be inferred from fold reconstruction. Cleavage appears discontinuously, more pervasive when

185   approaching the core of anticlines and seldom in the Bathonian-Callovian red beds cropping out at the

186   cores of the synclines. The Ikkou syncline is a remarkable exception to this rule, since pervasive

subvertical cleavage (Fig. 4c) can be observed along the red beds at its core (mainly in its Southern limb). Cleavage and bedding show in general similar strikes, almost parallel when dips of beds are steeper than 60º, and can also strike perpendicular to each other in some particular places near the fold periclines (Fig. 6).

Bedding-cleavage relationships indicate both layer-parallel shortening (cleavage perpendicular to bedding in shallow-dipping layers) and flattening combined with flexural-flow processes (cleavage defining reverse fans at the limbs of folds, independently of refraction geometries) as the main mechanisms of cleavage formation (Fig. 4). Their relative contribution depends on the mechanical stratigraphy and the dip of the sedimentary sequence. Cleavage associated with flexural-flow is dominant at fold limbs and thick, incompetent beds, delineating the axial planes of folds at the acute bisector between cleavage attitude at both limbs. Vertical cleavage appears in sub-horizontal beds as result of layer-parallel shortening. Hectometer-scale, secondary anticlines located at the limbs of the main folds allowed us to determine genetic relationships between cleavage and folding more accurately than when dealing with kilometer-scale folds. Locally, and especially in thick shaly units, cleavage can be affected by kink-bands generally indicating late, normal shear movements.

Because of their especial relevance in relation to remagnetization, we have focused in the study of cleavage origin in limestones occurring along the sedimentary sequence. Cleavage geometry in thin-sections in limestones shows a pressure-solution behavior (Fig. 5), with different degrees of development from short, discontinuous planes characterized by the accumulation of iron oxides in rocks without evidences of macroscopic cleavage at the outcrop scale (Fig. 5a, b and c) to an almost continuous cleavage and extremely thin microlithons (Fig. 5d, e and f). Some samples show an "en echelon" disposition of the cleavage planes (Fig. 5b, d) indicating simple-shear processes related to flexural-flow. It is remarkable the absence of phyllosilicates related with the cleavage, being carbonates, quartz, iron oxides, iron sulphides and organic matter the only components of the

211 limestones. Pyrites are not related to cleavage and probably they were formed during the early

212 diagenetic stages.

213

214 **4. Methodology of paleomagnetic analysis**

215

216 4.1. Sampling and paleomagnetic measurements

217

218   Forty-three new sites were sampled (Fig. 2 and supplementary data; 44 sites in Jurassic

219 carbonate rocks, namely marls and limestones, and two in red beds), taking at least eight cores per site

220 with a gasoline-powered machine. In addition to the paleomagnetic sites, bedding and cleavage were

221 also measured in 26 additional structural sites. Paleomagnetic analyses were conducted on 360 samples

222 using a 2G cryogenic magnetometer at the Paleomagnetic Laboratory of the University of Burgos

223 (Spain), which integrates Alternating Field (AF) coils. Stepwise thermal (Th) demagnetization was

224 conducted with a TD48-DC thermal demagnetizer. 6 to 16 steps were taken from room temperature up

225 to 450-500 ºC for limestones and to 670 ºC in red beds.

226   Paleomagnetic directional components were calculated by principal component analysis

227 (orientation and maximum angular deviation error –MAD- of the component; Kirschvink, 1980) on

228 orthogonal demagnetization diagrams using Remasoft software (Chadima and Hroda, 2006). Then, the

229 mean site directions and related statistical parameters were calculated (Fisher, 1953).

230

231 4.2. Small Circle Intersection (SCI) method and bedding restoration

232

233   According to Torres-Lopez et al. (2014) and Moussaid et al. (2015), carbonate rocks and red

234 beds from the CHA carry a synfolding remagnetization dated around 100 M.a.. Since the

235   remagnetization was acquired at the same moment (at geological scale) in all sites, it is possible to

236   calculate a local paleomagnetic direction for the study area using the SCI method, which is the

237   expected direction for that time (Shipunov, 1997; Henry et al., 2004; Waldhör and Appel, 2006).

238   Once the expected direction is obtained, and assuming the absence of complex rotations (e.g.

239   vertical axis rotation or two different axes of horizontal rotation, among others) after the acquisition of

240   the remagnetization, it is possible to restore the attitude of beds at the moment of the remagnetization

241   event, following the methodology explained in Villalaín et al. (2015). The optimal paleomagnetic

242   direction for each site is calculated considering the paleomagnetic direction that best approaches the

243   reference, and is assumed to be located within a small circle that links the paleomagnetic directions in

244   GEO and TILT coordinates (whose axis is the strike of bedding). Subsequently, the angle between the

245   *in situ* and the optimal paleomagnetic directions (along the small circle) can be calculated. Applying the

246   same rotation to beds, we obtain their paleodip at the moment of remagnetization (Villalaín et al., 2003;

247   Soto et al, 2008; Torres-López et al., 2016).

248   Therefore, it is possible to analyze the relationship between bedding and cleavage *in situ* and

249   after restoration at 100 M.a.. The comparison between them, together with the geometrical

250   relationships between cleavage and folds can be used to determine whether the cleavage predates or

251   postdates the remagnetization, and, therefore, whether it is related or not to pre-Cenozoic folding in the

252   CHA, the target of this work.

253   With this purpose, two detailed cross-sections were made along two key profiles (Fig 2) both

254   before and after the restoration at 100 M.a.. Furthermore, isolated keys outcrops with pre and post-

255   remagnetization folds were analyzed.

256

257   **5. Paleomagnetic directions**

258

259   Standard paleomagnetic analysis allowed us to calculate in each site statistically well-defined

260   paleomagnetic directions with systematic normal polarity (Table 1) and typical unblocking

261   temperatures between 300 ºC to 450 ºC in carbonates and 400/500 ºC to 600/660 ºC in red beds, after

262   removal of viscous overprint and thermal alteration (Fig. 7). Both in limestones and in red beds, most

263   samples show intensities of natural remanent magnetization (NRM) around 1-10 x 10^{-3} A/m and the

264   characteristic remanence (ChRM) represents about 30-50 % of the total NRM. In most of the

265   limestones the ChRM goes to the origin. However, in red beds the ChRM does not pass through the

266   origin, but it is not possible to isolate the high-temperature component because spurious components

267   induced during heating mask the highest temperature components. Detailed magnetic properties of

268   these rocks can be found in Torres-López et al. (2014) and Moussaid et al. (2015).

269   Applying the Small Circle Intersection (SCI) method (Waldhör and Appel, 2006) to a total of 65

270   paleomagnetic site mean directions (44 paleomagnetic directions from this work, 9 from Torres-Lopez

271   et al., 2014, and 12 from Calvín et al., in prep., Table 1) the direction of the remagnetization was

272   calculated obtaining a value of D= 330.6º / I= 36.1º. This direction is coincident with that obtained in

273   two sites having horizontal bedding and also agrees with the 100 M.a. expected direction determined

274   from the Global Apparent Polar Wander Path (GAPWP) in NW Africa coordinates (Fig. 8, Torsvik et

275   al., 2012). The good clustering of the best fit direction (BFD) for most sites (Fig. 8c) indicates the

276   absence of complex rotations that could preclude the application of this method. However, some sites

277   show angles between the BFD and the expected direction larger than 10º (Table 1), mainly sites of the

278   Outerbat-Amouguer sector. These sites should be analyzed carefully.

279

280   **6. Restoration of the structure at 100 M.a. and relation with cleavage**

281

282   Two detailed cross-sections were restored using paleomagnetic data (Table 1) to their 100 M.a.

283   geometry (Fig. 9). Both cross-sections, having a length of 5 and 15 km respectively, have been drawn

284   considering foliation and its geometrical relationships with bedding in two representative areas of the

285   studied structures: the tabular geometry of the Timarirhine sector, showing folds with kink geometry

286   and the Ikkou syncline, in whose core the Middle Jurassic red beds crop out. Furthermore, a detailed

287   map of the Outerbat sector, where 3D geometrical relationships between bedding and cleavage are

288   spectacularly depicted, were also analyzed.

289

290   The cross-section in the Timarirhine sector (Fig. 9a) shows a flat geometry with a South-

291   dipping envelope and box-fold anticlines. Cleavage shows both northwards and southwards dips and

292   appears both in the flat areas and at the limbs of the anticlines. Cleavage is particularly pervasive at

293   both walls of high-angle reverse faults located at the middle of the cross-section. The 100 M.a.

294   geometry (Fig. 9a) obtained from the restoration of paleomagnetic vectors shows incipiently developed

295   folds with the same disposition as the current folds but with shallower dips at their limbs. The overall

296   southwards tilting of the northern part of the section ~~was horizontal at this time~~. Interestingly,

297   deformation associated with the reverse fault is absent in the palinspastic section (Figs 9a and 10a). If

298   cleavage is restored according to its present-day angular relationship with bedding, no changes occur in

299   sub-horizontal beds, but changes are significant at the limbs of folds (sites AG01, SK06 and SK05),

300   where cleavage becomes strongly oblique to their axial planes, acquiring inconsistent orientations, in

301   the restored cross-section. Differences between cleavage attitude between sites SK08 and SK09 in the

302   restored cross-section are also remarkable (Figs. 9a, 10a). This, in addition to the presence of post-

303   remagnetization folds (Fig. 10a, b) in the sector (see location in Fig. 2) showing axial plane cleavage,

304   agrees with a post-remagnetization development of the foliation.

305

306   The Tissila cross-section (Fig. 9b) depicts a wide syncline (Ikkou syncline) with a thick series

307   of Lower-Middle Jurassic in its core, limited to the north by an inverted normal fault associated with

308   diapiric activity during the extensional stage, and to the south by the asymmetric Tissila anticline (see

309   also López-Torres et al., 2016). The Ikkou syncline could be related with a buttressing process because

310   of the difficulty to fold a thick sedimentary series and the steep dips of faults at basin borders. Fault

311   inversion of the northern basin margin was also precluded by the steep dip of the normal fault at this

312   margin, and the fault would act as a buttress. Across the syncline a sub-vertical cleavage (more

313   developed in its S limb) with constant dip appears, independently of the dip of beds and slightly

314   oblique to the average axial plane of the fold. After restoration of bedding and cleavage (following the

315   same criteria applied in the Agoudal cross-section) at 100 M.a., hinge migration from South to North

316   between the Cretaceous and the Cenozoic can be inferred and cleavage shows a steep dip towards the

317   North, but more parallel to bedding. Moreover, cleavage developed around the Tissila anticline is

318   consistent with an attitude of axial-plane cleavage for the fold in its present-day stage, rather than with

319   bed attitude at 100 M.a.

320

321   The Outerbat sector (Fig. 11) is particularly interesting because bedding/cleavage relationships

322   can be analyzed in plan-view within a relatively small area. The structural map of this area shows the

323   changing attitude of cleavage and bedding, with cross-cutting relationships at the limbs of the NE-SW

324   trending fold consistent with the axial plane but cutting perpendicular to beds at the hinge zone where

325   beds have a NW-SE strike. However, there are also dykes of Late Jurassic-Early Cretaceous age

326   (Hailwood and Mitchell, 1971) cutting across the structure and they are not folded with the beds (Fig.

327   11) indicating that the fold predates the emplacement of the dykes. As it occurs with the geometries

328   depicted in cross-sections, the 100 M.a. geometry is at an intermediate point between horizontal beds

329   and completely developed folds, thus indicating that folds were partially formed before the

330   remagnetization stage, and that its present-day geometry completely developed after flattening and

331 axial-plane cleavage formation, as suggested by the changes in orientation of cleavage planes that

332 underwent subsequent folding in some parts of the structure.

333   Furthermore, additional information is given by a fold of the westernmost sector. Most of the

334 deformation of this fold predates the acquisition of the remagnetization (Fig. 10c) but the cleavage was

335 again developed after the main folding according to bedding-cleavage relationship.

336

337 **7. Discussion**

338

339 7.1. Remagnetization-cleavage chronological relationship

340

341   Results indicate that the restitution of the geometry at the moment of the remagnetization is a

342 useful tool to relatively date tectonic processes in the absence of other markers. The use of this

343 methodology in this work clearly indicates that the development of the cleavage is related with folding

344 and it post-dates the remagnetization, solving the old discussion regarding the age of this cleavage

345 (with the proposed hypothesis of Upper Jurassic or Cenozoic cleavage). However, since cleavage and

346 chemical remagnetizations can triggered for common external processes (as a regional temperature

347 increase) or the cleavage development can generate regional remagnetization events itself, further

348 discussion about cleavage-remagnetization relationship is necessary.

349

350   Both organic matter maturation (Brothers et al., 1996) and smectite-illite transformations (Katz

351 et al., 2000) can generate authigenic magnetite with minimum formation temperatures around 90ºC,

352 similar in both processes (Pevear, 1999). Orogenic fluids can be the responsible for the formation of

353 new magnetite grains (Elmore et al., 2012). On the other hand, Oliva-Urcia et al. (2008) propose a

354 mechanism of remagnetization as result of mechanical reorientation of the magnetic grains during

cleavage development. Izquierdo-Llavall et al. (2013) found links between reflectance of the vitrinite, illite cristallinity and cleavage, all of them in relation with the critical temperature of 140 ºC for cleavage development in the Pyrenees fold-and-thrust belt. In this way, and taking into account that remagnetization in the High Atlas is syn-folding, we could be led to interpret remagnetization and the cleavage development as co-genetic in the frame of a main tectonic phase. However, the particularly fortunate conditions of the High Atlas provide two arguments that allow us to discard the link between these two events. On one side, the remagnetization is recognized more widely than the cleavage both in its areal extent as in its representation along the sedimentary series, what indicates that the remagnetization is less restrictive in regard to p-T and deformation conditions (supposing that they were genetically related). On the other side, the chronological relationship between remagnetization and cleavage, when they can be clearly obtained from the bedding/cleavage geometrical relationships, systematically show that cleavage postdates the remagnetization. If they were contemporaneous, we should see that cleavage both pre and postdates the remagnetization, or else that the remagnetization always postdates cleavage as it occurs in the Cameros basin (Villalaín et al., 2003; García-Lasanta et al., in prep.) (since the remagnetization will be less restrictive and therefore the acquisition should to finish after cleavage development). Hence, the remagnetization can be clearly bracketed in Cretaceous times, whereas cleavage development happened in the Cenozoic, related with folding during the main inversion of the CHA. Therefore, we can conclude that remagnetization and cleavage are two clearly different, unrelated processes, separated in time.

Another important question regarding this issue is the absence of phyllosilicates in some of the cleaved limestones which are remagnetized. This point seems to indicate there is no relation between remagnetization and illitization processes, being more important the presence of organic matter and iron oxides (pyrite) in the process of the remagnetization. This also explains the absence of a remagnetization related with the cleavage development since the latter is a pressure-solution cleavage

379   without important recrystallization processes involved.

380

381   7.2. Interpretation of paleomagnetic data after development of cleavage folds

382

383   Another question arising in paleomagnetic analysis in regions undergoing deformation and

384   cleavage development is the possible deformation of paleomagnetic vectors (Kingfield et al., 1983;

385   Cogné and Perroud, 1985; Hirt et al., 1986; Borradaile, 1997; Oliva-Urcía et al., 2009). In the CHA,

386   cleavage post-dates remagnetization and therefore a caveat about possible deformation of the magnetic

387   remanence can be considered. This possible deformation of the paleomagnetic vector depends of

388   different factors: (i) the intensity of the deformation of the rock, (ii) the angle between the flattening

389   direction and the paleomagnetic vectors (according to geometric relationship proposed by Ramsay and

390   Huber (1987) the deformation of remanence would be lower than the confidence angle, becoming

391   bigger for intermediate angles) and (iii) the morphology of the ferromagnetic minerals which carried

392   the magnetization (SD magnetite in this case), being anisotropic grains more likely to be rotated than

393   isomorphic grains.

394   In spite of the angle between flattening direction (according to cleavage geometry) is different

395   in different places (Fig. 9) and the variability of samples (regarding the degree of deformation), from

396   the studied samples there does not exist difference regarding paleomagnetic direction in cleaved or

397   non-cleaved rocks. One possibility is that ferromagnetic minerals within microlithons in pressure-

398   solution or slaty cleavage have not been involved in deformation. Other possibility is that the magnetic

399   grains are close to the multiaxial morphology. For the last, a more detailed study analyzing the

400   ferromagnetic fabric and the morphology of the magnetite grains in the sense of Jackson and Swanson-

401   Hysell (2012) could shed light in the future in this subject. However a magnetic behavior of the grains

402   as uniaxial no guarantee a uniaxial (anisotropic) behavior in a mechanic point of view since small

403 shape anisotropy (c/a axis relationship around 1.1) of the SD magnetite grains gives to the grains an

404 uniaxial magnetic behavior (Winklhofer et al., 1997).

405

406 **6. Conclusions**

407

408   Remagnetization in the ~~study area~~ shows systematically normal polarity, it has been dated as in

409 previous studies as Albian-Cenomanian (100 M.a.) and it shows a syn-folding ~~behavior~~.

410   The presence of remagnetizations in intraplate basins can allow restoring ~~the geometry of them~~

411 at the moment of the acquisition of the remagnetization; this methodology can help to resolve some

412 geological process. In this work some key cross-sections ~~of~~ the Central High Atlas are compared in the

413 present-day and the restored (at 100 Ma.) geometry in order ~~of~~ relatively ~~dating~~ the tectonic cleavage

414 (pre- or post-remagnetization) present in the area.

415   Cleavage-bedding geometrical relationships at present and at the 100 M.a. restored cross-

416 sections show that the development of cleavage clearly postdates the remagnetization acquisition.

417 Besides, geometrical relationships indicate that folding and cleavage development are genetically

418 related and there are not evidences of late folding of the cleavage. These facts support the absence of a

419 general cleavage development in the CHA before the Albian-Cenomanian ~~and it is~~ associated with the

420 Cenozoic basin inversion and folding. Local cleavage associated with Late Jurassic intrusions and

421 contact metamorphism (Schaer and Persoz, 1976; Laville and Piqué, 1992; Laville et al., 1994) is

422 restricted to the surroundings of the igneous bodies.

423 - Structural analyses of folds and cleavage have allowed observing different cleavage development

424   mechanism: The Timarirhine sector is a tabular area without extensional faults, and sub-horizontal

425   disposition only interrupted by box-folds (Fig. 11). Here, axial-plane cleavage can be interpreted as

426   generated both by flattening associated with flexural-flow mechanisms and layer-parallel

427   shortening. In this case, the geometrical relationships along the Timarirhine cross-section (and

428   folds close to it) clearly indicate a post-remagnetization development of cleavage, related to the

429   Cenozoic inversion of the CHA.

430   -   A completely different scenario is the central part of the studied area, where inherited extensional

431   faults control the subsequent compressional structure. Cleavage is sub-vertical and cleavage

432   trajectories trend parallel to faults (as in Tissila and Outerbat sector), indicative of buttressing

433   processes probably during the Cenozoic inversion, although this tentative chronology is not

434   conclusive.

435   It is noteworthy the presence of evidences of proto-box folds in the Timarirhine area and small

436   folds in the westernmost sector developed before the acquisition of the remagnetization. These

437   structures cannot be related to diapiric or extensional processes in the sense of Saura et al. (2014) or to

438   gabbroic intrusion (Calvín et al., in review) as the ones characterized by Torres-López et al. (2016).

439   Some of ~~which~~ can also be observed in the cross-sections (Figs. 9b and 12) associated with basement

440   normal faults. Precisely, the absence of deformations linked to halokinetic or igneous processes in the

441   studied area can be the key that allows us to observe shallow pre-remagnetization dips, and this

442   particular geometry can help to understand the whole evolution of the CHA. Theoretical, these

443   structures could be related to transpressional processes according to Laville and Piqué (1992).

444   However, these results have to be taken carefully because the shallow dip of beds at the flanks of the

445   structures is close to the uncertainties of the restoration method.

446   Finally, the paleo-geometrical reconstruction developed from restoration of a syn-tectonic

447   remagnetization has been demonstrated as a powerful methodology to analyze cleavage and folding

448   history.

449

450

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648

649 **Figure captions**

650

651 Fig. 1. Schematic map showing the western Tethys domain and the Mesozoic intracratonic basins in

652 which remagnetizations have been observed: Basque-Cantabrian basin (Soto et al., 2008),

653 Cameros (Villalaín et al., 2003), Aragonese Branch (Juárez et al., 1998), Maestrazgo (Moreau et

654 al., 1992), Lusitanian basin (Galdeano et al., 1989), Middle Atlas (Calvín et al., in review),

655 Central High Atlas (Torres-López et al., 2014; Moussaid et al., 2015).

656

657 Fig. 2. Geologic map of the study area showing the paleomagnetic sites used in this work (see also

658 supplementary data).

659

660 Fig. 3. Photographs showing representative structures in the study area (see text for explanation).

661

662 Fig. 4. Photographs showing the geometry of cleavage at the outcrop scale and its relationship with

663 bedding (see text for details).

664

665 Fig. 5. Thin-sections photographs showing the morphology of cleavage at the microscale. Solid (black

666 or white) line shows the general attitude of the cleavage and dashed line corresponds with the

667   bedding. Arrows are in relation with the text explanations

668

669   Fig. 6. Lower hemisphere, equal-area stereoplots showing structural data. a) Poles from bedding and

670   paleo-bedding (black circles and red diamonds, respectively) and cylindrical best fit for each data-

671   set (cylindrical best fit for paleo-bedding was calculated only with the 24 data whose paleo-dip

672   was at least the 70% of the total dip). b) poles of foliation and mean foliation plane (solid plane),

673   mean vector (and associated α 95) and cylindrical best fit. Note that cylindrical best fit are similar

674   between both bedding datasets but not for foliation.

675

676   Fig. 7. Othogonal plot of NRM thermal demagnetization of representative samples in geographic

677   coordinates of a) red beds and b) limestones. Solid black symbols are projected onto the

678   horizontal plane (N towards the left and W towards the down) and open symbols onto the vertical

679   E-W plane). Purple dashed line show the remagnetization component. Normalized NRM intensity

680   is shown.

681

682   Fig. 8. Equal-area projection (lower hemisphere) of paleomagnetic directions (with α 95) in a) GEO

683   and b) TILT coordinates (before and after bedding correction respectively). c) contours of equal

684   value of the parameter A/N (Waldhör and Appel, 2006) calculated for these data (Table 1). d)

685   Optimal paleomagnetic direction and its corresponding small circles.

686

687   Fig. 9. Present-day and restored cross-section of the a) Timarirhine and b) Tissila areas. Arrows indicate

688   the paleomagnetic inclination in each site before and after the correction at the Albian-

689   Cenomanian paleomagnetic direction. See location of the cross-sections in Fig. 2.

690

691   Fig. 10. Key outcrops showing post-remagnetization folds with axial-plane cleavage (a,b) and plane-

692   view sketch of a pre-remagnetization fold and post-folding cleavage (c).
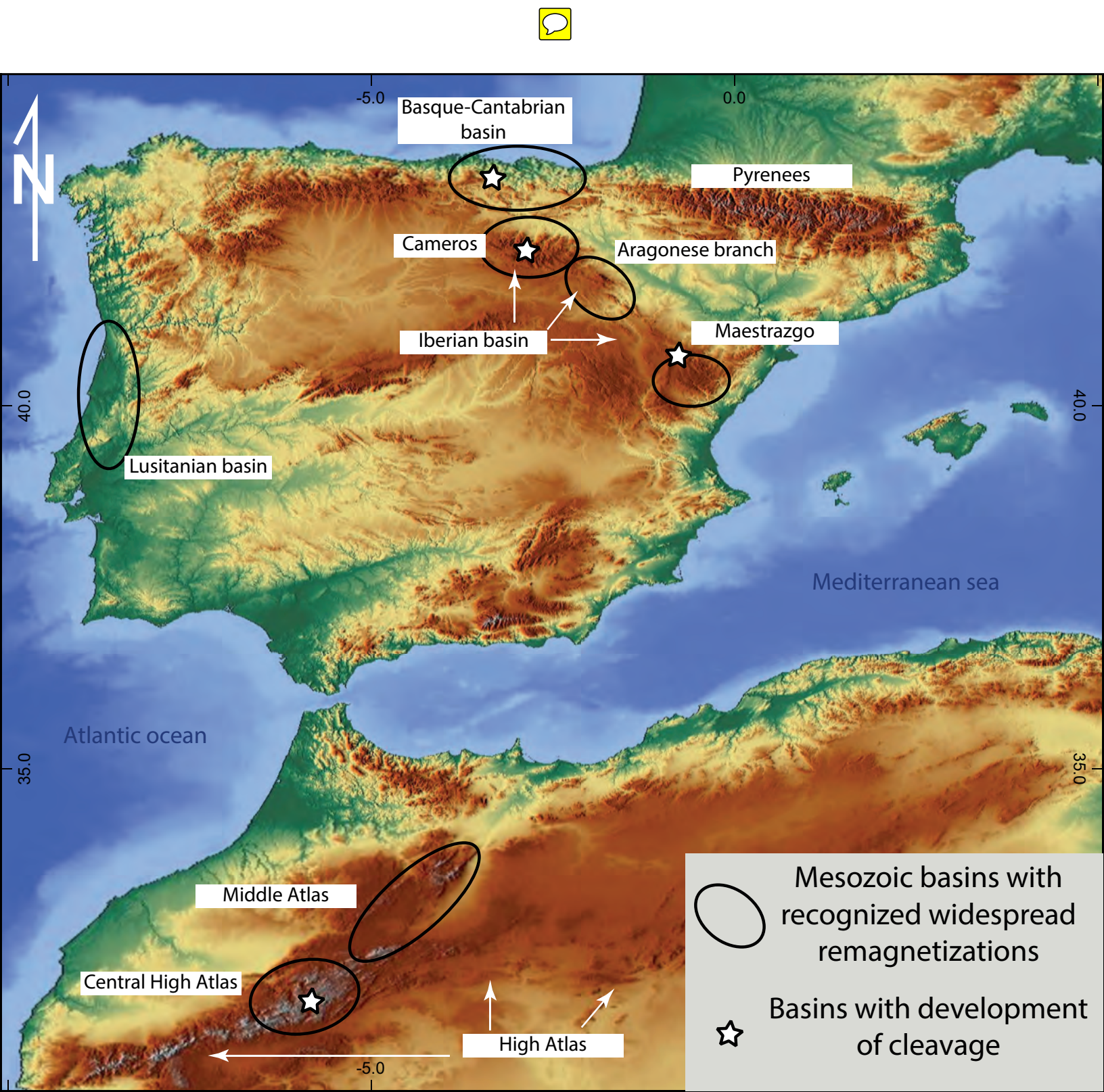
693

694   Fig. 11. Schematic geological map of the Outerbat sector showing relationships between different

695   structures: bedding, cleavage, folds and dikes. a) Present day attitute; note that dikes cut across

696   bedding and that bedding-cleavage relationship vary along the structure. b) Map with paleo-

697   bedding. c) Lower hemisphere, equal-area stereoplots showing structural data (S1: cleavage, So:

698   bedding, paleo-So: paleo-bedding) and cylindrical best fit of each data-set. d) Paleomagnetic

699   direction (Geo, Tilt and BFD) and associated small-circle for each site.

700

701   Fig. 12. General, idealized cross section of the studied area projecting foliation data onto the plane of
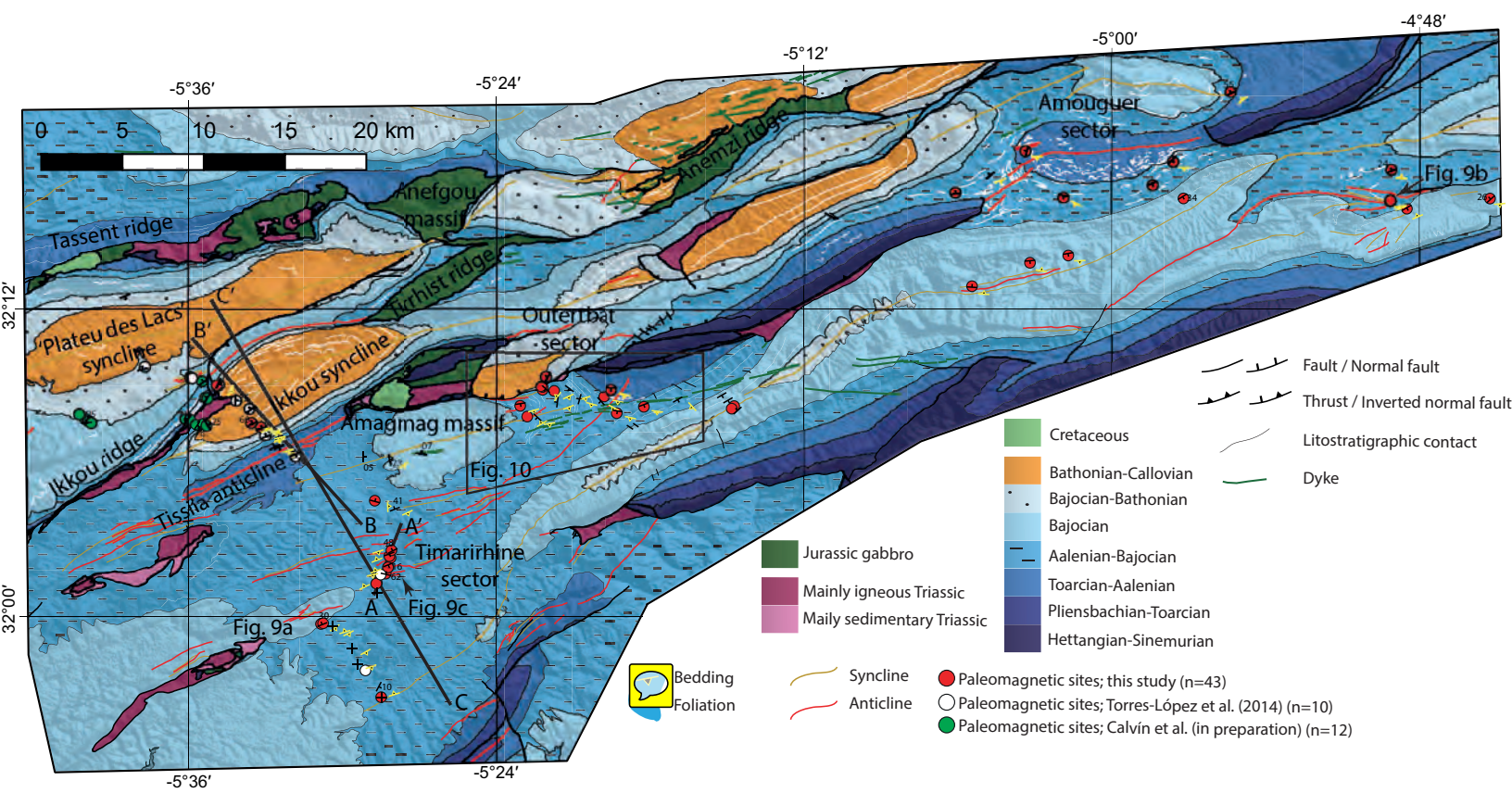
702   the section.

703   **Tables**

704   Table 1. n/N: number of samples used to calculate the paleomagnetic direction / number of measured

705   samples. Lit: sample lithology (Car: carbonate rocks -limestones and marls-, Rb: red beds -

706   sandstones and shales-). α 95 and κ , Fisher statistical parameters (Fisher, 1953). BFD-expec dir

707   angle: angle between the calculated best fit direction in each site and the calculated reference

708   paleomagnetic direction for the area. Ref: literature reference of the data (A, this work; B, Torres-

709   López et al. 2014; C, Calvín et al. (in preparation). For coordinates of each site, see

710   supplementary material.

Figure

Figure

Figure

Figure

Figure

a) AM03-3   500 μm

b) AM03-3   200 μm

c) SK01-6   300 μm

d) SK01   300 μm

e) SK13-11   500 μm

f) SK13-11   700 μm

Figure

a)

b)
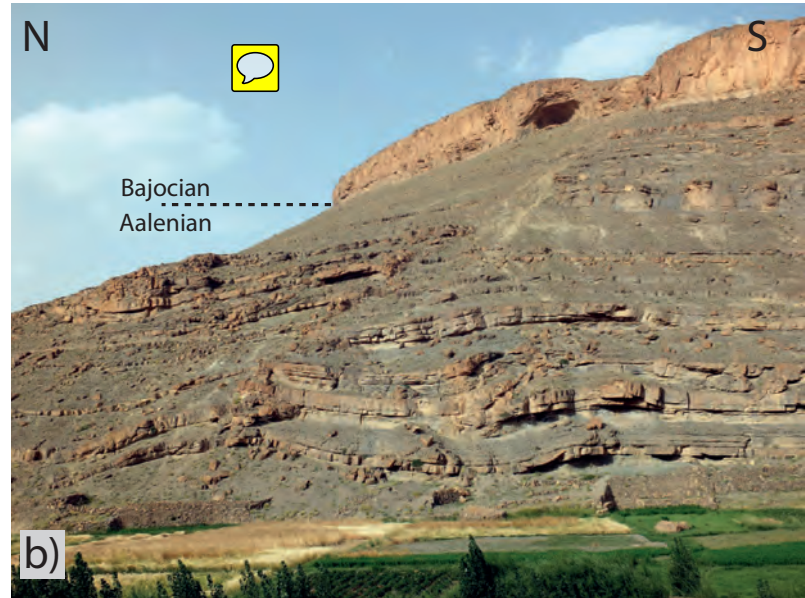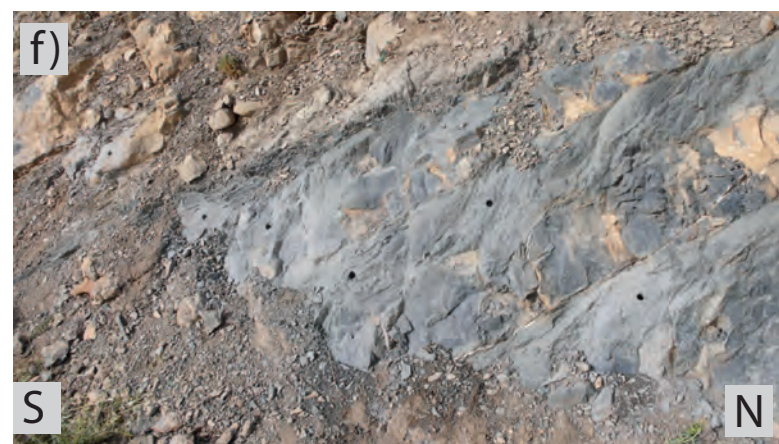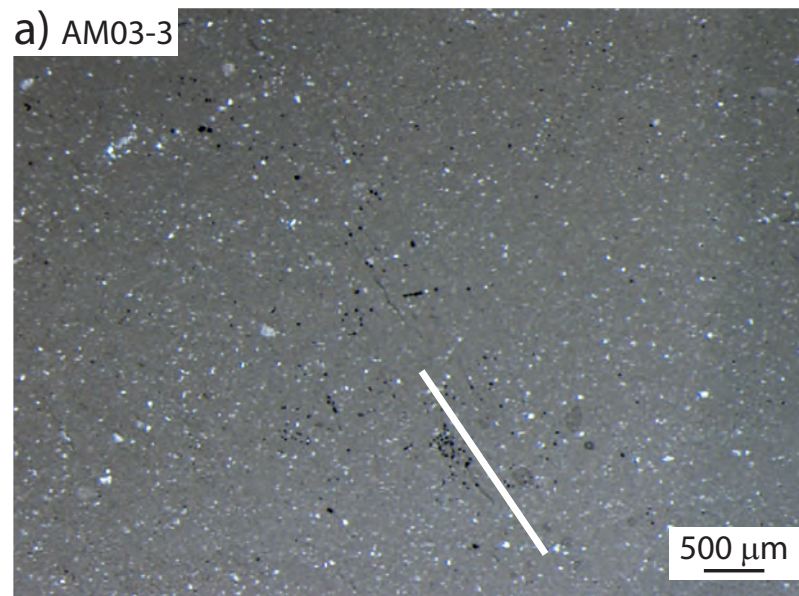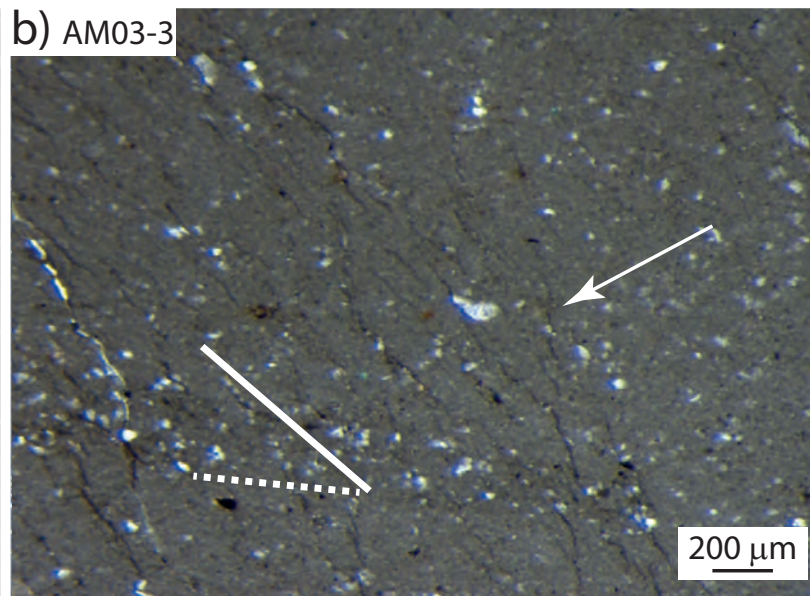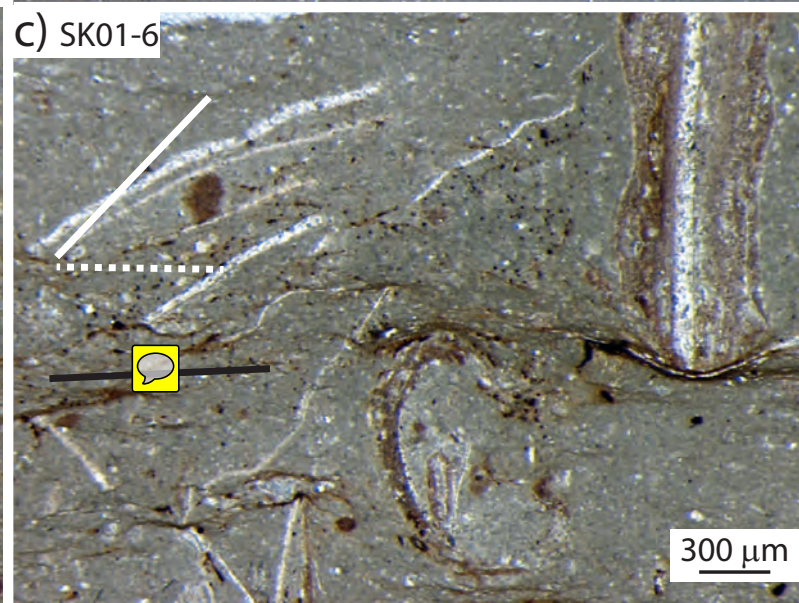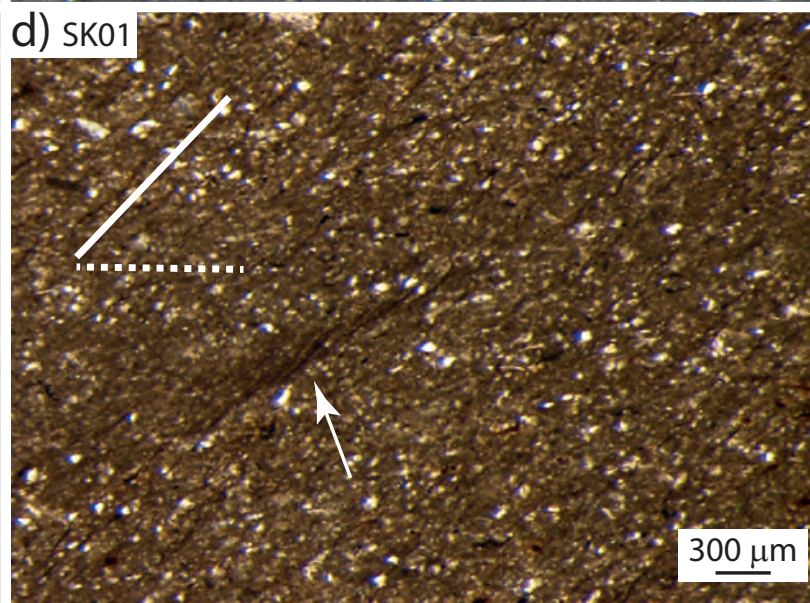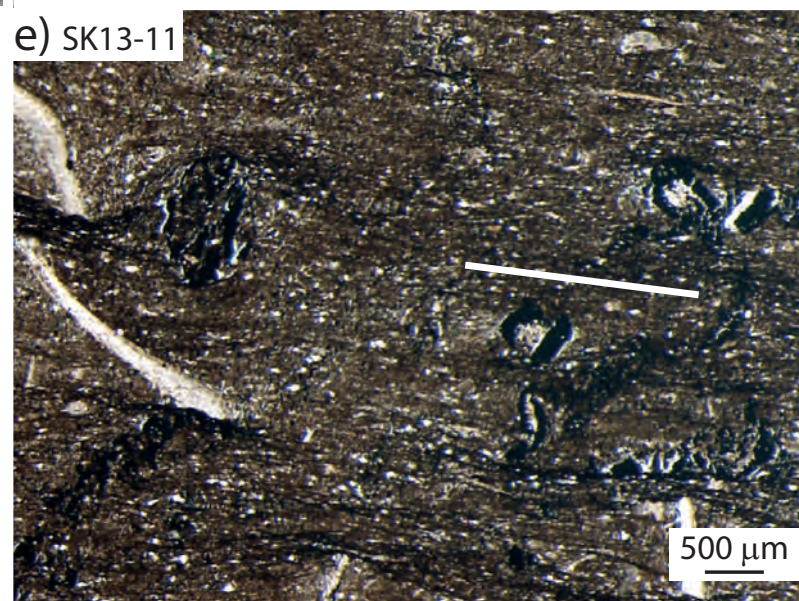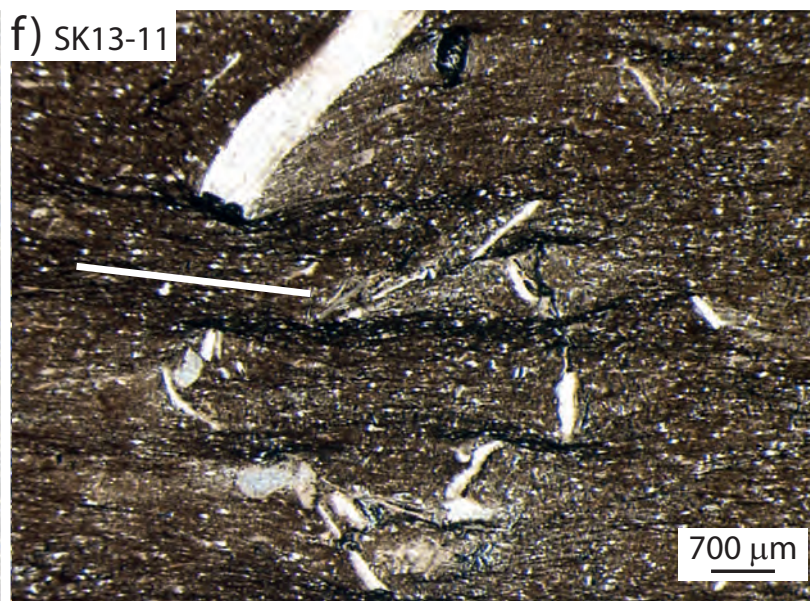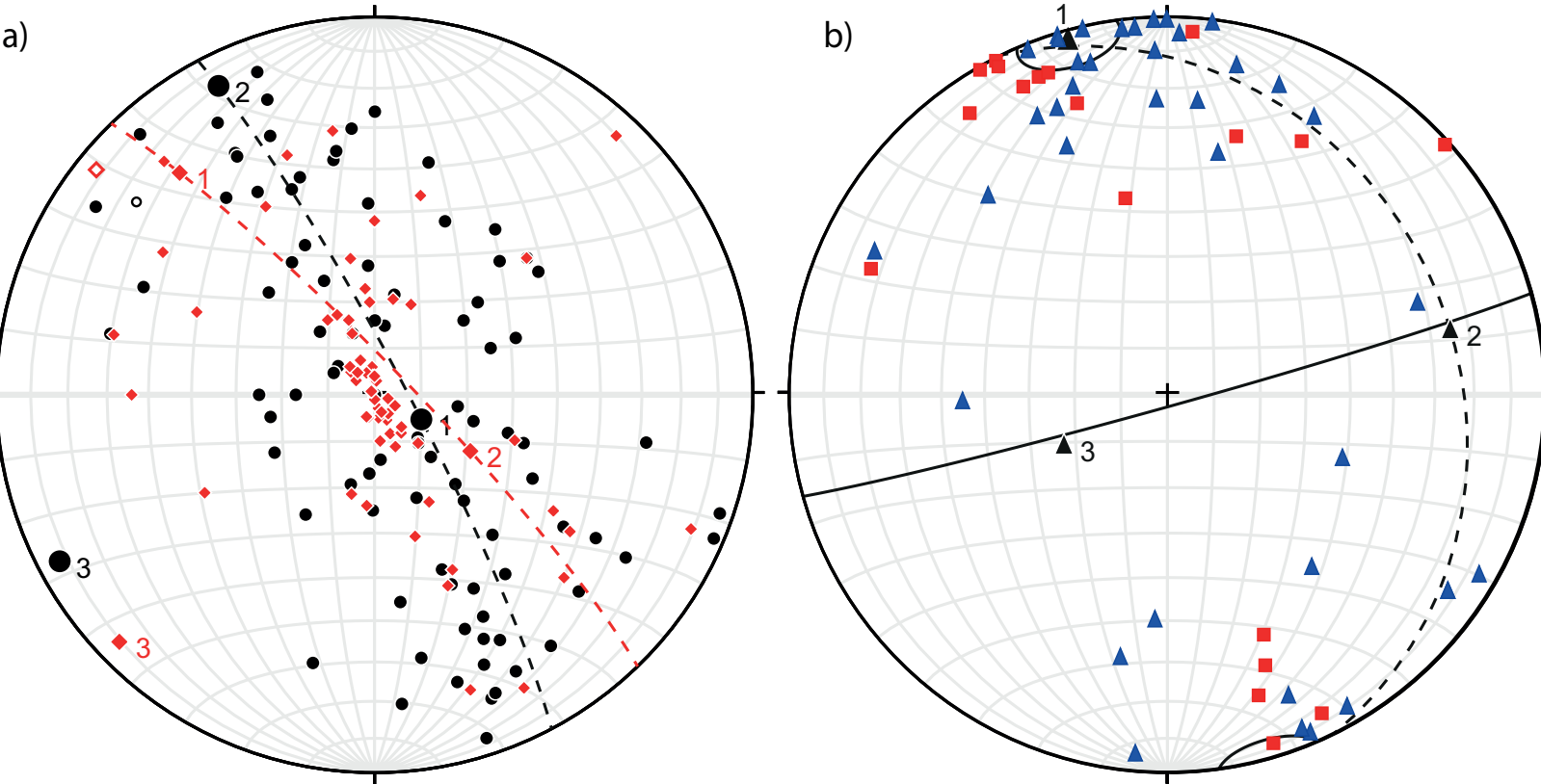
Bedding (black circles, n=95)
Paleo-bedding (red diamonds, n=65)

Cleavage Tissila-Amouguer sector (triangles, n=40)
Cleavage Timarirhine sector (cubes, n=19)

Figure

a) Red bed

GEO

SK02-06A

Unit= 719.e-06 A/m

600ºC

450ºC

● Horizontal
○ Vertical

M/Mmax

1

0.5

Mmax= 4.03e-03 A/m

0   200   400   600ºC

b) Limestone

GEO

SK16-02C

450ºC

275ºC

M/Mmax

1

Mmax= 7.49e-03 A/m

0.5

0   200   400   500ºC

Figure

a) Geo

b) Tilt

c)

50
100
0-5
150

d) Best Fit Direccion (BFD)

A/N

5 9 13 17 21 25 29 33 37 41 45 49 53 57 61 65 69 73
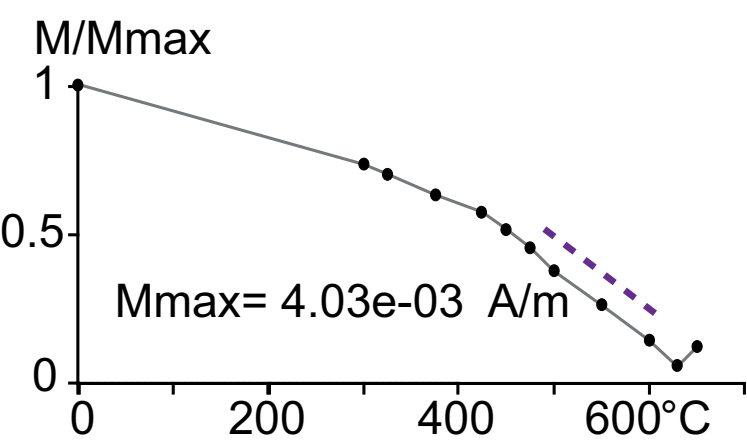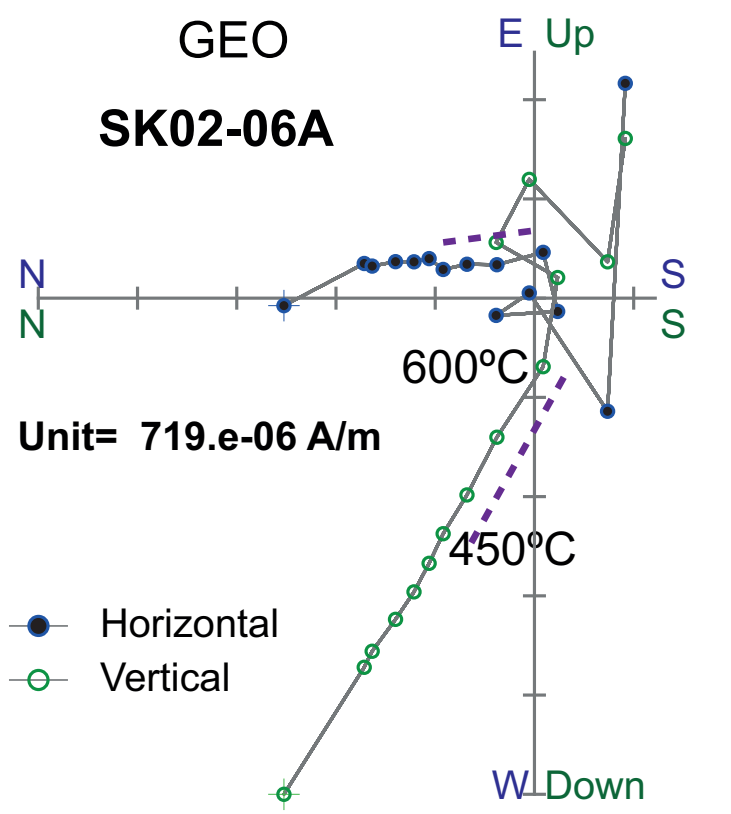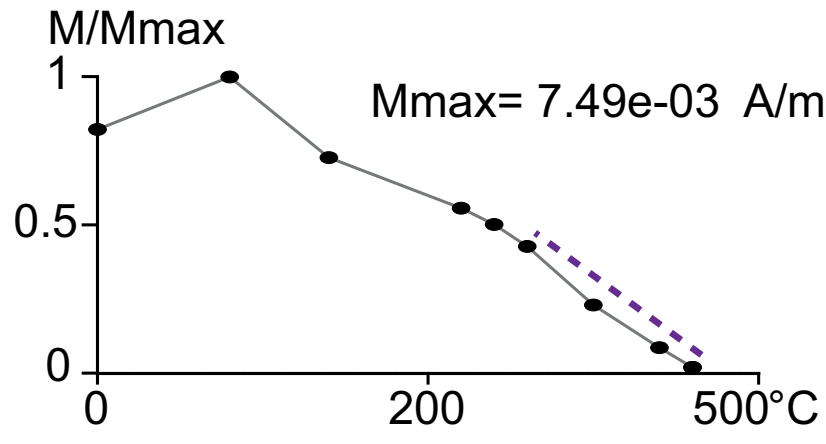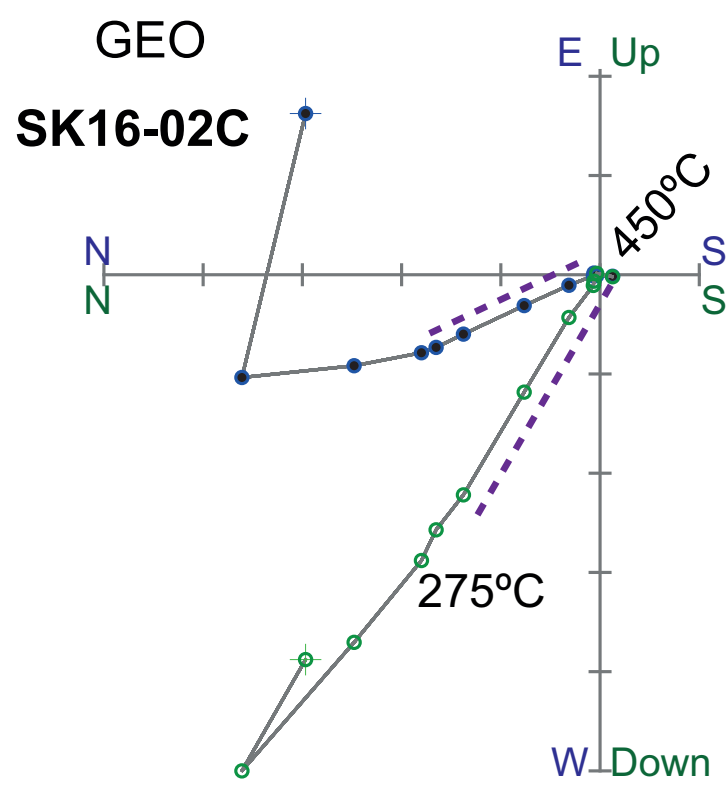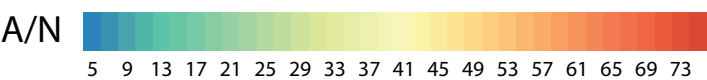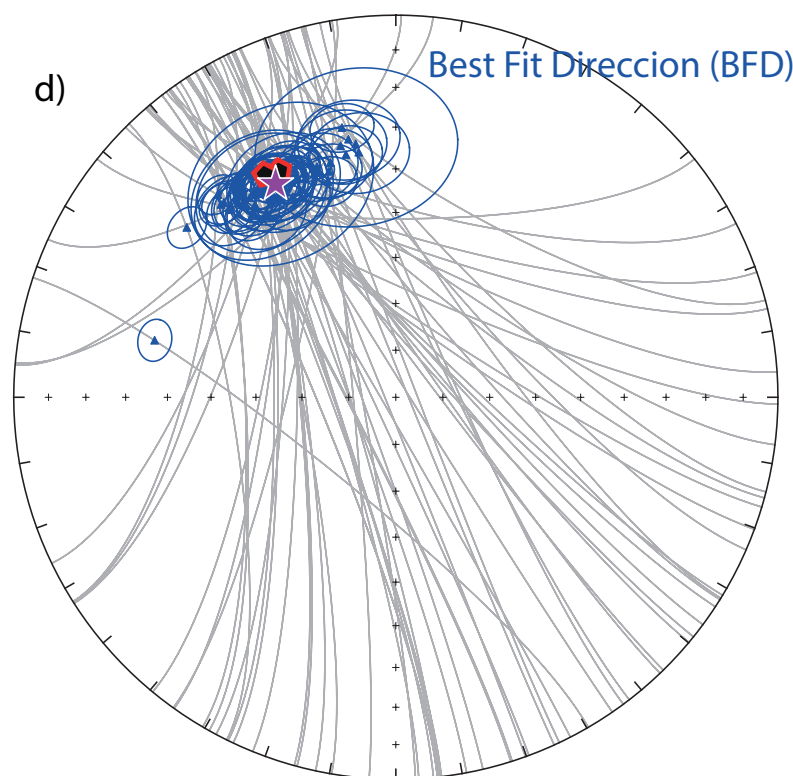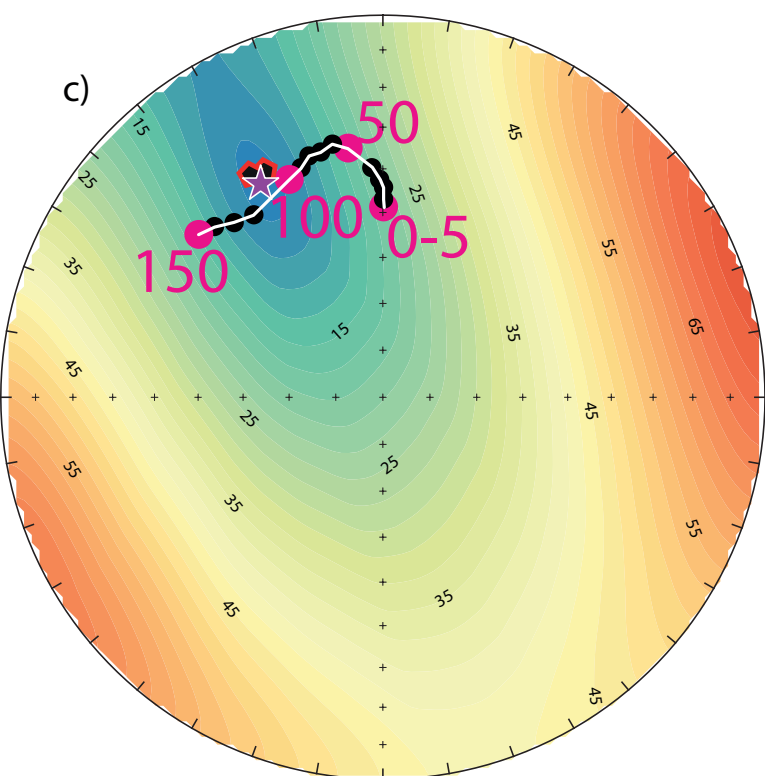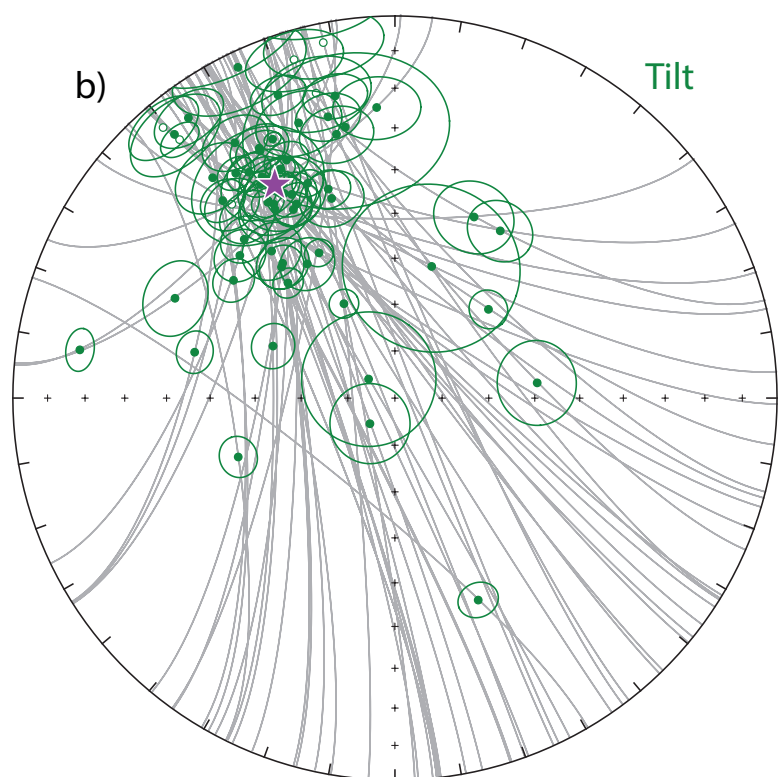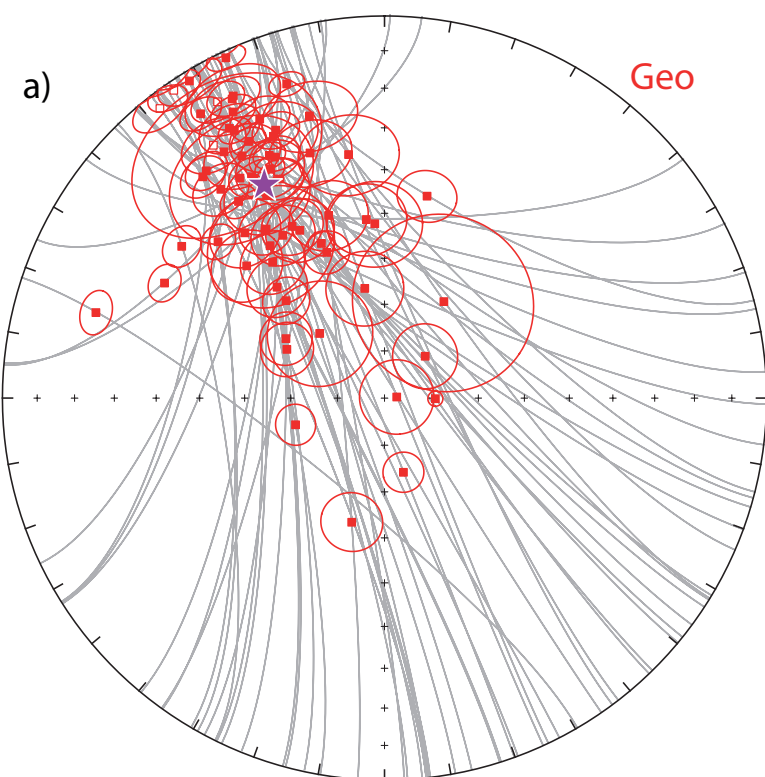
★ Direction of the remagnetization (D: 330.6, I: 36.1)

⬟ Horizontal-Bedding sites

●● Expected direction from Torsvik 2012 (Ma)

Figure

a)

2500

2000
(m)

Present-day geometry

1000 m

SK13
AG01
AG02
IC50
SK09
SK08
SK07
SK06
SK05

S   N

100 Ma geometry

AG01
AG02
¿?
SK13
IC50
SK09
SK08
SK07
SK06
SK05

b)

Present day inclination

B   B′

2000

1000

(m)

0

-1000

4000 m

Present-day geometry

SK04
IC48
IC47
SK02
IC46
IC45
SK01
DP07
SK03

SE   NW

100 Ma inclination

100 Ma geometry

2000

1000

(m)

0

-1000

IC47
IC48
IC46
IC45
SK02
SK03
SK01
DP07

Ikkou
salt-wall

Continental -
Dogger

Marine - Dogger

Upper Lias

Lower Lias

Basement

Triassic evaportites

Figure

b)

SK11

SK10

SK11

S
N

Geo
Tilt
BFD

SK11
SK10

SK09
SK08

N

Foliation trend

AM11

AM10

Road

AM09

53
75
34
13
67
79

100m

c)

S
N

SK08

SK09

a)

AM10
AM09
AM11

Figure

a)

39
110
40 70 45 74
80 55   80 18 60 30
85
28   87 26

1 45
41 55
41
65
86
17 15   89 80   63 89

b)

59
83 45
60
20
38
21
3
57

0   1   2   3   4 km

N

Anticline with inmersion

Beds

Syncline with inmersion

Litostratigraphic contact (see Fig. 2)

Fault / Normal Fault

Thrust / Inverted Normal Fault

Foliation trend   Dyke

c)

N
1
1
1
S1 Mean 3
3
2
2

● S1 (n=12)
▲ So (n=19)
■ Paleo_So (n=10)

d)

n=13
• BFD
■ Geo
▲ Tilt
★ Reference

Figure

SSE   NNW

3000

0

(m)

3000 m

¿ ⊙ ⊗ ?

-3000

Triassic   Middle Jurassic (limestones and marls)   ⫶⫶ Cleavage

Basement   Lower Jurassic   Middle Jurassic (red-beds)

C-C'cross-section

C 31.945497ºN 5.427680ºW
C'32.202765ºN 5.592537ºW

Table

Site	n/N	Lit	In situ (GEO) DEC	INC	alfa_95	k	100 % corrected (TILT) DEC	INC	Best Fir Direction DEC	INC	BFD-expec.dir angle	Bedding DipDir/Dip	Paleo-bedding DipDir/Dip	Ref
AG01	6/6	Car	314.9	70.5	11.2	36.7	334.6	4.7	332.4	36.4	1.4	344/68	344/32	A
AG02	6/6	Car	329	32.9	4.5	219.4	329	32.9	328.4	35.9	1.8	344/00	344/03	A
AM01	8/8	Car	335.5	31.3	4.9	130.1	338.9	16.1	333.3	37	2.3	004/17	004/24	A
AM02	8/8	Car	335	2	3.2	293.6	317.1	56.2	330	36.1	0.5	175/60	175/23	A
AM03	8/8	Car	342.7	15	3.1	316.6	331.6	67.1	341.1	37.5	8.5	170/53	170/30	A
AM04	8/8	Car	334.5	36.6	4.7	138.6	319.1	52.6	334	37.5	3	191/22	191/21	A
AM05	8/8	Car	44.2	77.6	6.9	64.7	347.5	30	348.3	35.4	14.4	334/55	334/06	A
AM06	8/8	Car	327.1	12.4	3.8	185.9	331.7	43.3	329.9	36.3	0.6	134/32	134/07	A
AM07	6/8	Car	331.7	47.7	6.3	114	327.9	22.2	329.4	36.3	1	318/26	318/14	A
AM08	7/8	Car	326.7	31.7	14.3	18.8	305.8	83.1	326.5	36.2	3.3	150/52	150/48	A
AM09	5/6	Car	333.2	49.3	7	120.3	329.7	36.8	329.6	36.3	0.8	315/13	135/01	A
AM10	4/4	Car	329.8	38.6	8.6	114.2	320.1	11	328.7	37	1.8	288/34	288/32	A
AM11	5/5	Car	321.9	25.4	4.2	327.7	282.9	45.3	318.7	30	11.7	193/53	193/45	A
AM12	8/8	Car	313.8	48.6	7.6	54.1	320.4	26.1	318.7	34.9	9.8	338/24	338/09	A
AM13	8/8	Car	330.7	20.8	3	350.9	332.4	54.7	331.1	36.2	0.4	148/34	148/19	A
AM14	8/8	Car	301.1	65.4	5.6	97.5	331.5	26.5	329.1	35.9	1.2	353/46	353/10	A
AM15	8/8	Car	343	48.6	7.9	50.4	327.8	34.3	329.4	36.8	1.2	285/22	285/03	A
AM16	6/8	Car	330.1	19.7	5.7	139.9	326.8	55.5	329.3	36.1	1.1	155/36	155/19	A
DP01	8/8	Car	194.8	62.5	6.4	75.5	342.4	44.4	343.5	38.2	10.5	355/71	175/06	B
DP02	8/8	Car	253.3	70.2	4.3	166.7	327.1	30.3	325.7	35.3	4.1	350/60	350/05	B
DP03	7/8	Car	314.7	60.3	5	144.4	333.1	40	334.3	37.2	3.1	001/25	181/03	B
DP04	8/8	Car	320.5	52	6.8	68.1	328	39.9	329.5	36	0.9	355/14	175/04	B
DP05	8/8	Car	325	45.1	5.6	99.2	319.9	-34.1	321.8	39	7.6	293/87	293/80	B
DP06	8/8	Car	328	48.4	6.6	70.4	319.4	-7.5	323.8	37.7	5.7	303/59	303/47	B
DP07	8/8	Car	90.7	79.2	1.6	1178.8	334.7	26	335.8	35.8	4.2	325/70	325/10	B
DP08	7/8	Car	345.1	24.6	8.7	48.8	83.9	59.3	347.6	33.1	14.3	138/82	138/72	B
DP09	8/8	Car	332.1	16.4	4.1	185.7	46.5	62.4	337.2	34.4	5.6	124/78	124/57	B
DP10	7/8	Car	321.9	31.2	5.7	115.1	320.8	-38.7	321.3	35.7	7.6	333/71	333/76	B
DP11	8/8	Car	323.4	36.1	3.7	219.5	320.2	-13	323.8	37.6	5.7	305/51	305/53	B
DP12	5/8	Rb	343.1	33.4	7.9	94.1	356.4	24.8	330.6	35.6	0.5	060/25	060/43	B
IC02	7/8	Car	325.6	-2.7	4.6	170.4	318.9	32	318.6	32.5	10.6	178/42	358/01	C
IC03	7/8	Car	85	87.4	7.9	59	340.7	24.7	341.1	36.4	8.4	338/66	338/12	C
IC44	7/8	Car	326.9	24.1	18.4	11.7	15.6	60.7	331.5	35.9	0.8	115/57	115/43	C
IC45	7/8	Rb	354.2	51.2	8.1	56.1	23.6	47.1	325.1	40.5	6.2	090/25	090/54	C
IC46	7/8	Rb	31.6	65.8	19.1	10.9	349.6	28.7	351	33.3	16.9	324/49	324/05	C
IC47	8/8	Car	323.1	48.7	13.2	18.6	327.1	-33.8	326.7	35.8	3.2	342/85	342/71	C
IC48	7/8	Car	328.4	2.9	5.5	119.9	320.2	52.1	325.5	35.6	4.2	161/51	161/17	C

IC50	9/10	Car	334.6	30.4	3.1	273.1	337.9	39.2	336.1	35	4.6	128/10	128/05	C
IC51	9/10	Car	337.9	25.3	4.4	136.6	342.3	42.1	339.9	34.9	7.7	139/18	139/08	C
OU01	8/8	Car	319.8	42.8	7.4	57.5	294.4	36.9	332.9	40.6	4.9	228/30	228/45	A
OU02	6/8	Car	11.9	45.1	5.9	131.7	346.6	25.3	348.7	28.8	16.9	298/39	298/05	A
OU03	6/8	Car	351.6	35.8	9.6	50.1	345.5	-18.7	349.6	31.8	16.3	314/64	314/59	A
OU04	8/8	Car	286.5	22.3	4	190.1	157.6	42.3	283.3	35.4	38.1	129/110	129/96	A
OU05	8/8	Car	297.6	35.3	3.7	223.2	278.7	17.7	329.7	34.8	1.5	223/40	223/83	A
OU06	8/8	Car	337	26.5	8.3	45.2	331.6	39	332.8	37	1.9	188/15	188/03	A
OU07	5/8	Car	333	13.2	8.5	82.4	224.3	82.4	331.5	36.3	0.8	160/80	160/57	A
SK01	7/8	Car	333.4	33.4	6.7	82.8	32.2	47.1	334.1	34.3	3.4	103/61	103/60	A
SK02	6/8	Rb	356.8	52.3	9.6	49.6	348.6	-5.7	351.4	35.3	16.9	336/60	336/42	A
SK03	7/8	Rb	349.8	66.2	8.1	56.4	343.4	-8.4	344.4	36.4	11.1	339/75	339/45	A
SK04	8/8	Car	313.2	40	3.7	228.2	324.7	28.7	322.4	31.9	8.1	015/20	015/05	A
SK05	8/8	Car	315.9	56.8	6.4	76.7	323.6	9.8	321.6	35.7	7.3	333/48	333/26	A
SK06	7/7	Car	325.9	-21.2	6.2	94.8	320	48.4	323.8	35.5	5.6	160/72	160/14	A
SK07	8/8	Car	329.5	27.3	7.4	57.2	327.6	41	328.5	36	1.8	160/14	160/05	A
SK08	7/8	Car	322.2	-4.6	5	144.3	316.5	42.2	318.7	34.9	9.8	158/49	158/08	A
SK09	7/7	Car	332.1	25	3.3	335.8	327	38.8	328.5	35.6	1.8	180/16	180/04	A
SK10	8/8	Car	338.4	56.3	4.7	141.5	331.4	27.2	332.5	36	1.5	320/30	320/09	A
SK11	8/8	Car	165.7	73.7	4.3	167.7	335.5	32.1	335.3	36.4	3.8	338/74	338/04	A
SK12	8/8	Car	333.4	33.4	2.9	366.1	333.4	33.4	331.1	36.4	0.5	020/00	020/05	A
SK13	8/8	Car	296.5	66.7	5.7	96.2	348.8	20.5	342.6	40.5	10.4	013/62	013/22	A
SK14	8/8	Car	333.4	12.6	4.7	140	293.1	61.6	327.6	35.3	2.6	180/64	180/38	A
SK15	8/8	Car	335.9	21.1	5.5	102.7	312.6	44.1	327.5	34.3	3.1	202/41	202/21	A
SK16	8/8	Car	337.8	54	2.7	404.8	332.4	36.8	332.3	36	1.3	318/18	138/01	A
SK17	7/8	Car	330.6	-12	4.8	159	333.1	42.5	332.2	36.1	1.3	143/55	143/06	A
SK18	8/8	Car	306.8	34.1	4.2	174.3	249.4	53.9	309.1	30.2	18.9	171/55	171/60	A
SK19	8/8	Car	320.6	26	4.5	149.4	306.1	46.6	317.8	32.4	11.2	177/28	177/20	A

Interactive Map file (.kml or .kmz)
[Click here to download Interactive Map file (.kml or .kmz): Supplementary.kmz](#)