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Tectono-stratigraphic evolution of salt-controlled minibasins in a fold and thrust belt, the Oligo-Miocene central Sivas Basin

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Corresponding Author: Dr. charlie kergaravat,

Corresponding Author's Institution: University of Pau UPPA

First Author: charlie kergaravat

Order of Authors: charlie kergaravat; Charlotte Ribes; Jean-Paul Callot; Jean-Claude Ringenbach

Abstract: The Central Sivas Basin (Turkey) provides an outcrop example of a minibasin province developed above a salt canopy within a foreland-fold and thrust belt. Several minibasins are examined to assess the influence of regional Oligo-Miocene shortening during the development of a minibasin province. The results are based on extensive field work, including regional and detailed outcrop mapping of at least 15 minibasin margins and analysis of the structural elements at all scales. This reveals a progressive increase in shortening and a decrease in salt tectonics during evolution of the province. The initiation of minibasins is driven mostly by the salt-induced accommodation forming a polygonal network of salt structures with mainly local halokinetic sequences (i.e. hooks and wedges). The initiation of shortening is marked by an abrupt increase in sedimentation rate within the flexural foreland basin causing burial of the preexisting salt structures. Orogenic compression encourages the rejuvenation of linear salt structures oriented at right angle to the regional shortening direction. The influence of orogenic shortening during the last steps of the minibasin province evolution is clearly shown by: (i) the squeezing of salt structures to form welds which are developed both at right angle and oblique to the regional shortening direction, (ii) the emergence of thrust faults, (iii) the tilting and rotation of minibasins about vertical axis associated with the formation of strike-slip fault zones, and (iv) the extrusion of salt sheets. The pre-shortening geometry of the salt structures pattern, polygonal versus linear salt walls, influence the resultant structural style of the minibasin province subjected to shortening. The thickness of the salt canopy, i.e. "the quantity of salt remobilized", which decreases during minibasin province development, appears to be a major factor controlling the impact of the regional shortening during salt province development.

Dr. Charlie Kergaravat
LFCR
Université de Pau et des Pays de l'Adour
Avenue de l'Université BP 1155
64013 PAU Cedex
FRANCE
charlie.kergaravat@univ-pau.fr
+33 6 23 14 45 12

Pau, 2017 April 19th

To *Journal of Structural Geology* Editors,

Dear Editors,

Please find enclosed a manuscript entitled “**Tectono-stratigraphic evolution of salt-controlled minibasins in a fold and thrust belt, the Oligo-Miocene central Sivas basin**” that I submit to *Journal of Structural Geology* for publication. Authors of this study are myself Charlie Kergaravat (to whom correspondence should be addressed), Charlotte Ribes, Jean-Paul Callot and Jean-Claude Ringenbach.

This manuscript treat of the tectono-sedimentary analysis of the Sivas mini-basins in a context of fold-and-thrust belt. The results are based on extensive field work, including regional and detailed outcrop mapping of at least 15 mini-basins margins and analysis of the structural elements at all scales, integrating previous sedimentological and lithostratigraphic data analyses of outcrops with great details along the tilted mini-basins margins reveal the complex interaction between salt tectonics and sedimentation leading to typical salt-related structures such as: hook and wedge halokinetic sequences, tabular and tapered composite halokinetic sequences, megaflap, allochthonous salt sheets and encapsulated mini-basins.

The minibasins structures are analysed to assess the influence of regional Oligo-Miocene shortening during the development of the minibasin province. This reveals a progressive increase in shortening and a decrease in salt tectonics during evolution of the province. The pre-shortening geometry of the salt structures pattern, polygonal versus linear salt walls, influence the resultant structural style of the mini-basin province subjected to shortening. The thickness of the salt canopy, i.e. “the quantity of salt remobilized”, which decreases during mini-basin province development, appears to be a major factor controlling the impact of the regional shortening during salt province development. We develop a new tectono-stratigraphic model for the evolution of the Sivas mini-basin province, and provide a better understanding of the interaction between halokinesis and regional tectonics on the mini-basin development.

Due to the nature of our results and since they provide useful material for further studies of tectono-sedimentary evolution of mini-basins in compressive setting, we think that *Journal of Structural Geology* is the most suitable medium in which these new results can be published.

The study under consideration is an original work, not published elsewhere or under consideration for publication elsewhere. All authors have seen the manuscript and agree to its submission to *Journal of Structural Geology*.

In its present shape, the paper is composed of a main text and 17 figures. Please let me know if anything is wrong in the files I joint to this letter. If necessary, I'll do immediately for the best to improve the submission shape of this manuscript.

Sincerely,

Charlie Kergaravat

Highlights

- Field work data used to examine influence of shortening on minibasin province
- Oligo-Miocene minibasins present an increasing number of shortening evidences
- Minibasins initiation is driven mostly by the salt-induced accommodation
- Minibasins are finally tilted and rotated about vertical axes
- Pre-existing evaporite wall network influences the lateral mobility of the minibasins

1 **Tectono-stratigraphic evolution of salt-controlled minibasins in a**
2 **fold and thrust belt, the Oligo-Miocene central Sivas basin.**

3 Charlie Kergaravat ^{*†}, Charlotte Ribes ^{*†‡}, Jean-Paul Callot^{*} and Jean-Claude Ringenbach[†].

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5 * IPRA-LFCR, UMR 5150 CNRS, Université de Pau et des Pays de l'Adour, Pau Cedex, France

6 † Total SA, CSTJF, Pau, France

7 ‡ Present address: IPGS-EOST, UMR 7516 CNRS, Université de Strasbourg, Strasbourg, France

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9 Corresponding author: charlie.kergaravat@univ-pau.fr

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11 Keywords: Salt tectonics, minibasins, shortening, halokinetic sequences, Sivas Basin.

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32 **ABSTRACT**

33 The Central Sivas Basin (Turkey) provides an outcrop example of a minibasin province
34 developed above a salt canopy within a foreland-fold and thrust belt. Several minibasins are
35 examined to assess the influence of regional Oligo-Miocene shortening during the
36 development of a minibasin province. The results are based on extensive field work, including
37 regional and detailed outcrop mapping of at least 15 minibasin margins and analysis of the
38 structural elements at all scales. This reveals a progressive increase in shortening and a
39 decrease in salt tectonics during evolution of the province. The initiation of minibasins is
40 driven mostly by the salt-induced accommodation forming a polygonal network of salt
41 structures with mainly local halokinetic sequences (i.e. hooks and wedges). The initiation of
42 shortening is marked by an abrupt increase in sedimentation rate within the flexural foreland
43 basin causing burial of the preexisting salt structures. Orogenic compression encourages the
44 rejuvenation of linear salt structures oriented at right angle to the regional shortening
45 direction. The influence of orogenic shortening during the last steps of the minibasin province
46 evolution is clearly shown by: (i) the squeezing of salt structures to form welds which are
47 developed both at right angle and oblique to the regional shortening direction, (ii) the
48 emergence of thrust faults, (iii) the tilting and rotation of minibasins about vertical axis
49 associated with the formation of strike-slip fault zones, and (iv) the extrusion of salt sheets.
50 The pre-shortening geometry of the salt structures pattern, polygonal versus linear salt walls,
51 influence the resultant structural style of the minibasin province subjected to shortening. The
52 thickness of the salt canopy, i.e. “the quantity of salt remobilized”, which decreases during
53 minibasin province development, appears to be a major factor controlling the impact of the
54 regional shortening during salt province development.

57 1. INTRODUCTION

58

59 In compressive regime, the preferential squeezing of salt structures exerts a powerful control
60 on the resulting deformation and structural style of the fold-and-thrust belt (e.g. Letouzey et
61 al., 1995 ; Vendeville and Nilsen, 1995; Rowan and Vendeville, 2006; Dooley et al., 2009;
62 Jahani et al., 2009; Callot et al., 2012). Existing field studies were focused on preexisting
63 diapirs and salt-withdrawal minibasins developed in rifted, cratonic or passive margin setting
64 which have been uplifted by later shortening, including the Great Kavir (Jackson et al., 1990);
65 the Axel Heiberg Island Arctic Canada (Jackson and Harrison, 2006; Harrison and Jackson,
66 2014) ; the Flinders Ranges (Rowan and Vendeville, 2006; Kernén et al., 2012 ; Hearon et al.,
67 2015), the High Atlas (Saura et al., 2014; Martín-Martín et al., 2017) ; the South Pyrenean
68 foreland (López-Mir et al., 2015; Saura et al., 2015); the French Alps (Graham et al., 2012)
69 and the Zagros fold belt (Sherkati et al., 2006; Jahani et al., 2009; Callot et al., 2012).
70 However, relatively few examples of minibasins province evolving in synchronous
71 shortening, such as at the toe of continental margins, have been described in the literature (e.g.
72 Peel et al., 1995; Brun and Fort, 2004; Dooley et al., 2013; Kergaravat et al., 2016; Duffy et
73 al., 2017).

74 The Sivas Basin in central Anatolia, Turkey, (Fig. 1a) is a minibasin province showing
75 Wall and Basin (WAB) structures (Harrison and Jackson, 2014) and the presence of two
76 generations of minibasin enveloped by a salt canopy and developed in a foreland fold-and-
77 thrust belt (e.g. Ringenbach et al., 2013; Callot et al., 2014; Ribes, 2015; Kergaravat et al.,
78 2016). It has been proposed that the impact of regional shortening on minibasins was (i) to
79 modify the volume, sorting and composition of the clastic input, (ii) to modify the flexural
80 subsidence and thus the relative influence of localized salt relative accommodation with

81 respect to regional tectonic accommodation, and (iii) to tilt some of them and weld the
82 contacts.

83 This last point, i.e. the expression of shortening within the minibasin province has not been
84 described in detail (e.g. Ribes, 2015; Kergaravat et al., 2016).

85 In this article, we investigate what we can learn about the development of minibasins
86 during coeval shortening from an observation-driven approach based on extensive fieldwork
87 in the Sivas Basin, including regional and detailed structural mapping. The aim of this paper
88 is to propose a mechanism that explains the evolution of Sivas secondary minibasins and salt
89 structures. We describe in detail the surface and sub-surface geometries of the Oligo-Miocene
90 minibasins and investigate the effects of both halokinesis and the tectonic setting. We develop
91 a new tectono-stratigraphic model for the evolution of the Sivas minibasin province, and
92 provide a better understanding of the interaction between halokinesis and regional tectonics
93 on the minibasin development. We discuss the influence of synchronous shortening during
94 salt tectonic activity on (i) the size and shape of the minibasins, (ii) the stratal architecture
95 within the minibasin, and finally (iii) their tilting and rotation.

96

97 **2. GEOLOGICAL SETTING**

98

99 The Sivas Basin is an intramontane basin situated at the junction between three crustal blocks:
100 the Pontides magmatic arc to the north, the Kırşehir continental block to the west, and the
101 Taurides-Anatolides continental blocks to the south (Fig. 1A) (Cater et al., 1991 ; Yılmaz and
102 Yılmaz, 2006). The northern and southern margins of the Basin are defined by two suture
103 zones: the Izmir-Ankara-Erzincan suture zone (IAESZ) to the north and the Inner-Tauride
104 suture zone (ITSZ) to the south (Fig 1A) (e.g. Görür et al., 1998; Okay et al., 2006; Yılmaz

105 and Yılmaz, 2006; Rolland et al., 2010; Karaoğlan et al., 2013). The Sivas Basin overlies the
106 Kirşehir and Taurus blocks and the obducted ophiolite produced by the Northern Tethys
107 closure (Görür et al., 1998; Okay et al., 2006; Yılmaz and Yılmaz, 2006; Rolland et al., 2010).

108 *2.1. From obduction to foreland basin (Maastrichtian – Eocene)*

109 During the Upper Cretaceous to Paleocene a carbonate platform was deposited directly above
110 the ophiolite nappe along the south margin of the Basin (Tecer and Gurlevik Fms; Fig 1B and
111 2) (Kurtman, 1973; Cater et al., 1991). Following the Sivas Basin basement assemblage, the
112 foreland basin developed during the Early Eocene (e.g. Kurtman, 1973; Cater et al., 1991 ;
113 Guezou et al., 1996; Poisson et al., 1996; Görür et al., 1998). The onset of contraction is
114 recorded by the development of very coarse conglomerates with clasts of ophiolite and
115 limestone derived from the growing topography of the Tecer and Gürlevik platforms covering
116 the active basin southern edge (Fig. 1B and 2) (e.g. Kurtman, 1973; Cater et al., 1991; Poisson
117 et al., 1996). In the south, this conglomeratic fan delta comprises the Bahçecik Fm and is
118 covered by volcanoclastic turbidites of the Bözbel Fm passing laterally to the Köseadağ Fm in
119 the North (Fig. 2) (e.g. Artan and Sestini, 1971; Kurtman, 1973; Özçelik and Altunsoy, 1996).
120 The foreland basin recorded significant shortening in several major pulses of thrusting and
121 folding and depocenter migration toward north from Early Eocene to Pliocene associated with
122 northward Arabian convergence (e.g. Kurtman, 1973; Cater et al., 1991; Guezou et al., 1996;
123 Kergaravat et al., 2016).

124

125 *2.2. Sivas salt basin*

126 *2.2.1. Autochthonous salt and primary minibasins*

127 At the end of the Eocene, the autochthonous salt level, known as the Tuzhisar Fm, was
128 deposited throughout the basin, overlaying the Bözbel Fm and the ophiolite on the southern

129 basin margin (Fig. 2) (e.g. Artan and Sestini, 1971; Kurtman, 1973; Özçelik and Altunsoy,
130 1996; Poisson et al., 2010). At outcrop this marine evaporite level comprises interbedded
131 gypsum and anhydrite associated with red silt but it may initially have contained a huge
132 amount of halite (Gündogan et al., 2005; Onal et al., 2008), as evidenced by the important salt
133 related features (e.g. Ringenbach et al., 2013; Callot et al., 2014; Ribes et al., 2015;
134 Kergaravat et al., 2016). Geochemical analysis of the Tuzhisar Fm sulfates demonstrated a
135 Bartonian age from the Sr isotopic ratio (Pichat et al., Submitted). Major continental clastic
136 and playa lake sediments, known as the Selimiye Fm (e.g. Kurtman, 1973; Cater et al., 1991;
137 Gündogan et al.; Onal et al., 2008), progressively covered the autochthonous evaporite level
138 during the Oligocene. The prograding sedimentary loading forced the evaporite to flow
139 basinward, initiating the primary minibasins characterized, to the south of the minibasins
140 province, by a large asymmetric sediment wedge with monoclinal dips and podlike basins
141 with large halokinetic wedges farther north (Fig. 3A) (Kergaravat et al., 2016). The
142 development of the canopy above these primary minibasins in the central part of the Sivas
143 Basin was most probably controlled by the load of the primary minibasins, a decrease of
144 sedimentary supply at the end of the Selimiye Fm, and a likely propagation of shortening
145 northward, inducing the squeezing of preexisting diapirs and walls between the primary
146 minibasins (Kergaravat et al., 2016).

147

148 *2.2.2. Secondary minibasin generation*

149 In the central part of the Sivas Basin, the secondary minibasins developed above the canopy
150 are filled at their base by (i) a thick succession of fluvio-lacustrine deposits (Karayün Fm), (ii)
151 then the deposition of the shallow marine Karacaören Fm, and finally (iii) the overlying
152 Benlikaya Fm characterized by alluvial to fluvial deposits (Figs. 2 and 3) (Ribes et al., 2015;

153 Ribes et al., 2016). These three formations, forming the minibasins above the salt canopy, are
154 significantly affected by salt tectonics and are the subject of this study.

155 The Karayün Fm, reaching a maximum cumulative thickness of 2 400 m, records the
156 fluvio-lacustrine sedimentation in the Oligocene (Poisson et al., 2010). Three long-lived
157 depositional systems have been recognised from base to top of the Karayün Fm: (1) the Lower
158 member corresponding to playa-lake and distal terminal splay deposits with sedimentary
159 facies similar to the Selimiye Fm deposits; (2) the Middle member corresponding to fluvial
160 braided deposits, and (3) the Upper member corresponding to saline lacustrine deposits (Fig.
161 2) (Ribes et al., 2015). These three depositional systems comprise large-scale genetically
162 related stratal packages that are separated by basin-wide surfaces expressed by changes in
163 textures and facies assemblages, as well as stratal and stacking patterns (Fig. 3). The
164 depositional setting of the Karayün Fm is interpreted as a Distributive Fluvial System (DFS)
165 (Ribes et al., 2015).

166 Above the Karayün Fm, the deposition of the shallow marine Karacaören Fm marks a
167 regional transgression during the Oligocene-Miocene (Özcan et al., 2009 ; Poisson et al.,
168 2010; Sirel et al., 2013; Poisson et al., 2015). The Karacaören Fm contains shallow-marine
169 marls and sandstones that are interbedded locally with algal limestones (Fig. 3) (Kurtman,
170 1973; Özcan et al., 2009; Poisson et al., 2010; Sirel et al., 2013). The Karacaören Fm is
171 divided in two main sub-environments: (i) mixed deltaic and carbonate ramp and (ii) coastal
172 plain and restricted lagoon (Ribes et al., Submitted). At the regional scale, the Karacaören Fm
173 includes two extensive deepening or shallowing-upward cycles which correspond to two
174 major transgressive-regressive sequences (Ribes et al., Submitted).

175 The overlying Benlikaya Fm is characterized by alluvial to fluvial deposits of Middle to
176 late Miocene age, composed of reddish sandstone and conglomerate interbedded with
177 floodplain mudstones (Fig. 2 and 3) (Poisson et al., 1996; Poisson et al., 2010; Ribes et al.,

178 Submitted). The depositional system of this formation is interpreted again as a distributive
179 fluvial system with alluvial/fluvial and playa-lake sub-environments. The Benlikaya Fm
180 overlies a regional erosional surface attributed to a sequence boundary that marks the sudden
181 regional development of a coarse clastic wedge. The overall fining-upward sequence
182 comprises an early aggrading phase (i.e Unit 1, Fig. 2), characterized by widespread coarse
183 deposits in multi-storey channel networks, followed by a retrogradational phase showing a
184 transition towards alluvial plain and playa lake deposits (i.e Unit 2, Fig. 2) (Ribes et al.,
185 Submitted). Toward the Middle of the Miocene, major shortening throughout the southern and
186 central part of the basin marks the end of life of the basin as a depocentre, associated with
187 regional uplift which has continued to the present day (Cater et al., 1991; Guezou et al., 1996;
188 Temiz et al., 2000).

189 **3. DATA AND METHOD**

190

191 This study is mainly based on remote sensing mapping and fieldwork data obtained during 6
192 months of ground-based work in the central Sivas Basin, using previous maps of Poisson et
193 al. 1996. Remote sensing mapping is based on analyses of very high resolution of colour
194 composite and orthorectified images from the Geoeye satellite (0.5 m resolution) and derived
195 digital elevation models (DEM) with a spot resolution of 2m x 2m. Fieldworks across at least
196 15 mini-basins have been performed to control remote sensing mapping analyses and to
197 measure onto outcrop systematic structural (bedding attitude, fracture and fault planes with
198 slickensides plotted on stereonets), sedimentological and lithostratigraphic data (more than 12
199 km of vertical sedimentological sections were measured, see Ribes et al., 2016). Detailed
200 mapping of minibasins margins have been performed using panorama view highlighting
201 stratal attitude and field mapping of salt-sediment contact and unconformities. Samples have

202 been collected for facies, anisotropy of magnetic susceptibility (AMS) (Kergaravat, 2016),
203 diagenetic (Pichat et al., 2016) and biostratigraphy analyses (Ribes et al., 2016).

204 Geological observations and measurements for the present study were compiled onto: (1)
205 a geology map of the minibasins covering an area of 50×30 km and finer-scale field maps (at
206 about 1/10,000) of the minibasin contacts and (2) a map of the main structures of the
207 minibasin organized by age, showing internal as well as boundary contacts. Cross sections are
208 based on the surface data, unpublished 2-D seismic lines acquired in 2010–2011 (provided by
209 Transatlantic Petroleum Ltd) and a structural model that we derived from a seismic line
210 published in Kergaravat et al., (2016).

211

212 **4. STRATAL RECORD OF HALOKINESIS AND SHORTENING**

213

214 The characterization of the minibasins province relies on the description of several structural
215 and sedimentary features including: (i) the size and the shape of the minibasins (i.e. polygonal
216 or linear), (ii) the stratal architecture related to salt withdrawal (i.e. Wedge and Hook
217 halokinetic sequences and megaflap, see Giles and Rowan (2012) and Rowan et al., (2016))
218 and the recognition of markers of the regional deformation (i.e. network of either
219 compressional, extensional and/or transfer-fault systems) during the minibasin development.
220 In this section, we analyze the halokinetic and tectonic setting markers through time, from
221 Oligocene to Miocene, in order to highlight the controlling factors of the minibasin
222 development. These markers are summarized on the main structure map (Fig. 4).

223 We refer to end-member Hook-type Halokinetic Sequence (HHS) and Wedge-type
224 Halokinetic Sequence (WHS), which are characterized by the vertical stacking of drape-
225 folded upturned strata along the edges of diapirs (Giles and Lawton, 2002; Rowan et al.,

226 2003; Giles and Rowan, 2012). These unconformity-bounded sequences are formed in
227 response to variations in sediment accumulation rate vs. diapir-rise rate (Giles and Lawton,
228 2002; Giles and Rowan, 2012). Tabular composite halokinetic sequences (TAB), which are
229 formed by stacked HHS, are characterized by drape-folding within 200 m of the diapir and are
230 bounded by unconformities with angular discordance up to 90°. Tapered composite
231 halokinetic sequences (TAP) comprise stacked WHS in which the drape-folding occurs up to
232 1 km from the diapir, and separated by low angle unconformities up to 30°. We also refer to
233 MegaFlaps (MF), which are defined as “packages of deep minibasin strata that extend far up
234 the sides of diapirs. They are near-vertical but may also be completely overturned in their
235 upper parts, at the transition between feeder diapirs and salt sheets. They occur adjacent to
236 both primary and secondary diapirs and are distinguished from composite halokinetic
237 sequences by their scale, with vertical relief of 2-5 km or more” (Giles and Rowan, 2012;
238 Graham et al., 2012; Callot et al., 2016; Rowan et al., 2016).

239

240 *4.1. Karayün Fm*

241 The Karayün Fm records the initiation of secondary minibasins above the canopy. This
242 continental formation is mainly exposed in the core of the WABS displaying circular to
243 elliptical geometries that extend for 10 to 25 km² at the surface (Figs. 1B and 3A). These
244 deposits, sub-divided into Lower, Middle and Upper members, display a large variety of salt-
245 related deformation recording various scales of salt-sediment interactions.

246 *4.1.1. Lower member: HHS and WHS*

247 The base of the minibasins expose pronounced thickness variability within and between
248 minibasins with local internal unconformities (Figs. 3A and 4) (e.g. Ribes et al., 2015).
249 Primary sediments above allochthonous evaporite show a characteristic WHS that thins within

250 a few kms towards the diapir and displays low-angle onlap onto the evaporite such as in the
251 Emirhan and Ilkindi minibasins (Figs. 4, 5A and 5B). These observations show that the
252 allochthonous salt canopy was remobilized almost immediately after the early deposits.

253 Above the base WHS, sediments continue upward to form successive WHS bounded
254 by internal unconformities with angular discordances of up to 20° (see top-lap on Figs. 5A
255 and 5B). To the East of Emirhan minibasin, the sequences thin over a distance of less than 2
256 km, from up to 1,000 m in the depocentre to 50 m or less against the eastern evaporite wall,
257 thus forming a TAP (Fig. 5A). This halokinetic wedge succession is partially cut by syn-
258 depositional normal faults dipping both towards the minibasin core and its eastern wall (Fig.
259 5A). A few meter-scale folds occur that verge toward the minibasin. To the north of the
260 Ilkindi minibasin, this TAP is particularly well exposed, showing a gradual upturning and
261 thinning of beds of the Lower member (Fig. 5B). WHS are limited by internal unconformities
262 toward the Emirhan evaporite weld and defined by southward dips close to 90° decreasing to
263 30° farther south, over a horizontal distance of up to 300 m (Fig. 5B).

264 Along other salt structures, such as along the western edge of Emirhan, early WHS
265 can pass upward into a succession of local stratal deformations. Along the evaporite weld
266 which separates the Emirhan minibasin to the east from the Köy minibasin to the west (Figs.
267 5A and 5C), these deformations consist of 10 to 30 m thick set of strata with little variation in
268 thickness or sand content, which are drape-folded up to a distance of 40 m away from the
269 evaporite weld before becoming parallel to the evaporite weld (Fig. 5C). Each drape-folded
270 sedimentary sequence is cut by an angular unconformity with up to 90° of angular
271 discordance, but becomes conformable within a distance of 50 m from the evaporite weld
272 forming a HHS. Unconformities are mainly connected laterally to reentrants of the evaporite
273 weld, which forms local cusps (Fig. 5C). This vertical succession of HHS, define a TAB,
274 which passes laterally into TAP toward the eastern minibasin margin (Fig. 5A).

275

276 *4.1.2. Middle member: Megaflap*

277 The Middle member exposes less thickness variability with only basin-scale, halokinetic
278 folds, involving the 300-400 m basal interval, passing upward into wedges along the evaporite
279 structures (Figs. 3A and 4).

280 Along the eastern Emirhan margin, the lower half of the Middle member comprises a
281 400 m isopachous sequence of sandstone beds, which is folded over a distance of 1 km from
282 the eastern evaporite wall with bed rotation of up to 90° (Fig. 5A). This sequence is bounded
283 by the evaporite wall with a 90° angular discordance, defining a megaflap. The upper half of
284 this Middle member thins gently eastwards from 700 m in the west to 600 m in the east (Fig.
285 5A). Rather than being truncated by the basal Karacaören unconformity, the end of the
286 Middle member probably corresponds to WHS.

287 In the Karayün minibasin, the base of the Middle member is sub-isopachous, while the
288 upper two thirds of it form WHS separated by unconformities, defining a TAP to the eastern
289 margin of the minibasin (Fig. 6). The western extremity of the Middle member displays bed
290 rotations of up to 80° compared to the minibasin center which is truncated by an
291 unconformity of up to 10° and covered by the Upper member (Fig. 6). Numerous syn-
292 sedimentary normal faults cut the tip of the Middle member, dipping both towards the
293 minibasin centre and toward the western Karayün wall and weld (Fig. 6). The eastern margin
294 of the Karayün minibasin displays the deep strata of the Lower member and of the base of the
295 Middle member that extend 5km along the edge of the western evaporite wall. This wall
296 separates the Karayün and Akpınar minibasins, with vertical to slightly overturned beds
297 compared to the center of the Karayün minibasin, thus forming a megaflap (Figs. 6 and 7A)
298 (Rowan et al., 2016). The Middle member lower beds forming the megaflap show few
299 apparent channel migrations, instead comprising both laterally and vertically amalgamated

300 channelized unit (Fig. 7A) (Ribes et al., 2016). The extremity of the Karayün megaflap is a
301 complex structure showing a refolded tip of the megaflap limb, which is truncated and
302 overlain by the Karacaören Fm to the west and by a complexly interbedded gypsum and shale
303 horizon to the east (Figs. 7B and 7C). The eastern end of the Middle member section
304 corresponds to a tilted, faulted and recumbent fold with a right-lateral strike-slip fault (Figs.
305 7B and 7C).

306 Along the western margin of the Karayun minibasin, the Lower and Middle members
307 are locally cut by a northeast-verging thrust fault connected to the evaporite wall between the
308 Arpayazı minibasin to the north and the Ilkindi minibasin to the south (Fig. 6). The
309 westernmost end of the Karayün evaporite wall, separating the Ilkindi and Arpayazi
310 minibasins, disappears buried beneath a small E-W trending anticline, the northern flank of
311 which is cut by a thrust fault verging north (Fig. 6). On the northern side of the north-verging
312 thrust fault, beds of the Middle member display a set of asymmetrical folds with axial planes
313 dipping toward the south (Fig. 6). This large-scale structure defines a thrustured evaporite-cored
314 anticline, whose northern flank is cut by a north-verging thrust fault, emplacing the anticline
315 core on top of the Arpayazı beds (Fig. 6).

316

317 4.1.3. *Upper member: WHS and encapsulated minibasins*

318 The Upper member is observed above both preexisting minibasin and allochthonous
319 evaporites. At outcrop, the overall thickness of the member is highly variable due to large-
320 scale WHS (Fig. 4).

321 In the Karayün minibasin, the entire Upper member displays a large stratigraphic wedging
322 that extends on both sides with vertical to slightly overturned beds compared to the minibasin
323 center (Fig. 6). Along the western minibasin margin, the wedge involving the Upper member
324 shows a drape-fold geometry affecting a wide zone of 500–1 000 m from the Karayün weld,

325 with bed rotations of up to 110° from the minibasin center (Fig. 6). This halokinetic drape-
326 fold upper boundary is a 90° angular discordance that becomes conformable within up to 1
327 km from the Karayün weld (Fig. 6). To the eastern margin of the Karayün minibasin, a large
328 sedimentary wedging, involving the entire Upper member, also displays a drape-fold
329 geometry affecting a zone up to 1000m wide with bed rotation of up to 100° from the
330 minibasin center. In a way similar to the western margin, an erosional unconformity cuts the
331 lip of the wedge but with lower angular discordance (50-60°) preserving a larger part of the
332 limb of the wedge and covering the Karayün megaflap than in the west (Fig. 6).

333 Four small-scale minibasins, composed exclusively of the Upper member of the Karayün
334 Fm (i.e. Pınarca, Köy, Inceyol and Ulukapı) west of the Emirhan minibasin, have circular to
335 elliptical shapes defined by synclines covering allochthonous evaporite (Fig. 5A). One of
336 these minibasins, the Inceyol minibasin is composed of a single syncline in the north, which
337 passes laterally into two tight synclines to the south (Fig. 8A, see Collon et al., (2016)). These
338 two synclines are separated by an exposed evaporite wall, interpreted at depth as a weld or a
339 narrow evaporite wall juxtaposing steep to overturned flanking strata on both sides (Figs. 8B
340 and 8C). Along the western flank of the eastern syncline, the beds display apparent onlaps on
341 the evaporite wall with overturned strata dipping 55°W passing to vertical attitude over a
342 distance of 50 m in the core of the syncline (Fig. 8A). Strata in the two synclines are cut by
343 numerous normal faults, and local reverse faults are also observed in the core of the eastern
344 syncline. Due to the overturned strata along the evaporite-flanked wall, the isolated tight
345 synclines forming the Inceyol minibasin define an encased minibasin sensu Pilcher et al.,
346 (2011), also known as an encapsulated minibasin sensu Rowan and Inman (2011).

347 *4.2. Karacaören Fm*

348 The Karacaören Fm fills minibasins that extend 10 to 30 km² at the surface, displaying
349 elongated geometry with roughly NE-SW trends (Fig. 3A). This shallow marine deposit

350 overlays both preexisting primary and secondary minibasins either limited by an angular
351 unconformity or lying directly above the canopy (Fig. 3B).

352 *4.2.1. Base of the Karacaören Fm*

353 A major unconformity is observed in the minibasin province at the base of the Karacaören
354 Fm, cutting down to variable stratigraphic depths on different structures (Fig. 4). For example,
355 in the Celallı anticline, this erosive unconformity separates the Selimiye Fm. from the
356 Karacaören Fm, with high-angle (up to 90°) unconformities between the marine Karacaören
357 beds and the Selimiye Fm folded beds (Fig. 9A, location Fig. 4) (e.g. Cater et al., 1991). A
358 second example of the major marine unconformity is present between the Karayün and the
359 Karacaören formations, characterized by high-angle unconformities along minibasin margins
360 within the Emirhan and Karayün minibasins (Fig. 9B, location Figs. 4 and 5A).

361 *4.2.2. Stratal architecture*

362 Along the western margin of the Karayün minibasin, above the marine unconformity, the base
363 of the Karacaören Fm presents a stratigraphic wedge which thins over a distance of 400 m
364 from the Karayün evaporite weld, and is bounded by angular discordances of up to 15°
365 forming a TAP (Fig. 6). To the west of the Akpınar minibasin, the basal beds consists of a
366 marine conglomerate preserved as an eroded TAP to the SE above the evaporite diapir, and as
367 a syncline above the mixed gypsum and shale complex (Fig. 7C). Above the basal marine
368 TAP, the marine shale and sandstones record a succession of stratigraphic wedges which
369 progressively onlap the mixed gypsum and shale as well as the marine conglomerate syncline,
370 over a thickness of 400 m, recording successive steps of the salt withdrawal (Fig. 7C). The
371 Karayün megaflap and the tapered CHS at the Akpınar minibasin base are both overlapped by
372 the Middle to Upper Karacaören Fm.

373 The Karacaören formation is also exposed as broad stratigraphic wedges extending up to
374 2000 m away from the evaporite structures (Fig. 4). These halokinetic wedges are observed in

375 several minibasins (i.e. Akpınar, Tuzhisar, Bingöl, Emirhan and Ağilkaya) and are both N-S
376 and E-W trending.

377 In the Tuzhisar minibasin, large stratigraphic wedges are observed in map view thinning
378 towards both the eastern and western minibasin margins where an unconformity cuts the
379 halokinetic wedge limb at an angle ranging between 40 and 50° (Figs. 3A and 4). Two large
380 stratigraphic wedges thin toward the center of the Tuzhisar minibasin over 3 km, where the
381 limbs are cut by numerous syn-sedimentary normal faults (Fig. 3A). These stratigraphic
382 wedges are also observed in panorama view with N-S trending beds thinning towards the
383 south over a zone more than 2000m wide (Fig 10A, location Fig. 4). Farther south, the
384 Ağilkaya minibasin is composed of two synclines showing vertical to overturned flanks,
385 bounded by a central anticline which passes westward to an evaporite wall (Fig. 10B, location
386 Fig. 4). These synclines expose asymmetrical wedges on both flanks, thickening towards the
387 fold axes with progressive bed rotation (Fig. 10B). The northern flanks also show wedges of
388 sediments that thin out over a shorter distance than along the southern flank (Fig. 10B). The
389 same type of halokinetic growth strata is observed in the Bingöl and Çaygören minibasins
390 (Fig. 4). Numerous syn-sedimentary normal faults cutting the base or the Middle part of the
391 Karacaören Formation are observed, mainly in minibasins emplaced directly above the
392 allochthonous evaporites, for instance in the Tuzhisar and Ağilkaya minibasins (Fig. 4).

393 *4.3. Benlikaya Fm*

394 The Benlikaya Fm is exposed mainly at the rim of the minibasin province (Fig. 3A). These
395 deposits display moderate thickness variations compared to the Karayün and Karacaören
396 formations (Fig. 4). Some large stratigraphic wedges are localized at the front of regional
397 thrusts passing through the NE-SW salt wall and few local WHS are observed to the north of
398 the minibasin province (see the eastern margin of the Kizilkavraz minibasin in Fig. 4).

399 Locally, traces of allochthonous salt are observed, such as in the Çaygören minibasin and
400 around the Kabali Diapir (Fig. 4). This continental sequence is deposited both above
401 preexisting secondary minibasins such as the Çaygören minibasin, and allochthonous
402 evaporite such as the Küpecik minibasin (Fig. 3A).

403 *4.3.1. Thrust faults systems*

404 The eastern part of the minibasins area is characterized by major, sub-parallel N70E, striking
405 thrust faults passing through evaporite walls, delimiting elongated minibasins with a regular
406 spacing of 4 to 6 km (Fig. 4). Some of these thrusts were previously described and named by
407 Temiz (1996). All the thrusts are south verging, parallel to the regional fold trend, and
408 associated with blocks of serpentinized peridotites (Figs. 4 and 11) (e.g. Cater et al., 1991).
409 From south to north, these tectonic structures are referred to as the Celallı (CT), Gölcük (GT)
410 and Tuzhisar (TT) thrusts, connected to the Karayün Transfer Zone (KTZ) to the west. The
411 Gölcük thrust (GT) is considered to be one of the major thrusts within the secondary
412 minibasin domain, separating the Karayün and Akpınar minibasins to the NW, from the
413 Celallı anticline to the SE (Fig. 11, location Fig. 4). The GT footwall is characterized by a
414 growth syncline, involving the Benlikaya Fm., affected by south-verging satellite thrust faults
415 (Fig. 11). The GT contains blocks of serpentinized peridotite, some of which are 100m in size.
416 These ultramafic blocks, also observed below and within the autochthonous evaporite
417 horizon, are interpreted as olistoliths and debris flow deposits derived from the uplifted
418 southern margin of the Basin, emplaced before and during deposition of the autochthonous
419 salt (Fig. 1A). We suggest that these blocks were later transported upward by the flowing
420 evaporite during diapirism, squeezing of the evaporite wall, and finally emergence of the
421 thrust.

422 4.3.2. *Strike-slip faults systems*

423 Several strike-slip fault zones are observed along the KTZ in Fig. 4 and the associated stereo
424 plot in Fig. 12. The first of strike-slip fault zone is located between the Emirhan, Eğribucak
425 and Karayün minibasins (Fig. 6, location 1). Along the evaporite weld separating the
426 Eğribucak and Karayün minibasins, beds are cut by N130 right-lateral strike-slip faults with a
427 few meters of offset (Figs. 6 and 12). Fault planes are distributed en-echelon and left-stepping
428 with lengths of about 100 m, defining the weld as a wrench weld between the Eğribucak and
429 Karayün minibasins (Fig. 6, location 1). Farther west in the Karayün minibasin, the upper
430 Karacaören beds are cut by a synthetic strike-slip, en-echelon fault array, with a dextral offset
431 of several tens of meters as well as left-stepping faults (Figs. 6 and 12, location 2). Fault plane
432 traces trending N130 are connected to the evaporite wall and extend over a length of 1 km
433 (Fig. 6).

434 The second strike-slip fault array along the KTZ is located between the Arpayazı and
435 Karayün minibasins (Fig. 6, location 3). To the north of the Arpayazı minibasin, at the
436 wrenched weld contact, the Karayün Fm is cut by strike-slip faults with dextral displacement
437 along the KTZ between the two minibasins (Figs. 6 and 12). To the northeast of the Arpayazı
438 minibasin, numerous N150 trending faults with traces extending over a few hundred meters
439 cut the minibasin edges, where the evaporite wall grades into a wrench weld with dextral
440 motion (Fig. 6, location 3). The present-day distribution of these faults at the base of the
441 Arpayazı minibasin suggests that these structures could initially have been normal faults,
442 reactivated after the rotation of the minibasin as synthetic strike-slip faults with a dextral
443 offset, assisted by the presence of gypsum. However, most of the syn-sedimentary normal
444 faults observed in other minibasins associated with stratigraphic wedge development (i.e. west
445 Karayün minibasin, Fig. 6) verge toward the centers of the minibasins, which is not the case

446 for the faults situated at the base of a large stratigraphic wedge truncated to the north-east of
447 the Arpayazi minibasin (Fig. 6).

448 Another example of a strike-slip fault zone is the wrench weld bounding the Emirhan
449 minibasin to the north and the Ilkindi minibasin to the south, i.e. the Emirhan weld (Fig 5A,
450 location 4). Synthetic strike-slip faults trending N80 and N120, with a dextral offset and fault
451 traces of a few hundred meters, are connected to the wrench weld and cut beds of the Karayün
452 Fm (Figs 5A and 12). Antithetic strike-slip faults with sinistral offsets are also observed with
453 a N160 trend (Fig. 12). These fault structures record a dextral component of displacement for
454 the wrench weld between the Emirhan and Ilkindi minibasins.

455 To the north of the Emirhan minibasin, two other faults, with sinistral offset, trend
456 N30-N60 and merge along-strike within the E-W evaporite wall, with 500-m-long fault traces.
457 Both cut the base of the Eğribucak and the top of the Emirhan minibasins (Fig. 5A and 12,
458 location 5). The two faults delimit an evaporite wall segment, which shows an apparent
459 clockwise rotation around vertical axes recording a dextral component of displacement
460 between Emirhan and Eğribucak minibasins (Fig 5A).

461 Strike-slip fault zones are also observed affecting the cores of minibasins. Along the
462 western edge of the Arpayazi minibasin (Fig. 6, location 6), numerous en-echelon strike-slip
463 faults cut through the entire minibasin, with right-stepping faults showing sinistral offsets of a
464 few meters (Fig. 12). This cluster of strike-slip faults is probably conjugated with the Karayün
465 Transfer Zone (KTZ) that shows a dextral offset to the east (Fig. 6).

466 Fault zones can also be observed along thick evaporite walls. Along the N-S evaporite
467 wall separating the Ilkindi minibasin from the Eskiboğazkesen minibasin to the west, the
468 southwestern part of the Ilkindi minibasin shows a left-lateral strike-slip fault cutting beds of
469 the lower and Middle member (Fig. 4, location 7). The fault is NW-SE trending and 1.5 km

470 long. This fault is linked to the N-S evaporite wall to the north, and to the secondary weld
471 delimiting the Yavu minibasin to the south, with a large offset, probably greater than 500 m.

472 *4.3.3. Salt sheet*

473 Evidences of an allochthonous salt are found in the Çaygören minibasin, located to the north
474 of the Emirhan minibasin (Figs. 3A and 13). On the northern side of the Çaygören salt wall,
475 the Karacaören and Benlikaya strata form large stratigraphic wedges, showing progressive
476 bed rotation with dips varying continuously from 70° toward the south along the flank of the
477 evaporite wall, to 35° farther north (Figs. 13A and 13B). Within the Benlikaya Fm, an
478 evaporite body, about 600m in width and reaching a thickness of 100m, is present at surface
479 (Fig. 13A). At the base of the evaporite body corresponding to its southern limit at surface,
480 the Benlikaya beds, dipping 80°N, are truncated by a steep evaporite-sediment interface
481 defining an evaporite ramp. Northeast of the evaporite body, the Benlikaya fluvial beds,
482 dipping 80°N and flanking the evaporite body, are concordant with the evaporite-sediment
483 contact, defining a flat contact, with only rare evidence of normal faults within the Benlikaya
484 Fm and no evidence of shear at the salt-sediment contact (Figs. 13A, 13B and 13C, location
485 number 1). Northeast of the flat contact, the Benlikaya beds dipping 35°N and flanking the
486 evaporite body, are truncated with an apparent angular discordance of 30° by an evaporite-
487 sediment interface, again defining a basal ramp (Fig 13A, 13B and 13D, location number 2).
488 This evaporite-sediment ramp contact is characterized by a shear zone, up to 1 m thick,
489 composed of sandstone, gypsum lenses and sandstone boudins displaying clockwise rotation
490 related to a dextral motion (Fig. 13D). The top of the evaporite body, corresponding to its
491 northward outcrop limit, is marked by drape-folds involving Benlikaya strata with rotations of
492 up to 70° and no evidence of thrust faults (Fig. 13B). The Benlikaya beds, overlying and
493 flanking the evaporite body, locally contain normal faults with cm-scale extensional
494 displacements. North-verging recumbent folds associated with shear zones extend tens of

495 meters within the evaporite body (Fig. 13B). The large-scale isolated evaporite body
496 presenting ramp-flat geometry, is interpreted as remnant of a section across an evaporite sheet
497 limb, emplaced during deposition of the Benlikaya Fm and probably fed by the nearby
498 southern Çaygören evaporite wall, the connection to which has been eroded (Fig. 13B).

499

500

501

502 **5. SECONDARY MINIBASINS STRUCTURES**

503

504 Three N-S cross-sections passing through the minibasin province illustrate mainly the
505 geometry of secondary minibasins, which are well constrained at the surface but poorly
506 constrained at depth by unpublished seismic lines, due to the presence of both allochthonous
507 and autochthonous salt levels, as well as complex structures along the vertical contacts of the
508 minibasins (Fig. 14, see Fig. 3A for locations). Therefore, several geometries, thicknesses and
509 basement configurations are possible.

510 Several secondary minibasins, located to the north of the Ilkindi and Karayün
511 minibasins, are tilted up to vertical toward the north (i.e. Emirhan, Eğribucak, Çaygören,
512 Tuzhisar and Karayün minibasins, Figs. 3A and 14). The continental Karayün Fm and the
513 marine Karacaören Fm are characterized by large stratigraphic wedges, which generally thin
514 toward the south in the case of the Karacaören strata, such as in the Tuzhisar minibasin, and
515 by the tightening of synclinal minibasins above the canopy, such as in the Ağılkaya
516 minibasin.

517 Diapirs rising from the canopy have varying geometries related to various halokinetic
518 sequences along their flanks. Although some diapirs are still preserved, many others with
519 outcropping evaporite walls have been squeezed, forming vertical welds, sometimes evolving
520 to thrust welds where minibasins are juxtaposed. Teepee-like geometries are observed when
521 strata dip away from the welds in opposite directions (e.g. Rowan and Vendeville, 2006).
522 Section C in the east shows diapirs verging toward the south compared to those on sections A
523 and B where the diapirs are less defined (Fig. 14). The salt geometries change radically
524 laterally, as seen between Ilkindi in the south and Emirhan and Arpayazı in the north, passing
525 from a teepee-like geometry to a thrust evaporite wall. These salt structures can also display
526 a strike-slip component of movement generated by the translation and rotation of the
527 minibasins about a vertical axis, as shown in the previous section.

528 **6. EVOLUTION OF THE SIVAS SECONDARY MINIBASINS**

529

530 Based on the previous observations, summarized on the main structure map and cross sections
531 (Figs. 3B, 4 and 14), an evolutionary model of the secondary minibasin generation is
532 proposed. It is illustrated in Fig. 15 by five sequential schematic diagrams, starting in the
533 Mid-Oligocene during the initiation of the minibasins (Lower Karayün Fm), and ending in the
534 Middle Miocene (Benlikaya Fm). The aim of this schematic restoration is to highlight the
535 competition between halokinesis and contractional loading on the minibasins development.

536 *6.1. Secondary minibasins and diapirs initiation (A)*

537 During the sinking of early sedimentary deposits, mainly local composite halokinetic
538 sequences developed along both East-West and North South directions (e.g. Ribes et al.,
539 2015; Ribes et al., 2016). This results in the formation of a polygonal network of salt

540 anticlines with pillows at their intersection surrounding isolated, subcircular to elliptical
541 basins, filled by lower Karayün beds (Fig. 15a). The topography generated by the salt rise
542 relatively to the sedimentation rate locally controls the sediments dispersal and may facilitate
543 the local chemical and mechanical remobilization of evaporites (e.g. Lawton and Buck, 2006 ;
544 Paz and Rossetti, 2006; Ribes et al., 2016). Syn-sedimentary normal faults, rooted in the
545 basal allochthonous salt, cut edges of the halokinetic wedge sequences. In the case of the
546 secondary minibasin initiation, the salt canopy limits both (1) the controls exerted by the
547 subsalt network of salt structures surrounding primary minibasins (e.g. Diegel et al., 1995;
548 Harrison and Jackson, 2014) and (2) the influence of regional boundary conditions related to
549 the northward propagation of the Sivas foreland fold and thrust belt (e.g. Kergaravat et al.,
550 2016).

551 The initiation of the secondary minibasins during the deposition of the Lower member is
552 driven mostly by the salt-induced local accommodation, generated by salt withdrawal (e.g.
553 Ribes et al., 2016). Although the random localization of the primary depocenter of the
554 secondary minibasins is still poorly understood, local depressions at the salt canopy surface
555 potentially initiated the primary deposits. Local allochthonous salt depressions may have
556 originated from (1) the heterogeneity of intra-salt deformation between levels of gypsum,
557 anhydrite and halite (e.g. Cartwright et al., 2012; Jackson et al., 2014), (2) local salt collapse
558 within the allochthonous salt due to salt dissolution (e.g. Jackson et al., 2010), and (3)
559 morphology of the salt canopy such as the suture synclines at junctions between salt sheets
560 (e.g. Dooley et al., 2012) (Fig. 15a). In the case of the Sivas basin, where the salt level is
561 composed by halite, gypsum and anhydrite, intra-salt deformation allowed by regional
562 shortening is probably the most efficient way to initiate local topography in the salt canopy.

563

564 *6.2. Buried diapirs (B)*

565 The Middle member records an abrupt lithological change with the arrival large amount of
566 coarser sediments, with a dominantly northward fluvial transport direction (Ribes et al.,
567 2016). A globally isopachous and homogeneous sedimentary package covers both preexisting
568 depocenter and salt structures, obscuring the preexisting salt topography (Kergaravat et al.,
569 2016; Ribes et al., 2016) (Fig. 15b). Small thickness variations reflect the crests of salt
570 structures showing the weak influence of halokinesis. At the top of preexisting salt structures,
571 syn-sedimentary normal faults, sometimes connected to the evaporite, cut this coarser
572 sedimentary package, recording the local influence of salt withdrawal, which is weak but still
573 active (Fig. 15b).

574 The abrupt increase of sedimentary rate in the minibasin province is attributed to a
575 regional uplift of the southern margin of the basin, a consequence of a pulse of activity of the
576 orogenic wedge and associated thrusts (Kergaravat et al., 2016) (Fig. 15b). Burial of the salt
577 structures results from a period of regional accommodation induced by foreland flexural
578 subsidence and relative high sedimentation rate (Kergaravat et al., 2016; Ribes et al., 2016).
579 As proposed by Ribes et al., (2016), the relative decrease of salt withdrawal rate could also
580 represent a slightly delayed response to the abrupt and regional sediment loading. In addition,
581 we suggest that the presence of coarser sediments at the top of salt structures, which are more
582 difficult to deform, have probably decreased the vertical flow rate of salt diapirs.

583

584 *6.3. Rejuvenation of diapirs (C)*

585 The end of deposition of the Middle member is marked by a sharp increase in vertical diapiric
586 flow, associated with large halokinetic folding and even megaflaps development affecting the
587 homogeneous and isopachous Middle member (Fig. 15c). Large halokinetic folds form along
588 both East-West and North-South salt structures (Fig. 15c). Coeval drape folding and wedging

589 of the Upper member strata both illustrate renewed diapir motion related to their squeezing
590 most probably due to the orogenic shortening. High evaporite topographies are produced
591 during halokinetic fold development, and probably fed saline lacustrine deposits of the Upper
592 member by salt walls and diapir crests remobilization. At the top of salt walls and diapir
593 crests, encapsulated minibasins showing large wedging of the Upper member are developed.
594 Their development at the crests of squeezed salt walls is probably favored by (1) local
595 extension at diapir crests during salt diapir squeezing (e.g. Vendeville and Nilsen, 1995;
596 Callot et al., 2007) and (2) early strike-slip motion within the salt wall and diapir producing
597 local pull-apart between minibasins where sediments may be deposited (e.g. Sherkati and
598 Letouzey, 2004). In addition, we suggest that the rejuvenation of salt diapir rise is favored by
599 a decrease of sedimentation rate compared to the diapir growth rate, in particular due to the
600 transition from fluvial sediments of the Middle member with a relatively high sedimentation
601 rate, to the low sedimentation rate of the lacustrine deposits of the Upper member.
602 Encapsulated minibasins, located at diapir crests, are geometrically similar to the pod- like
603 structure incorporated within the ductile layer modeled by Fort and Brun (2004),
604 preferentially formed in domains subjected to shortening. The presence of this intrasalt
605 sediment have probably influence the lateral mobility of minibasins during shorting and the
606 resultant structural style (e.g. Duffy et al., 2017).

607 *6.4. East-West elongated marine minibasins and preferential growth of salt* 608 *structures (D)*

609 The arrival of the marine transgression is marked by regional erosion affecting high relief
610 areas such as diapir crests where the tips of halokinetic folds expose continental beds (Fig.
611 15d). In contrast to the older minibasins, filled by the Karayün formation, linear minibasins
612 develop elongated at right angles to the regional shortening direction (Fig. 15d). Local
613 halokinetic sequences are mainly developed within the base of the shallow marine sequence.

614 Most of the minibasins present large stratigraphic wedges which can form “Heel/Toe”
615 geometries, where the marine succession thickens in a direction opposite to that of the early
616 Karayün wedges, highlighting the presence of a basal welding of the basin (Fig. 15d) (e.g.
617 Kluth and DuChene, 2009).

618 The preferential growth of salt walls and diapirs trending East-West is attributed to the
619 squeeze of preexisting evaporite walls at right angle to the regional N-S shortening which act
620 as thrust faults where minibasins developed. However, the presence of halokinetic wedges
621 along both East-West and North-South salt walls suggest that salt withdrawal related
622 deformation is still effective. Elongated minibasins seems to result from a combination of
623 thrust-top basin subsidence, i.e. piggy-back basin, related to salt walls and diapirs squeezing
624 during thrusting, and local salt withdrawal accomodation.

625 *6.5. Minibasin rotation and tilting (E)*

626 During deposition of the Benlikaya Fm in a peripheral position in the southern and northern
627 minibasin province, the coeval uplift of the central minibasin province is associated with
628 substantial tilting of the minibasins during thrust emergence (Fig. 15e). The squeezing of salt
629 structures leads to the formation of evaporite welds, which are developed both at right angles
630 and oblique to the regional shortening direction (Fig. 15e). As there is little to no evidence of
631 a shift of the minibasin depocenters toward the future salt weld, the shrinkage and welding of
632 the salt walls is attributed to the orogenic shortening transmitted to the minibasins province
633 (e.g. Rowan et al., 2012). At surface, allochthonous evaporite emerges due to strong
634 squeezing of salt structures (Fig. 15e). The fully developed welds in the minibasin province
635 are attributed to wrench welds whereby the layer-parallel translation of wall rock and the
636 associated dissolution enhance salt removal until complete evacuation of the remaining
637 evaporite (e.g. Hudec and Jackson, 2007; Wagner and Jackson, 2011). Strike-slip fault zones
638 affect both entire minibasins and their margins along welded contacts, the origin of which are

639 related to the various degrees of minibasin translation and rotation about vertical and
640 horizontal axes during orogenic shortening, see section below (Fig. 15e).

641

642 **7. DISCUSSION**

643

644 *7.1. Impact of shortening on minibasin behavior*

645 The domain of secondary minibasins records in the Sivas Basin the evolution from a basin
646 controlled by salt tectonics to a tectonically controlled basin. To analyze the relative
647 importance of these two main structural controls, several features have been identified as key
648 indicators, among them the size and shape of the minibasins, their stratal architecture and
649 their tilting and rotation.

650 We propose that the recognition and analyses of these markers can be used to
651 discriminate between a mainly salt-controlled and a mainly shortening-controlled system with
652 a range of possibilities in between (Fig. 16).

- 653 • For the salt dominated/controlled system, the minibasins are mainly sub-
654 circulars surrounded by large salt walls and diapirs. There is a high variation in
655 thickness within and between minibasins, and local halokinetic sequence
656 shapes and dimensions (both wedges and hooks structures) vary from one side
657 of the minibasin to the other (Fig. 16A).
- 658 • For the compressive dominated system, the minibasin shapes evolve from
659 subcircular to elongated (i.e. dominated by thrusting and thrust top basin
660 development) (Fig. 16B). The pre-existing minibasins record major tilting and

661 rotation about vertical axis, accommodated by strike slip fault zone along the
662 margins, large thrust faults at right angle to the regional shortening, rooted in
663 the salt walls and complete welding of salt structures are observed (Fig. 16C).

664 • Between these two end-members, the initial architecture of salt controlled
665 minibasins and the salt structures network are more and more affected by the
666 regional shortening through time and may be characterized by the progressive
667 development of halokinetic folds, megaflaps, allochthonous salt stocks
668 emplacements, and tilting of minibasin.

669 The effect of orogenic shortening on minibasin evolution is clearly dependent on the
670 available salt stock for minibasin accommodation (i.e. salt level thickness). The coupling of
671 the salt related minibasin deformation to the regional tectonic setting initiated when the salt
672 horizon thinned such that there was not enough to decouple deformation.

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674 *7.2. Impact of salt structures pattern on shortening style*

675 The previous sections present the rotation about vertical axes as well as the translation of
676 minibasins, accommodated by strike slip faults zone along minibasin edges during diapir
677 squeezing (see Fig. 15F). A similar situation is observed on passive margins with rotation of
678 blocks during sediment gravitational gliding/spreading, accommodated laterally by strike-slip
679 shear (e.g. Fort et al., 2004). In the case of the Angolan margin, rotation of block about
680 vertical axis started early and the cause of rotation is attributed to a differential sedimentary
681 load above salt during rafting of block (e.g. Fort et al., 2004). In our study, there is no clear
682 evidence of minibasin rotation about vertical axis during downbuilding of the minibasins (i.e.
683 depocenter migration toward salt weld). The gravity-driven processes (i.e. gliding and
684 spreading) seem to have minor effect, contrary to the regional shortening influence that is

685 preferentially accommodated by squeezing of salt structures (e.g. Kergaravat et al., 2016).
686 Given homogenous regional shortening, what is the origin of minibasins rotations about
687 vertical axes?

688 In map view, the structural pattern of the secondary minibasins changes from West to
689 East limited by the KTZ (Fig. 4). In the West, salt walls and welds with NE to NW directions
690 separated sub-circular minibasins and encapsulated minibasins, whereas in the east, sub-
691 parallel N70E salt walls separated dominantly linear minibasins. The KTZ, a major strike-slip
692 fault zones with sinistral motion is developed at minibasin margins, and evidences a variation
693 of minibasins lateral mobility (Fig. 16C). We suggest that in case of the Sivas Basin, the main
694 factor controlling the minibasin lateral mobility is the differences in width and orientation of
695 the pre-existing complex 3D structure of the evaporite wall network, compared to the regional
696 shortening direction (Fig. 16C). The various amount of minibasins lateral displacement
697 encourage the rotation about vertical axes of the minibasins (Fig. 16C). The minibasin
698 rotation is recorded by strike-slip fault zones located at minibasin margins and particularly
699 along salt structures that are at high angle to the regional shortening direction (i.e. the salt-
700 sediment contact between Arpayazi and Karayun minibasins).

701

702 *7.3. Origin of the minibasin tilts*

703 Considering the rotations about horizontal axes, or tilting, the rotation of the minibasins
704 appears systematically oriented toward the north (e.g. Emirhan and Karayün minibasins, Fig.
705 14). Tilting of minibasins up to 90° rotation suggests a significant amount of shortening.
706 However, part of the tilting may result from the downbuilding of the minibasin and
707 depotcenter migration due to basal salt flow associated with halokinetic wedging (e.g. Hudec
708 et al., 2009). This process is in particular evidenced by the important contrast between the

709 apparent high stratigraphic cumulated thicknesses (up to several kilometers) and the poor
710 maturity recorded in the rocks. Available maturity data suggest that the Karayun levels are
711 still immature to very low maturity, indicating a limited amount of minibasin burial (T_{max} of
712 430°C to 440°C , $\%R_o < 0.7$, i.e. less than 3km; (Huvaz, 2009 ; Erik et al., 2015)). This burial
713 is much lower than the recorded cumulative stratigraphic thickness, and this suggest that this
714 thickness may be only apparent and overestimating the real accommodation. Differential
715 downbuilding, such as Heel-Toe geometries, may explain this discrepancy, evidencing thus a
716 progressive rotation of the basins during their development. But such process cannot
717 generally explain complete 90° tilt of a minibasin, thus in case of the Sivas basin, several
718 processes are advocated to explain the tilting of minibasins (Fig. 17):

719 (1) The advance of the fold and thrust belt underneath the minibasins is accommodated by
720 the formation of thrust sheets (Fig. 3B). This development of subsalt, south verging
721 thrust sheets, resulted in the rise and the rotation of the minibasins located: (i) at
722 leading edge of the thrust sheet that pushes the minibasin against a welded minibasin
723 acting as a stopper, i.e. Ilkindi minibasin at front of tilted Emirhan minibasin or else
724 (ii) at the leading edge of the thrust sheet uplifting the minibasin along a backthrust
725 acting as a triangular zone (Figs. 3B and 17A).

726
727 (2) The development of the southern tectonic wedge to accommodate the regional
728 compression induces a tilt of the foreland toward the south (Fig. 3B) (see Kergaravat
729 et al., 2016). The subsalt tilting may induce the gliding of the minibasins toward the
730 center of the Wall and Basin domain (Fig. 17B). In a way similar to the toe of passive
731 margins, where the shortening domain develops in the distal part of the slope, thrust
732 fault passing through salt structure have transported minibasins against a welded
733 minibasin acting as a stopper (Fig. 17B) (e.g. Fort et al., 2004).

734

735 (3) The heterogeneity of the domain located below the canopy, including primary
736 minibasins and early salt feeders results in a pre-canopy basal topography. Formation
737 of early basal welds at the periphery of the minibasins domain induces a rotation
738 toward the thicker salt central domain (Fig. 17C). A similar process is described in the
739 Paradox Basin where the presence of an asymmetric basal weld induces a rotation of the
740 minibasin forming a 'Heel-Toe structure' (e.g. Kluth and DuChene, 2009).

741 Tilting of minibasins up to 90° have not been observed at the toe of passive margins
742 where gravity gliding and spreading is the main cause of shortening. We suggest that the
743 association of (1) depocenter migration, i.e. stratigraphic wedging due to basal salt escape,
744 and (2) formation of thrust sheets are the dominant process in the Sivas basin allowing for the
745 strong tilting of some minibasins.

746

747 **8. CONCLUSION**

748

749 The central Sivas basin provides a spectacular example of a minibasin province developed
750 above an evaporite canopy, and offers a rare opportunity to study the interaction between
751 regional shortening and halokinesis. We have shown that the Oligo-Miocene period is
752 characterized by an increasing number of shortening evidences, and a correlative decrease of
753 the local halokinesis imprint, within the minibasin province. The major results of the general
754 tectono-stratigraphic framework of the Sivas minibasin evolution are listed below.

- 755 • The initiation of the Sivas secondary minibasins is driven mostly by the salt-
756 induced local accommodation forming a polygonal network of salt structures
757 surrounding isolated, sub-circular to elliptical depocenters, with mainly local

758 composite halokinetic sequences developed all along the margins of the
759 minibasins.

760 • The relative abrupt increase of sediment deposition rate, compared to salt
761 withdrawal, is attributed to the advance of the orogenic wedge toward the
762 minibasin province. This period of tectonically controlled regional
763 accommodation, induced by flexural foreland accommodation, results in the burial
764 of the preexisting salt structures.

765 • Orogenic compression encourages a rejuvenation of salt structures marked by a
766 sharp increase in vertical diapiric flow, producing large post-depositional
767 halokinetic folds such as megaflap.

768 • The network of salt structures evolved from a polygonal to a linear pattern,
769 oriented at right angles to the regional shortening direction. Shortening leads to the
770 squeezing of salt structures forming welds, which developed both at right angle
771 and in oblique position compared to the regional shortening direction.

772 • The importance of composite halokinetic sequences decreases trough time, and
773 large stratigraphic wedges become the dominant salt-related structures.

774 • The orogenic shortening is clearly recorded during the end of the secondary
775 minibasin province evolution, associated to emergences of thrust faults and
776 squeezing of salt structures causing emplacement of the salt sheet. This period
777 seems to correspond when allochthonous salt became thinner and insufficient to
778 efficiently decouple surface deformation from the orogenic shortening.

779 • The pre-existing complex 3D structure of the evaporite wall network compared to
780 the regional shortening direction influences the lateral mobility of the minibasins
781 and the resultant structural style of the minibasin province. Minibasins are both

782 tilted and rotated about vertical axes in response to the formation of strike slip
783 fault zones.

784 The shortening has a major influence during the evolution of a minibasin province, the
785 importance of which increases with the expulsion of the salt.

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800

801

802 **10. FIGURE CAPTIONS**

803

804 **Fig. 1.** (A) Tectonic setting of Turkey, showing main continental blocks, Oligo-Miocene Sivas basin
805 deposits, outcrops of ophiolites, and ophiolitic mélanges belonging to the Tethyan realm and major
806 suture zones including the Izmir-Ankara-Erzincan suture zone (IAESZ), the Inner-Tauride suture zone
807 (ITSZ), the Bitlis-Zagros suture zone (BZSZ), and Oligocene-Miocene deposits of the Sivas Basin
808 after Okay (2006), Stampfli (2000) and Karaođlan (2013). (B) Map of the distribution of evaporite
809 outcrops at the Sivas Basin scale and Oligocene-Miocene deposits with main thrusts and back thrust
810 faults and folds axes, location of study area corresponding to geological map (Fig. 4A), after
811 Kergaravat (2016)

812

813 **Fig. 2.** Composite regional lithostratigraphic column showing depositional environments, formations,
814 average thicknesses of the various stratigraphic units in the central Sivas Basin and tectonic events of
815 the Central Sivas Basin (modified after Kurtman, 1973; Çiner et al., 2002; Ribes et al., 2015;
816 Kergaravat et al., 2016). Light grey box shows relevant stratigraphy to this study.

817
818 **Fig. 3.** (A) Geological map of the central Sivas Basin corresponding to the secondary minibasins
819 domain with position of cross sections and geological maps of minibasins margins (see Fig. 2 for
820 location), after Kergaravat (2016) and modified after Poisson (1996). (B) North-South cross section
821 through the center of the Sivas Basin based on seismic line and surface data showing, from south to
822 north the subsalt tectonic wedge of Paleocene-Eocene beneath the autochthonous evaporite, a large
823 asymmetric minibasin belonging to the first generation of minibasins, the second generation of Oligo-
824 Miocene minibasins above an evaporite canopy exposed in the central Sivas basin, and the flat
825 northern widespread evaporitic domain, after Kergaravat (2016).

826
827 **Fig. 4.** Map of structural elements and the distribution of evaporite outcrops at the WAB domain scale
828 (same location as Fig. 3A) showing traces of salt weld, ultramafic blocks and fold axis. The age of the
829 trace of thrusts, extensional and strike-slip faults, Hook (HS) and Wedge (WS) halokinetic sequences,
830 Tabular and Tapered composite halokinetic sequences in orange correspond to the deposition of the
831 Karayün Fm (Oligocene), in blue to the deposition of the Karacaören Fm (Late Oligocene-Early
832 Miocene) and in red to the deposition of the Benlikaya deposition (Middle-Late Miocene).

833
834 **Fig. 5.** (A) Detailed geological map of the tilted Emirhan minibasin surrounded by the Inceyol,
835 Ulukapı, Köy, Pinarka, Eğribuçak, Arpayazi and İlkindi minibasins with the location of the composite
836 halokinetic sequences, halokinetic folds, trace of unconformities, welds, strike-slip and syn-
837 sedimentary normal faults and the encased minibasins to the west (see Fig. 3A for location) and
838 location of fault kinematic sites; (B) Un-interpreted and interpreted view towards the NW of the
839 Emirhan weld characterized both by complete and incomplete weld with remnant gypsum that
840 represents a cusp at the halokinetic sequence boundary, defined as tapered CHS in the lower Karayün
841 strata of the İlkindi margin minibasin to the south which are affected by strike slip faults with dextral
842 motion connected to the salt weld (see Fig. 5A for location). (C) Interpreted satellite image of the
843 upper part of the Lower Member of the Karayün Fm showing a succession of Hook halokinetic
844 sequences with unconformities and axial traces forming a tabular composite halokinetic sequences
845 (CHS) along evaporite weld separating the Emirhan minibasin to the east and the Köy minibasin (see
846 Fig. 5A for location; Image courtesy of Google Earth).

847
848 **Fig. 6.** Detailed geological map of the tilted Arpayazi, Karayün and Eğribuçak minibasins showing
849 tapered CHS, wedge HS, halokinetic fold, trace of unconformities, megaflap, welds, strike-slip faults
850 and syn-sedimentary normal faults and location of fault kinematic measurements sites (see Fig. 3A for
851 location).

852
853 **Fig. 7.** (A) Geoeye satellite colour composite image of the east Karayün minibasin, where vertical to
854 overturned strata make the map view pattern roughly equivalent to a cross-section. Lower and Middle
855 Karayün members become progressively thinned and drape-folded along the edge of the diapir,
856 forming a large megaflap whose limb is overturned close the Akpınar minibasin (Fig. 6 for location).
857 (B) Geoeye satellite colour composite image of the limb of the Karayün megaflap and the western
858 margin of the Akpınar minibasin. (C) Geological map of the folded limb of the Karayün megaflap and
859 the western margin of the Akpınar minibasin showing Tapered CHS within the base of the Karacaören
860 Fm (see Fig. 7A for location).

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Fig. 8. (A) Geological map of the encapsulated Inceyol minibasin with location of the cross-section presented on Fig. 8C (see Fig. 5A for location). (B) Overview of an encapsulated minibasin, the Inceyol minibasin and associated salt diapir (see Fig. 8A for location). (C) Schematic cross-section passing through the encapsulated Inceyol minibasin showing two isolated tight synclines delimited by a thinned to squeezed salt diapir (see Fig. 5A for location).

Fig. 9. (A) View toward the east showing an erosive unconformity that separates the Selimiye Fm from the Karacaören Fm, with high-angle unconformities up to 90° between the marine Karacaören beds and the folded beds of the Selimiye Fm in the Celallı anticline (see Fig. 4, location b). (B) View toward the west showing the major marine unconformity characterized by high-angle discordance affecting the limb of the halokinetic drap-folding made of Karayün Fm and covered by onlap the Karacaören Fms with onlaps along eastern Emirhan minibasin margin (see Fig. 4 for location).

Fig. 10. (A) View toward the north-west showing showing the Tuzhisar Thrust (AT) hanging-wall formed by a large stratigraphic wedge with N-S trending beds thinning towards the south over a zone more than 2000m wide. (B) View toward the east showing the Ağılkaya Thrust (AT) hanging-wall formed by the Ağılkaya minibasin characterized by two synclines with an axis at right angle to the north-south regional shortening direction exposing dissymmetric halokinetic wedges on both flanks, with vertical to overturned strata thinning over a shorter distance on the northern flanks (see Fig. 4 for location).

Fig. 11. View toward the east of the Gölcük Thrust (GT) passing through salt walls associated with megaclasts of serpentinized peridotite, separating the Karayün and Akpınar minibasin to the NW from the Celallı anticline to the SE, showing growth syncline in footwall position making of Benlikaya Fm (see Fig. 4 for location).

Fig. 12. Stereo plot of strike-slip fault zone showing fault kinematics located along minibasin edges, see Fig. for location.

Fig. 13. (A) Geological map of the Çaygören and northern part of the Eğribuçak minibasins separated by the Çaygören wall, with locations around the salt sheet section within the Çaygören (see Fig. 3A for location). (B) Un-interpreted and interpreted view towards the NW of the Çaygören minibasin showing large wedge halokinetic sequence and interpreted section of the salt sheet showing recumbent folds extending over tens of meters with a north vergence (see Fig. 13A for location). (C) View of flat contact beneath the salt sheet showing concordant strata with the only evidence of normal faults within the Benlikaya strata and no evidence of shear faults (see Fig. 13 B for location). (D) View of ramp contact beneath the salt sheet characterized by a shear zone, up to 1 m wide, delimiting sandstone lenses and boudins displaying clockwise rotation, related to a dextral motion (see Fig. 13B for location).

Fig. 14. N-S cross-sections across the secondary minibasins (WAB domain) of the Sivas Basin based on the seismic interpretation from surface data and Fig. 3B (see location on Fig. 3A). The sections illustrate mainly the geometry of secondary minibasins, which are well constrained at the surface but poorly constrained at depth due to the presence of both allochthonous and autochthonous salt levels. Thus, several geometries, thicknesses and basement configurations are possible. Bedding attitudes are indicated by short black dashed lines and welds by pairs of dots.

909 **Fig. 15.** Tectono-stratigraphic diagrams of the Karayün, Karacaören and Benlikaya formations in the
910 studied mini-basins. (A) Depositional model illustrating minibasin structures and sedimentary pattern
911 of the Lower member of the Karayün formation. Minibasin margins are formed by local composite
912 halokinetic sequences developed along both East-West and North-South directions resulting in the
913 formation of a polygonal network of salt anticlines with pillows at their intersection surrounding
914 isolated, subcircular to elliptical basins. Structures and sediment distribution across this area are
915 influenced by the salt-induced local accommodation, generated by salt withdrawal (e.g. Ribes et al.,
916 2015; Ribes et al., 2016). (B) Depositional model illustrating minibasin structures and sedimentary
917 pattern of the Middle member of the Karayün Formation, showing a globally isopachous sedimentary
918 package covering both preexisting depocenter and salt structures. Small thickness variations reflect the
919 crests of salt structures showing the weak influence of halokinesis. At the top of preexisting salt
920 structures, syn-sedimentary normal faults cut this coarser sedimentary package, recording the local
921 influence of salt withdrawal, which is weak but still active. The relative abrupt increase of sedimentary
922 rate in the minibasin province is attributed to a regional uplift of the southern margin of the basin
923 (Kergaravat et al., 2016). (C) Depositional model illustrating minibasin structures and sedimentary
924 pattern of the Upper member of the Karayün Formation, showing large halokinetic folding and even
925 megaflaps development associated with rejuvenation of diapirs and formation of encapsulated
926 minibasins. Structures and sediment distribution across this area are influenced by the rejuvenation of
927 salt diapir leading to minibasin disconnection and important salt topography feeding encapsulated
928 minibasins. (D) Depositional model illustrating minibasin structures and sedimentary pattern of the
929 Karacaören Formation, showing linear depocenter with preferentially large stratigraphic wedges along
930 salt walls. Structures and sediment distribution across this area are influenced by the squeeze of
931 preexisting evaporite walls at right angle to the regional shortening direction. (E) Depositional model
932 illustrating minibasin structures and sedimentary pattern of the Benlikaya Formation, showing the
933 squeezing of salt structure leading to the formation of thrust faults passing through preexisting salt
934 walls, allochthonous salt and salt weld, which are developed both at right angles and oblique to the
935 regional shortening direction. Structures and sediment distribution across this area are influenced by
936 the regional shortening associated with the squeeze of the salt structures and the tilting of minibasins
937 in the central area.

938 **Fig. 16.** Conceptual models of minibasin province illustrating stratal geometries and salt structures
939 pattern showing the influence of shortening and salt thickness during sinking of minibasin, diagrams a
940 and b, and on pre-existing minibasins province with polygonal and linear salt structures, diagrams c,
941 based on interpretation of the Sivas minibasins.

942 **Fig. 17.** Synoptic models illustrating the possible origin of the Sivas minibasin tilting: (a) The advance
943 of the fold and thrust belt underneath the minibasins is accommodated by the formation of thrust
944 sheets; (b) The subsalt tilting may induce the gliding of the minibasins toward the center of minibasin
945 area; (c) The heterogeneity of the domain located below the salt canopy, including primary minibasins
946 and early salt feeders results in a pre-canopy basal topography.

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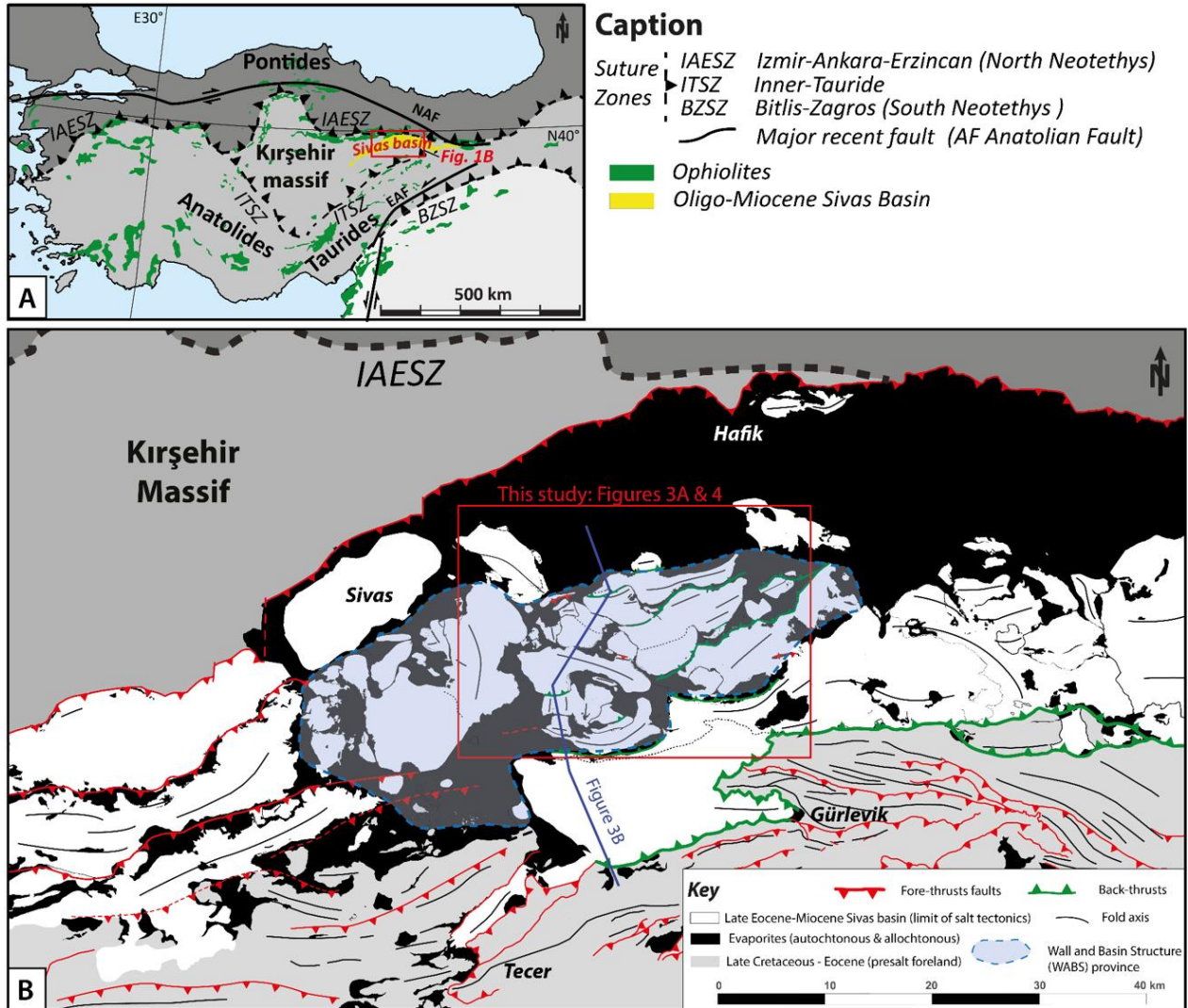


Fig. 1

| Age | Formation | Lithology | Depositional environment | Thickness (meters) | Tectonics event | | | |
|--|---|--|---|---|----------------------------|----------------------|----------------------|------------------------|
| | | | | | S | Salt tectonics | N | S Regional tectonics N |
| Plio. 3.3 | Incesu & Merakom Fm. | | Lacustrine and fluvial | | | | | North Anatolian Fault |
| | Miocene Lang. Serrava. Burd. | Benlikaya Fm. | Unit2: Playa-lake | 500 | Tilting of 2nd mini-basins | 2nd minibasins | Fold and Thrust Belt | Arabian collision |
| | | | Unit1: Alluvial fan and fluvial braided | 1000 | | | | |
| | | | Allocthonous evaporite | | | | | |
| | 23.8 | Karacaören Fm. | Shallow marine Mixed deltaic and shallow-marine carbonate, delta plain and restricted coastal lagoon | 1000 | 2nd minibasins | Fold and Thrust Belt | Arabian collision | |
| | | | | 2500 | | | | |
| | Oligocene Chatthian Rupelian | Hafik Fm. | Allocthonous evaporite | | Canopy | Arabian collision | | |
| | | | | Upper Member: Fluvio-saline lacustrine | | | 1000 | |
| | | Karayün Fm. | Middle Member: Highly amalgamated fluvial braided | 2400 | | | | |
| | | | Lower Member: Playa-lake with fluvial intercalations | | | | | |
| 33.7 | | Selimiye Fm. | Allocthonous evaporite | | Canopy | | 1st minibasins | |
| Eocene Lutetian Ypresian | Tuzhisar Fm. | Sabkha-platform evaporite | | Evaporitic deposition autochthonous level | Foreland | | | |
| | | | | | | | | |
| | Kösedag Fm. | Shallow marine carbonates platform, sandstones and andesites | S | 1500 | | Foreland | | |
| | | | | 3000 | | | | |
| | Bözbel Fm. | Deep-water turbidites with volcanoclastics & olistostromes | | | | Foreland | | |
| Bahçecik Fm. | Shallow marine conglomeratic fan delta | 300 | 600 | | | | | |
| Paleo. 54.8 | Gürlevik Fm. | Shallow marine carbonate platform | 1000 | | Foreland | | | |
| | Teçer Fm. | Shallow marine carbonate platform | 1500 | | | | | |
| Late Cretaceous | Obducted North Neotethys & Inner-Tauride ophiolites | Ophiolite mélanges & nappes | | | Obduction | | | |
| Basement: Kırşehir and Taurides metamorphic rocks | | | | | | | | |
| Non-deposition outside withdrawal minibasins | | | | | | | | |

Fig. 2

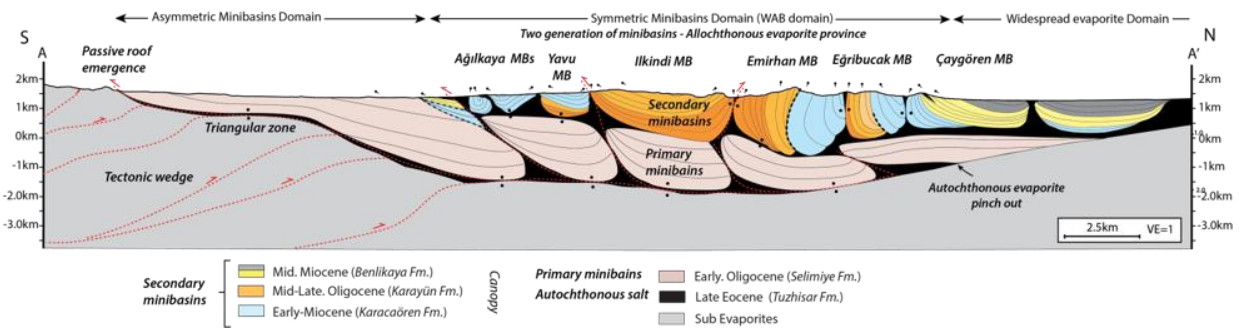
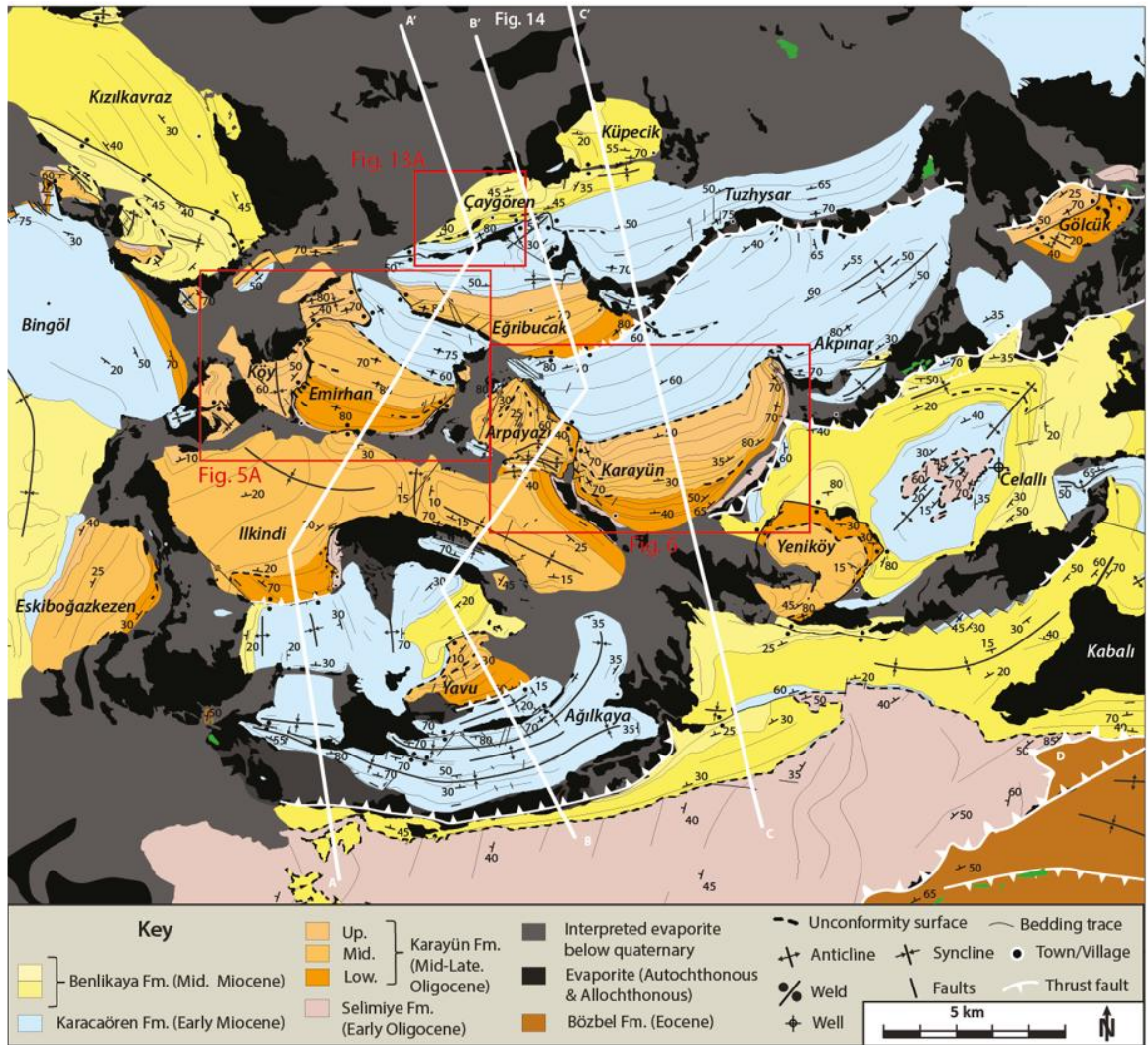


Fig. 3

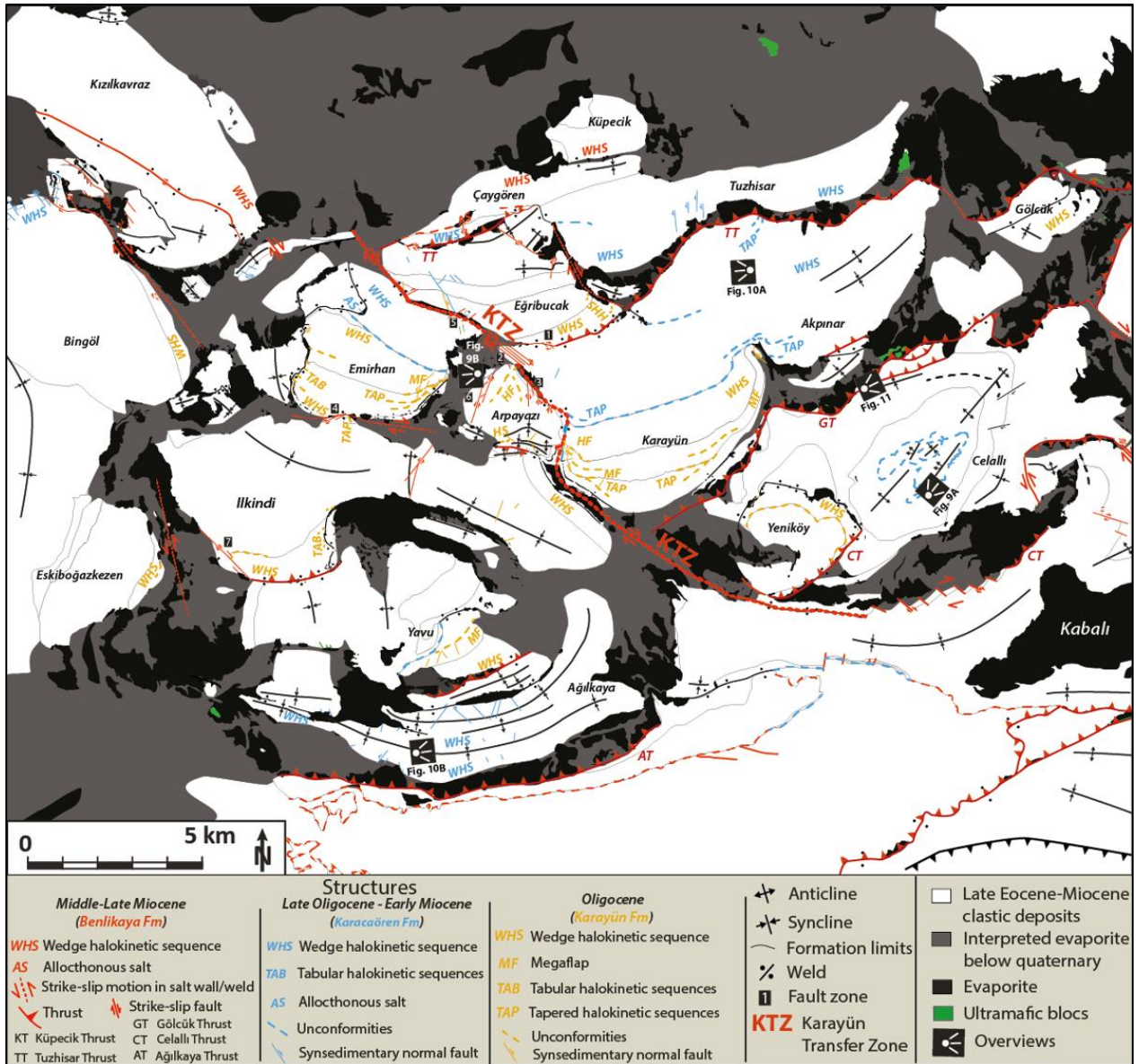


Fig. 4

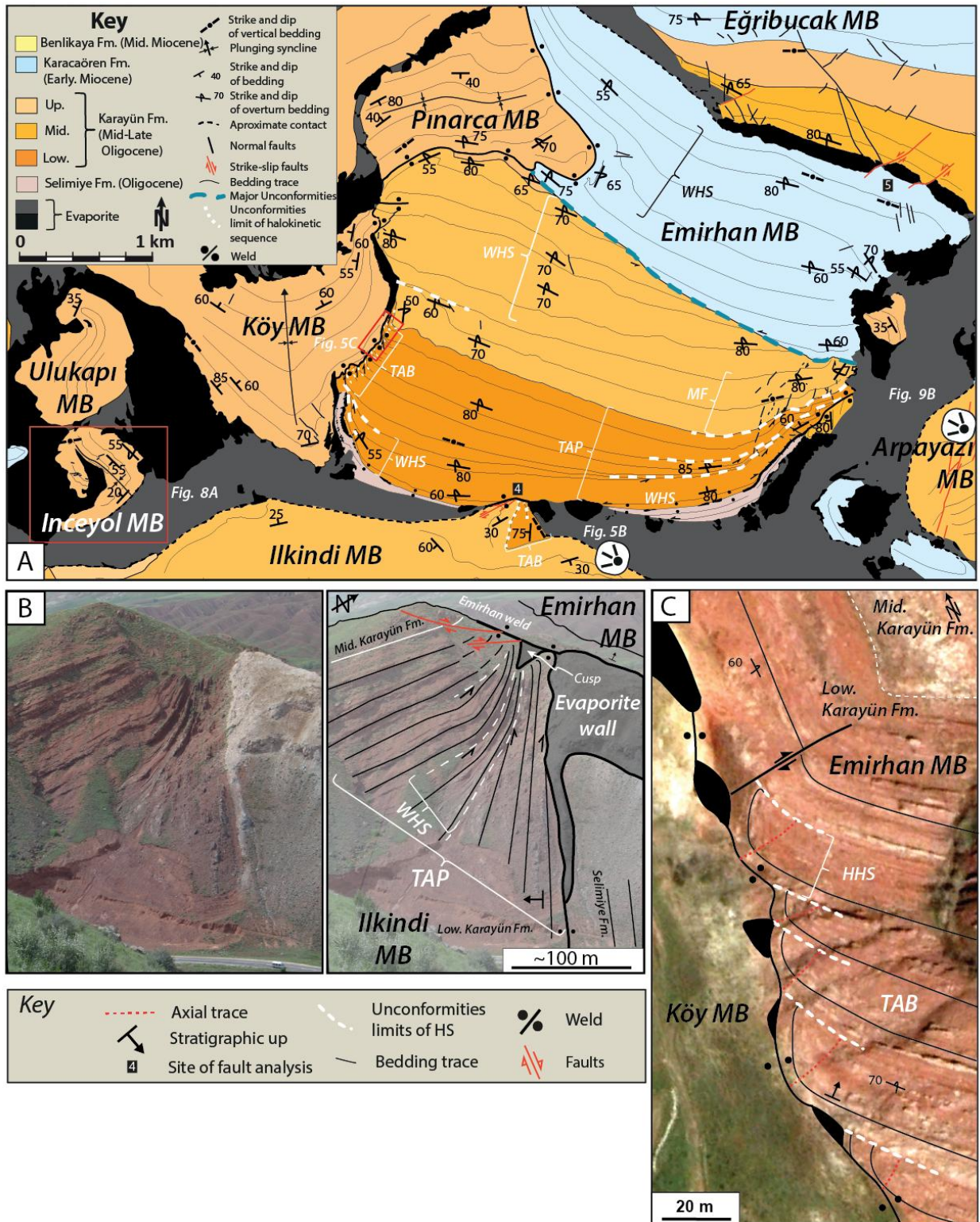


Fig. 5

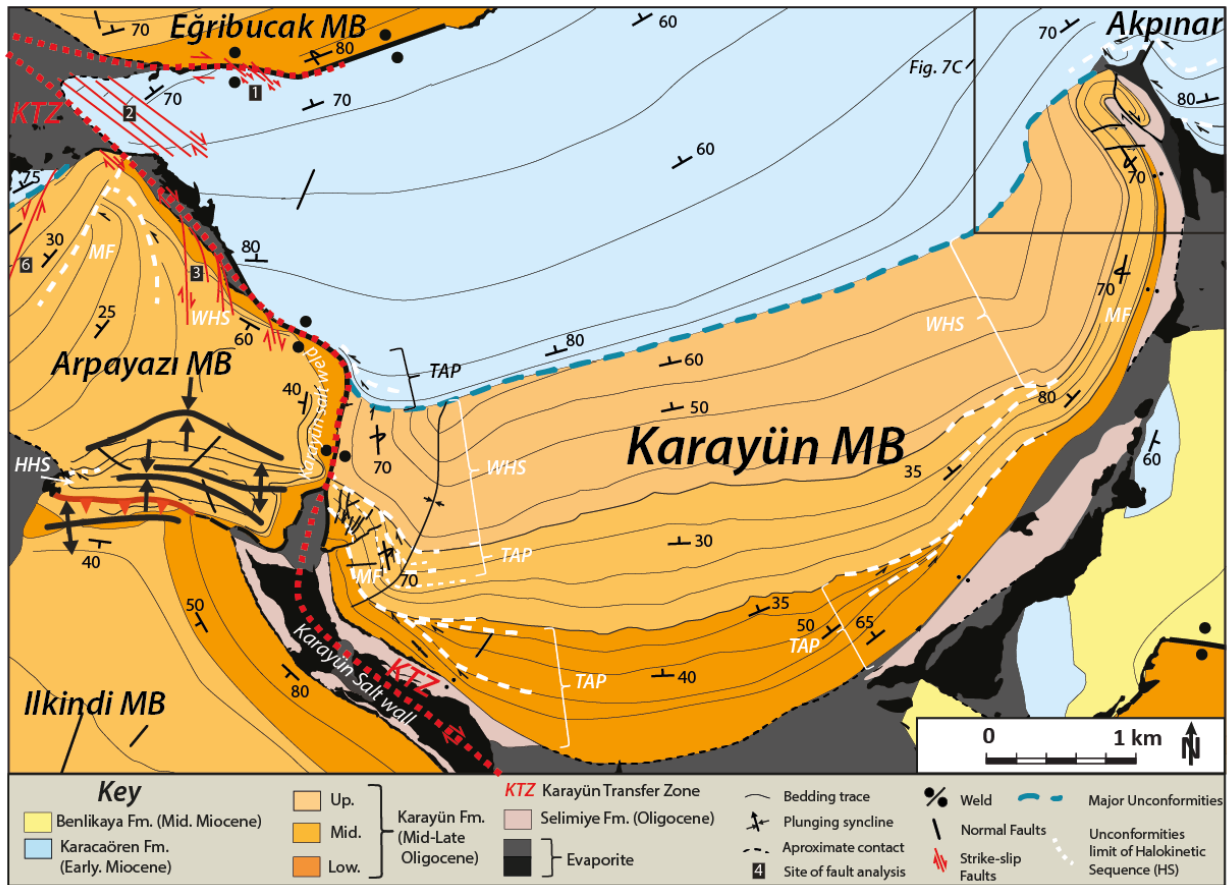


Fig. 6

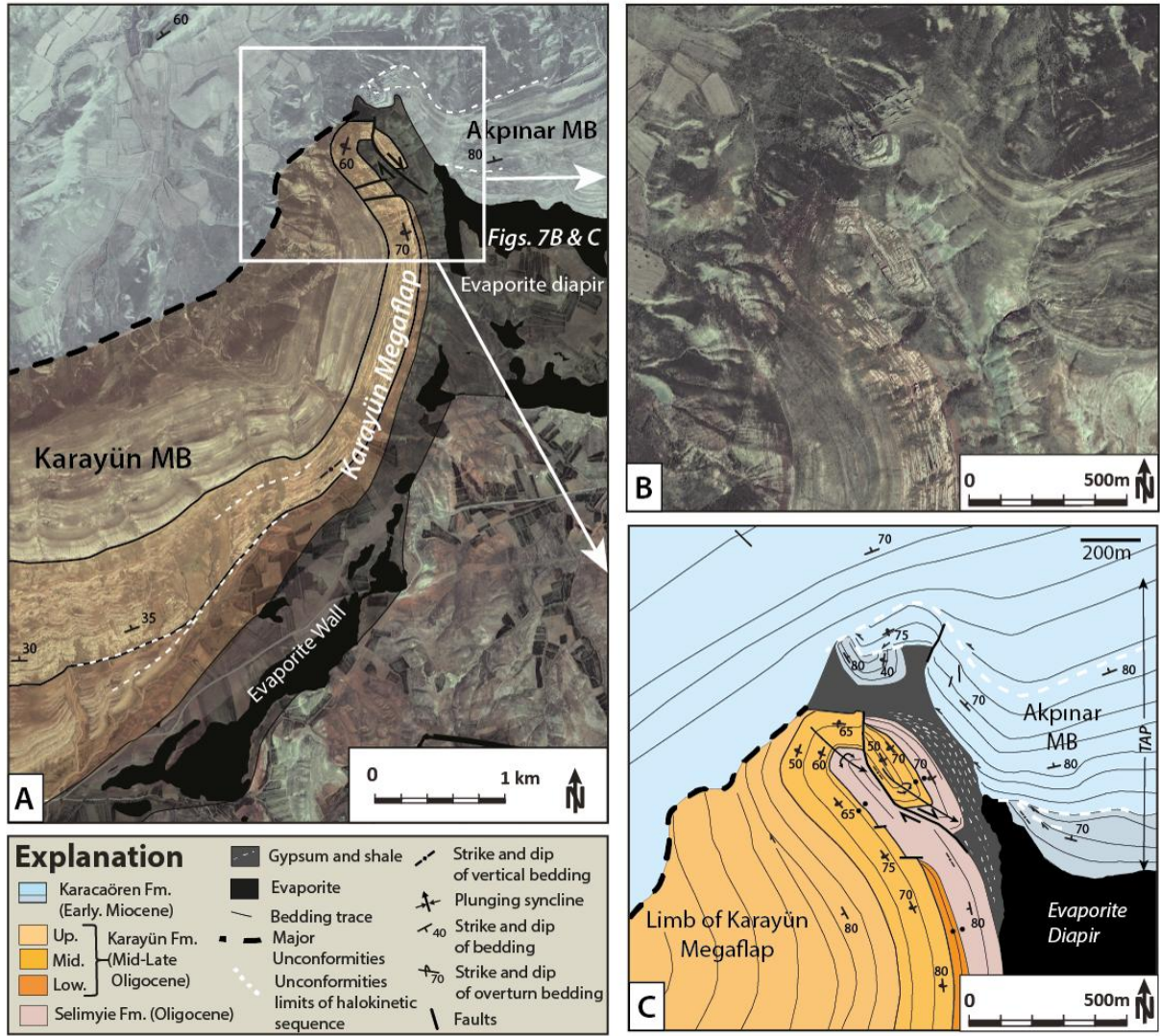


Fig. 7

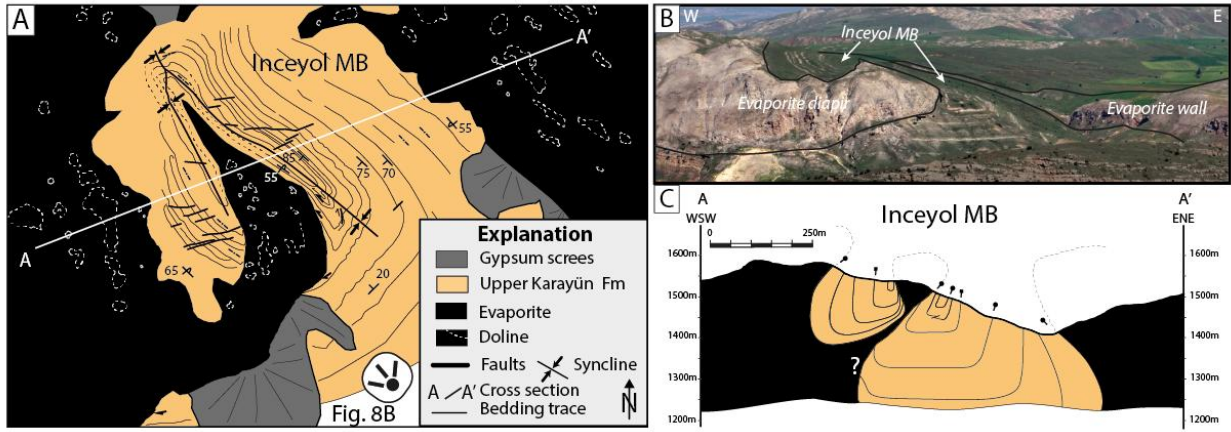


Fig. 8

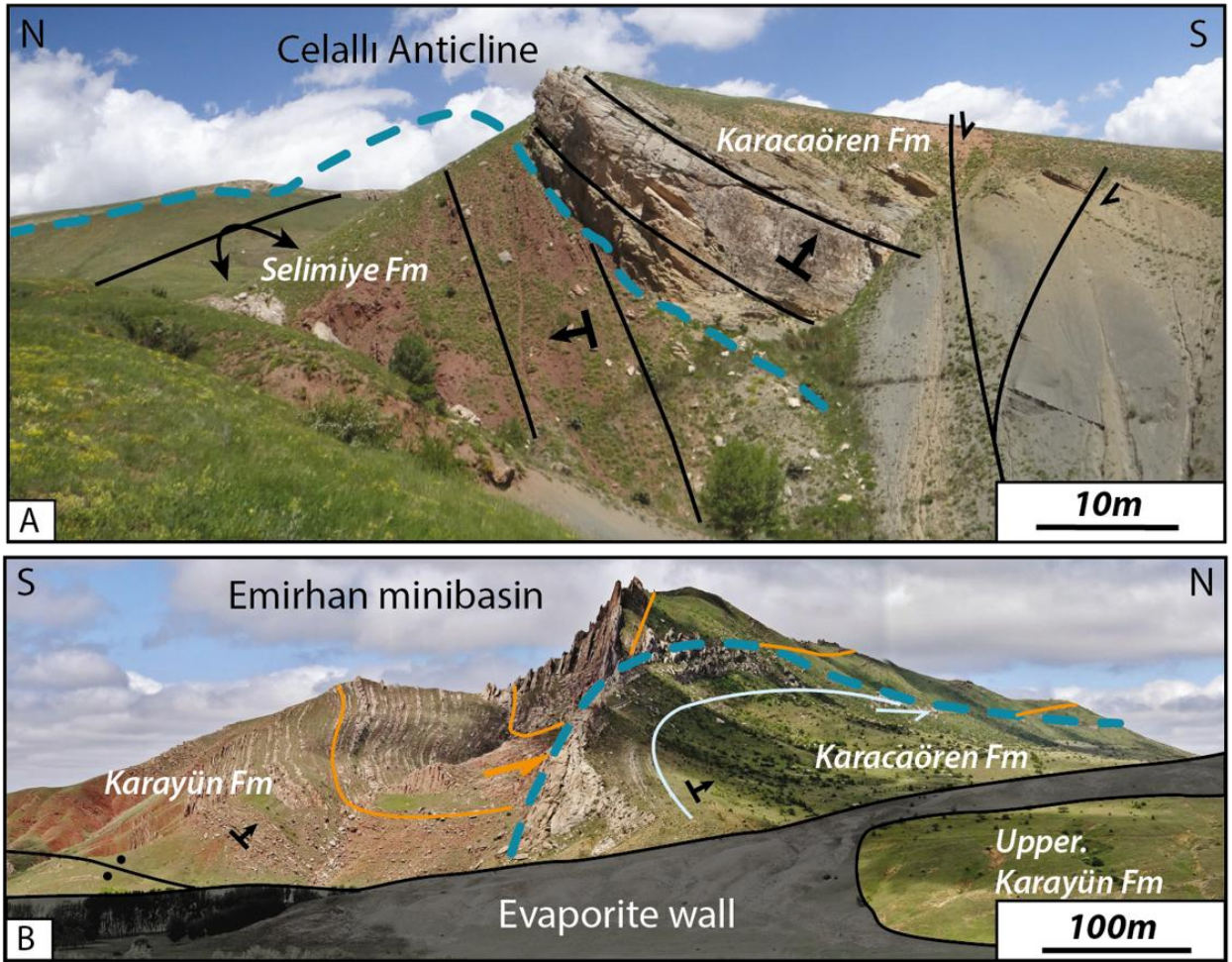


Fig. 9

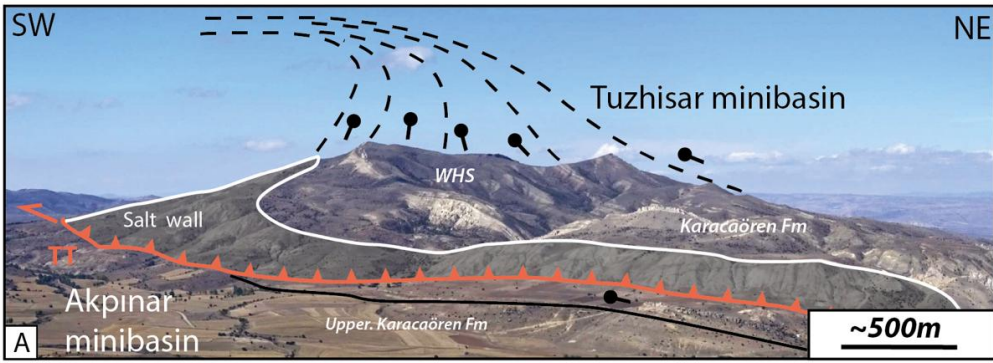


Fig. 10

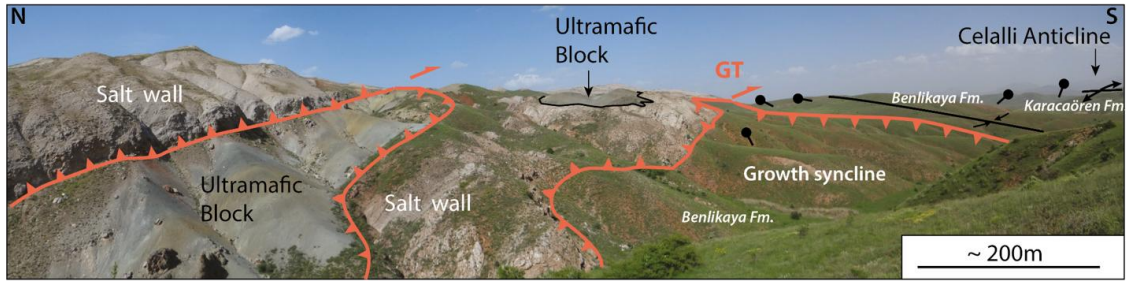


Fig. 11

Stereo plot in Geographic position of Strike-slip fault zone

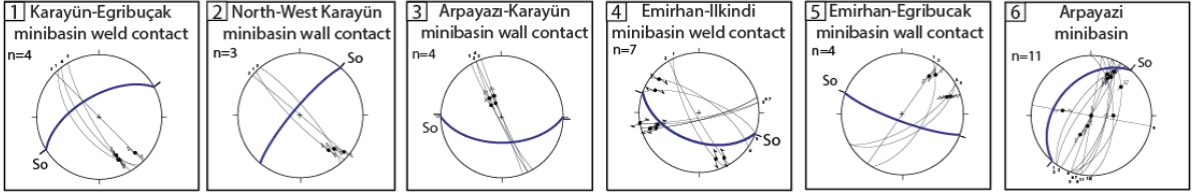


Fig. 12

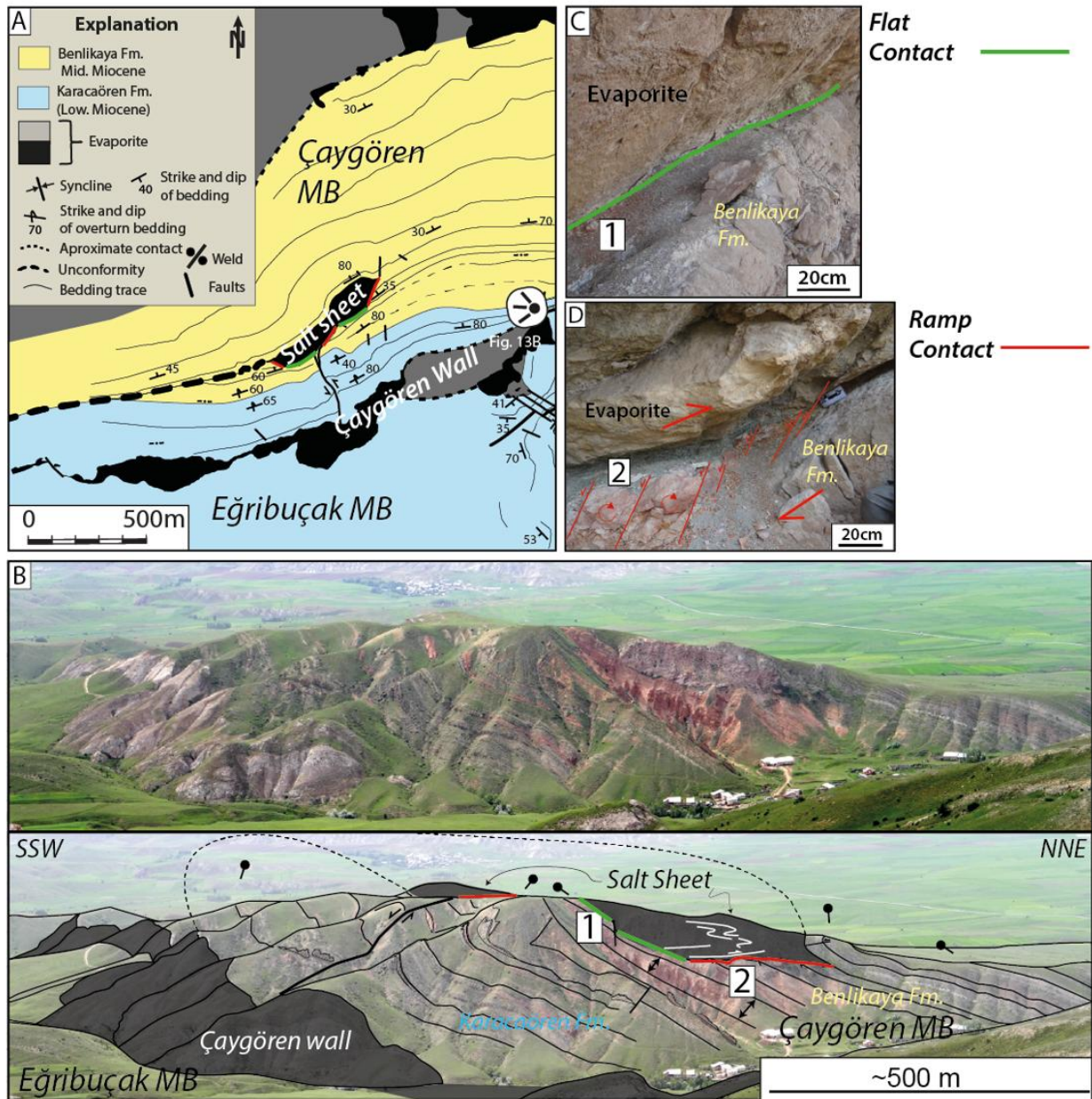


Fig. 13

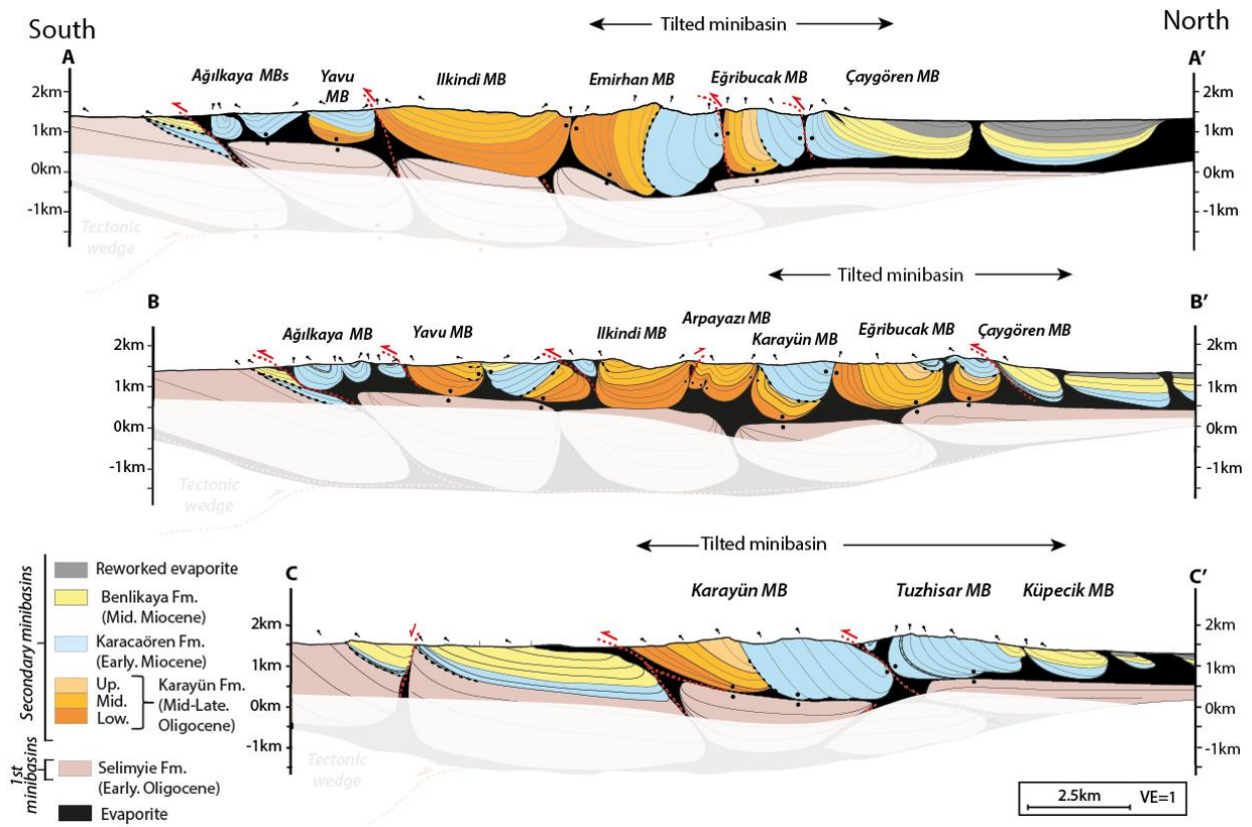
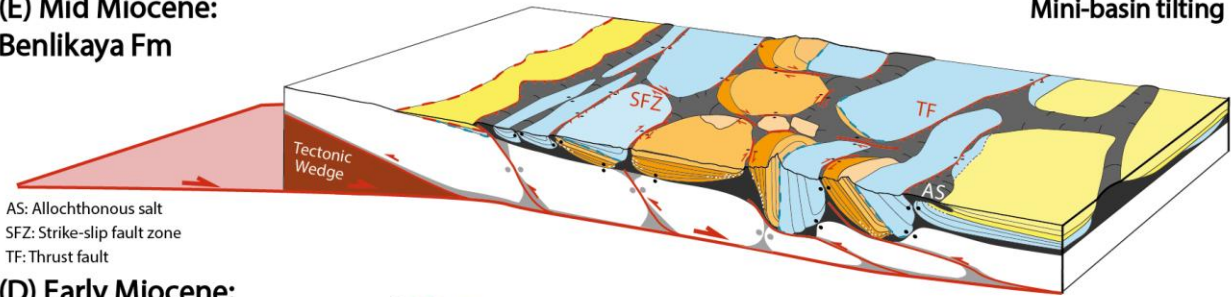


Fig. 14

(E) Mid Miocene:
Benlikaya Fm

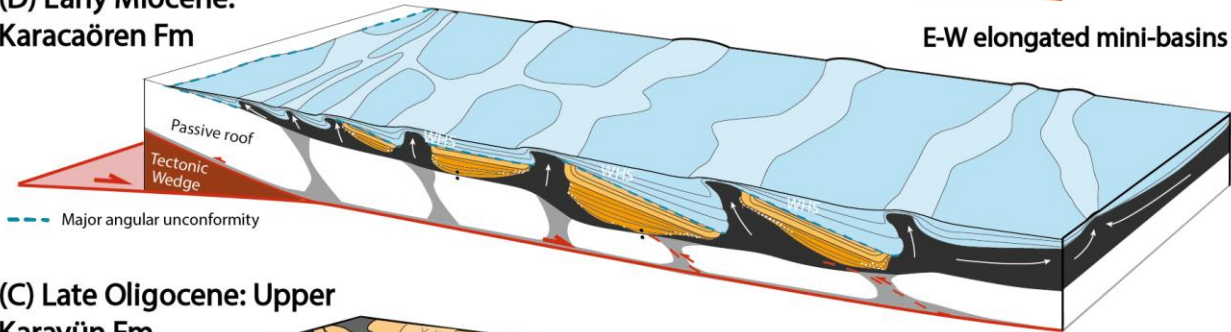
Mini-basin tilting



AS: Allochthonous salt
SFZ: Strike-slip fault zone
TF: Thrust fault

(D) Early Miocene:
Karacaören Fm

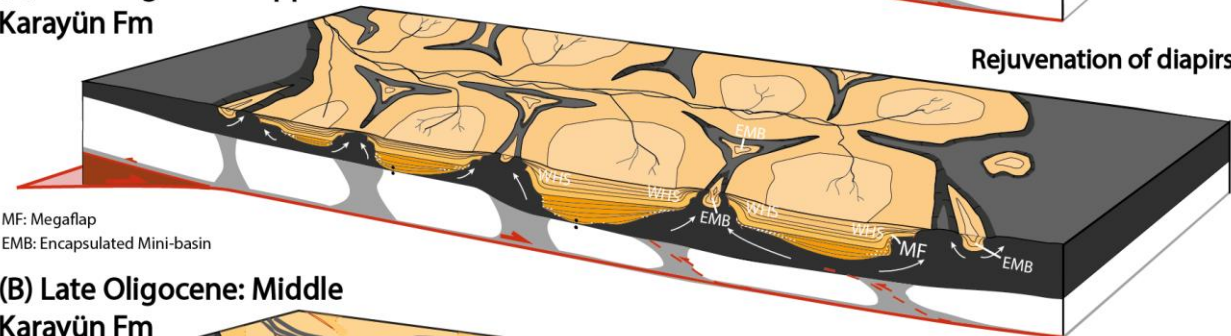
E-W elongated mini-basins



--- Major angular unconformity

(C) Late Oligocene: Upper
Karayün Fm

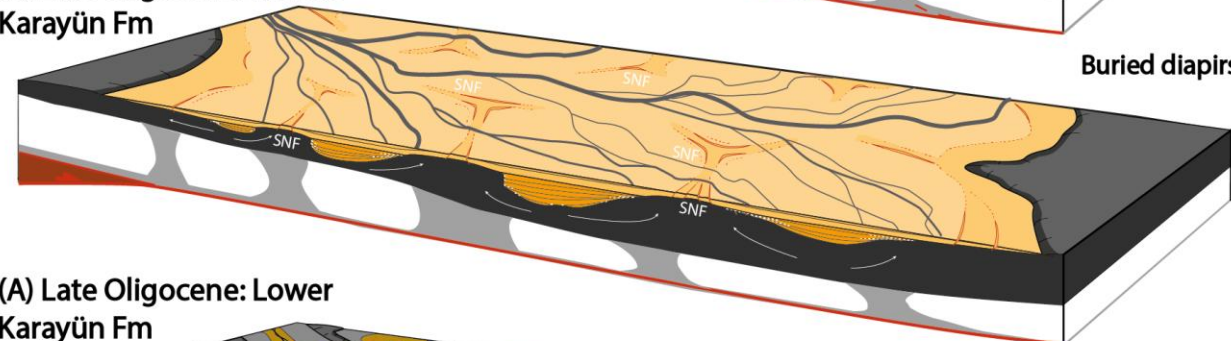
Rejuvenation of diapirs



MF: Megaflap
EMB: Encapsulated Mini-basin

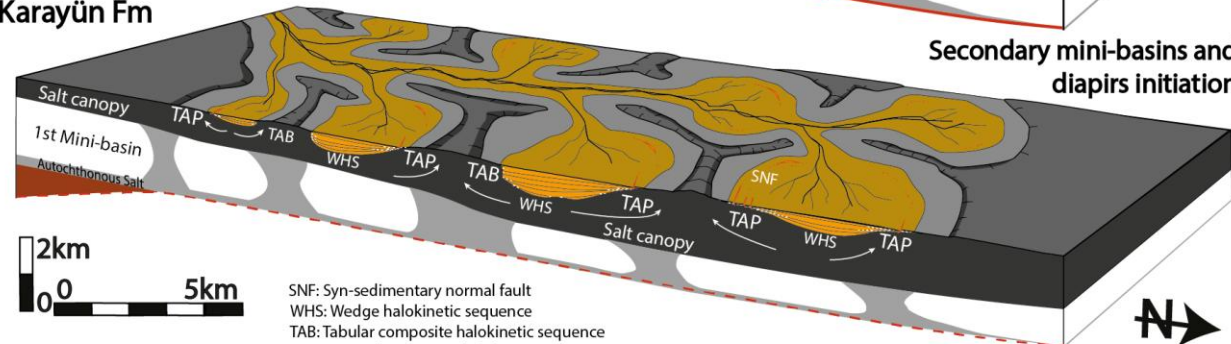
(B) Late Oligocene: Middle
Karayün Fm

Buried diapirs



(A) Late Oligocene: Lower
Karayün Fm

Secondary mini-basins and
diapirs initiation



SNF: Syn-sedimentary normal fault
WHS: Wedge halokinetic sequence
TAB: Tabular composite halokinetic sequence
TAP: Tapered composite halokinetic sequence



Fig. 15

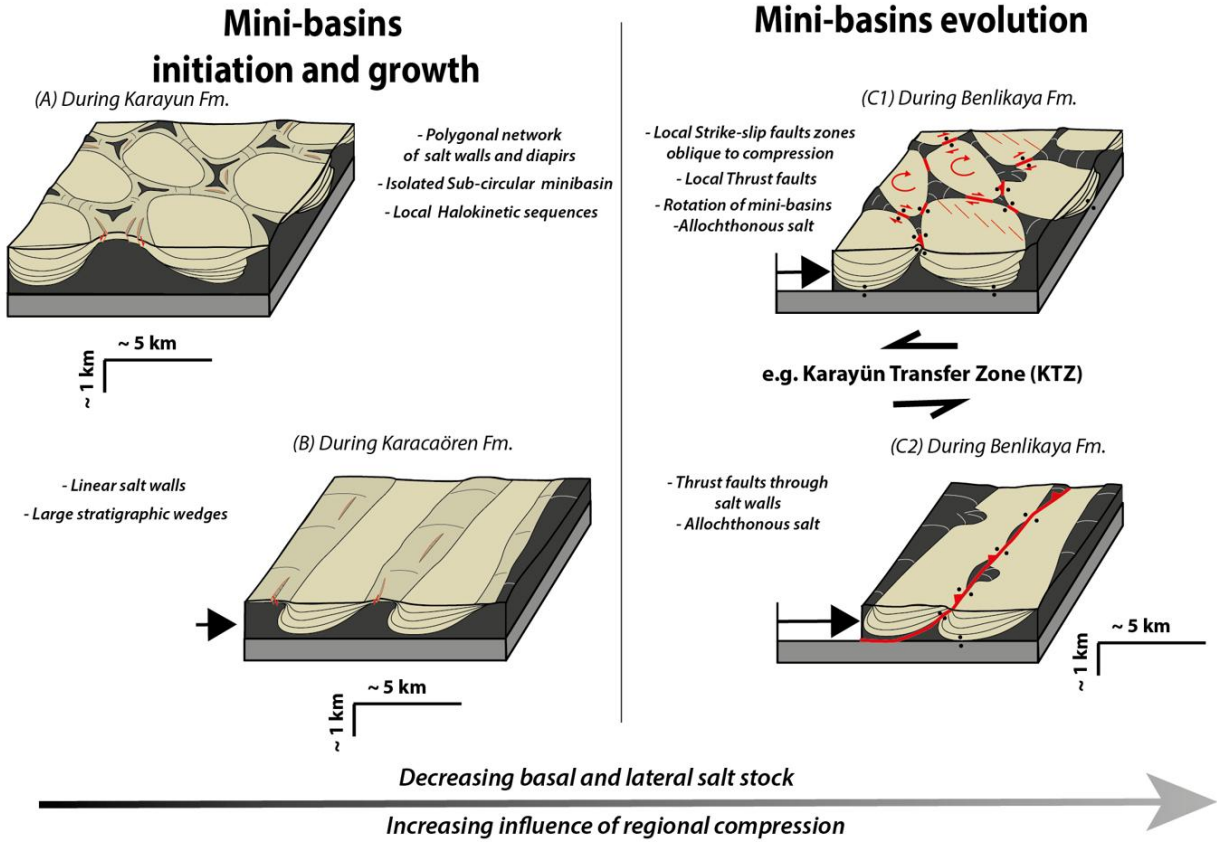
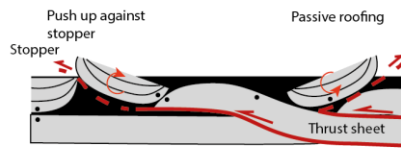


Fig. 16

Tectonic process responsible
for rotation of Sivas mini-basins

(A) Underneath thrust sheet

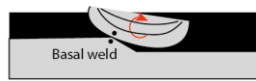


(B) Gliding against stopper



(e.g. Angola, Fort et al., 2004)

(C) Subsalt heterogeneity



(e.g. Paradox Basin, Kluth & Duchene, 2009)

Fig. 17