Effect of Diapir Growth on Synkinematic Deepwater Sedimentation: The Bakio Diapir (Basque-Cantabrian Basin, Northern Spain)*

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Abstract

The Bakio Diapir (Basque-Cantabrian Basin) is an outcropping salt structure flanked by turbidites. Its structural and sedimentological features make it an interesting exposed analog for deepwater plays in the Gulf of Mexico and other passive margins. The studied dataset includes hundreds of stations with structural data, stratigraphic sections, and a detailed geological map. The data were acquired by conventional field techniques, combined with more innovative ones, such as mapping on photorealistic digital terrain models, analysis of airborne LIDAR data, and multiview 3D reconstruction. Surface data have been complemented by subsurface 2D seismic data. The Bakio Diapir is a NNE-elongated salt structure developed during Lower Cretaceous rifting related to the Bay of Biscay opening and was subsequently reactivated during the Pyrenean contractional deformation (Upper Cretaceous-Miocene). The diapir (comprising Upper Triassic evaporites, mudstones and basic subvolcanic rocks) is flanked by synkinematic deepwater strata showing growth geometries characteristic of tapered composite halokinetic sequences. The deposits are made up of a lower carbonate unit and an upper siliciclastic unit bounded by a sharp contact, a facies change thought to be related to regional basin-scale processes. A comparison of the two exposed flanks of the diapir reveals remarkable differences in terms of dominant facies and trends. In the SE, the carbonate unit is fining-upwards and is dominated by a limestone-breccia facies, whereas in the NW it exhibits an overall coarsening-upwards trend dominated by a fine-grained facies. The siliciclastic unit is coarsening-upwards in the SE and fining-upwards in the NW. It is coarser-grained and more erosional in the NW than in the SE, with erosional channels and abundant debrites in the NW and deposits from unconfined flows and shallow channels in the SE. The observed differences in near-diapir facies on either flank are probably related to differences in salt deformation. Factors that may have contributed include: variable thickness of the diapir roof; the height and width of topographic relief over the two diapir flanks; the dip of the salt-sediment interface (outwardly dipping or flaring); and the amount and rate of deep salt evacuation beneath the two minibasins.

Introduction

The northern margin of the Basque-Cantabrian Basin is characterized by the presence of thick Cretaceous to Paleocene turbiditic successions deformed by large WNW-trending folds locally pierced by salt diapirs (Soler et al., 1981; Cuevas and Tubia, 1985; Cámara, 1997; Gómez et al., 2002). One of these is the Bakio Diapir, which has well exposed flanking turbidites that record halokinetic deformation and its response in the neighboring sediments. Whereas models of the interaction between diapiric rise and associated growth sediments are based on shallow-water or subaerial outcrops in Mexico, Australia and Utah (Giles and Lawton, 2002; Rowan et al., 2003; Giles and Rowan 2012), the Bakio Diapir provides an interesting exposed analog for deepwater equivalents in the Gulf of Mexico and other passive margins.

The objective of this work is to analyze the growth strata related to the rise of an exposed deepwater diapir and to characterize the resulting halokinetic sequences. To achieve this goal, our study includes a dataset consisting of hundreds of stations with structural data, stratigraphic sections, and a detailed geological map. These data were acquired on several field campaigns using conventional techniques combined with more innovative ones, such as analysis of airborne LIDAR data, mapping on photorealistic digital terrain models, and multiview 3D reconstruction (virtual outcrops). Surface data have been complemented by subsurface 2D seismic data.

Geological Setting

The Basque-Cantabrian Basin (Figure 1), located along the northern margin of Iberia, has a polyphase deformational history characterized by Mesozoic extension related to the opening of the North Atlantic Ocean (Le Pichon et al., 1971; Ziegler, 1988) followed by an inversion episode as a consequence of the collision of Iberian and Eurasian plates during the Pyrenean orogeny (latest Cretaceous to middle Miocene). The extensional episode included two rifting episodes (Early Triassic and Late Jurassic to middle Cretaceous in age). During the second episode the basin was filled by a 12.5 km thick succession of Upper Jurassic-Cretaceous carbonate and siliciclastic sediments overlying the Upper Triassic (Keuper) evaporites. WNW-ESE-trending Early Cretaceous – Santonian salt diapirs of Upper Triassic evaporites pierced the thin overburden at both margins of the basin (Brinkmann et al., 1967; Serrano and Martínez del Olmo, 1990).

With the drifting of the Afro-Iberian plates towards the north against Eurasia since the late Santonian, the Mesozoic extensional basins were inverted and then incorporated into the Pyrenean orogen. During this contractional episode, Mesozoic salt structures of the Basque-Cantabrian Basin were squeezed in different degrees and later transported passively in the hangingwall of the main thrusts detached on the Upper Triassic evaporites. The structures of the northern Pyrenean wedge are part of the Basque Arc (Feuillee and Rat, 1971), which is composed of the North-Biscay Anticlinorium, the Biscay Synclinorium, and the Bilbao Anticlinorium (Figure 1). The Bakio Diapir is located in to the North-Biscay Anticlinorium, near the northern front of the Pyrenees (Figure 1).

The Bakio Diapir

The Bakio Diapir is a NNE-elongated salt structure located in the southern limb of the North-Biscay Anticlinorium (Figure 1). The diapir (comprising Upper Triassic evaporites, mudstones and basic subvolcanic rocks) is flanked by Aptian-Albian synkinematic deepwater strata showing growth geometries characteristic of tapered composite halokinetic sequences (Figure 2) (Giles and Rowan, 2012). A lower carbonate unit and an upper siliciclastic unit are separated by a sharp contact; the facies change is thought to be related to regional basin-scale processes. Remarkable differences exist between the two exposed flanks of the diapir in terms of dominant facies and trends.

Whereas in the SE, the carbonate unit fines upwards and is dominated by a limestone-breccia facies, the NW exhibits an overall coarsening-upwards trend dominated by fine-grained facies. In contrast, the siliciclastic unit coarsens upwards in the SE and fines upwards in the NW. It is coarser-grained and more erosional in the NW than in the SE, with erosional channels and abundant debrites in the NW and deposits from unconfined flows and shallow channels in the SE.

In the western outcrops near the diapir, Aptian marls and marly limestones, as well as lower Albian breccias, are drape-folded with bed rotation to vertical and overturned (Figure 2). They show an internal deformation including conjugate sets of tilted extensional faults oblique to the diapir. Farther away from the diapir, the internal deformation of Albian breccias, turbidites, and overlying channels of siliceous conglomerates disappear and bedding dips decrease to 30^{o}. These units are truncated by a high-angle major halokinetic unconformity close to the diapir edge (Figure 2). Above the unconformity, the dip of onlapping middle-upper Albian deepwater turbidites decreases to 15^{o}. In contrast, equivalent successions on the eastern flank of the diapir are characterized by overturned Aptian marls and marly limestones of a marine platform environment that include some thin carbonate breccias and up to 500 m of resedimented carbonate breccias (lower Albian) deposited in a talus environment (García-Mondejar and Robador, 1986). Above this, onlapping middle Albian turbidites consist of interchannel turbiditic facies with some carbonate platform debrites deposited on a slope apron (García-Mondejar and Robador, 1986). Sedimentological studies of this middle-upper succession (Bravo and Robles, 1991) show that its evolution was controlled by the development of paleohighs over diapirs.

Discussion

Field and seismic observations show that strata linked to the rise of the Bakio Diapir and its related unconformities form at least three wedge halokinetic sequences. Strata within these wedges converge and thin towards the diapir over a distance of 500-600 m. Stacking of these wedges creates a tapered composite halokinetic sequence, as in the models proposed by Giles and Rowan (2012).

The geometry of the composite halokinetic sequence studied in this work is similar to the tapered examples described adjacent to other diapirs exposed in Mexico, Australia, and Utah (Giles and Rowan, 2012). In these examples, the thickness of the roof controls the width and style of the drape-fold, with tapered composite halokinetic sequences developing when there is a high ratio of sediment-accumulation rate to diapir-rise rate, and thus a thick roof (Rowan et al., 2003). Moreover, debrites are rare and the bounding unconformities form due to local erosive processes (Giles and Rowan, 2012).

However, the Bakio Diapir shows several differences from published models. First, the thick roof was related to a preexisting carbonate platform developed over the diapir rather than relatively rapid ongoing sedimentation. Second, the relief maintained by this roof remained high, supplying the interbeded debrites into the marls and turbidites of the halokinetic sequences and creating a wide zone of folding despite the slow deposition. Third, the uppermost unconformity was not related to the kinematics of the diapir and an increasing ratio of sediment-accumulation rate vs. diapir-rise rate, but instead had a regional sedimentological origin related to the turbiditic processes.

The field studies suggest that the observed differences in near-diapir facies on either flank are probably related to differences in salt deformation. Several factors that may have contributed to this include variable thickness of the diapir roof, the height and width of the topographic relief over the two diapir flanks, the dip of the salt-sediment interface (outwardly dipping or flaring), and the amount and rate of deep salt evacuation around the diapir.

In summary, the studied diapir is flanked by a tapered composite halokinetic sequence that formed due to drape folding, as proposed by the published models. However, its origin is not related to a high ratio of sediment-accumulation rate to diapir-rise rate, but to the presence of a thick preexisting roof related to the development of a carbonate platform over the diapir.

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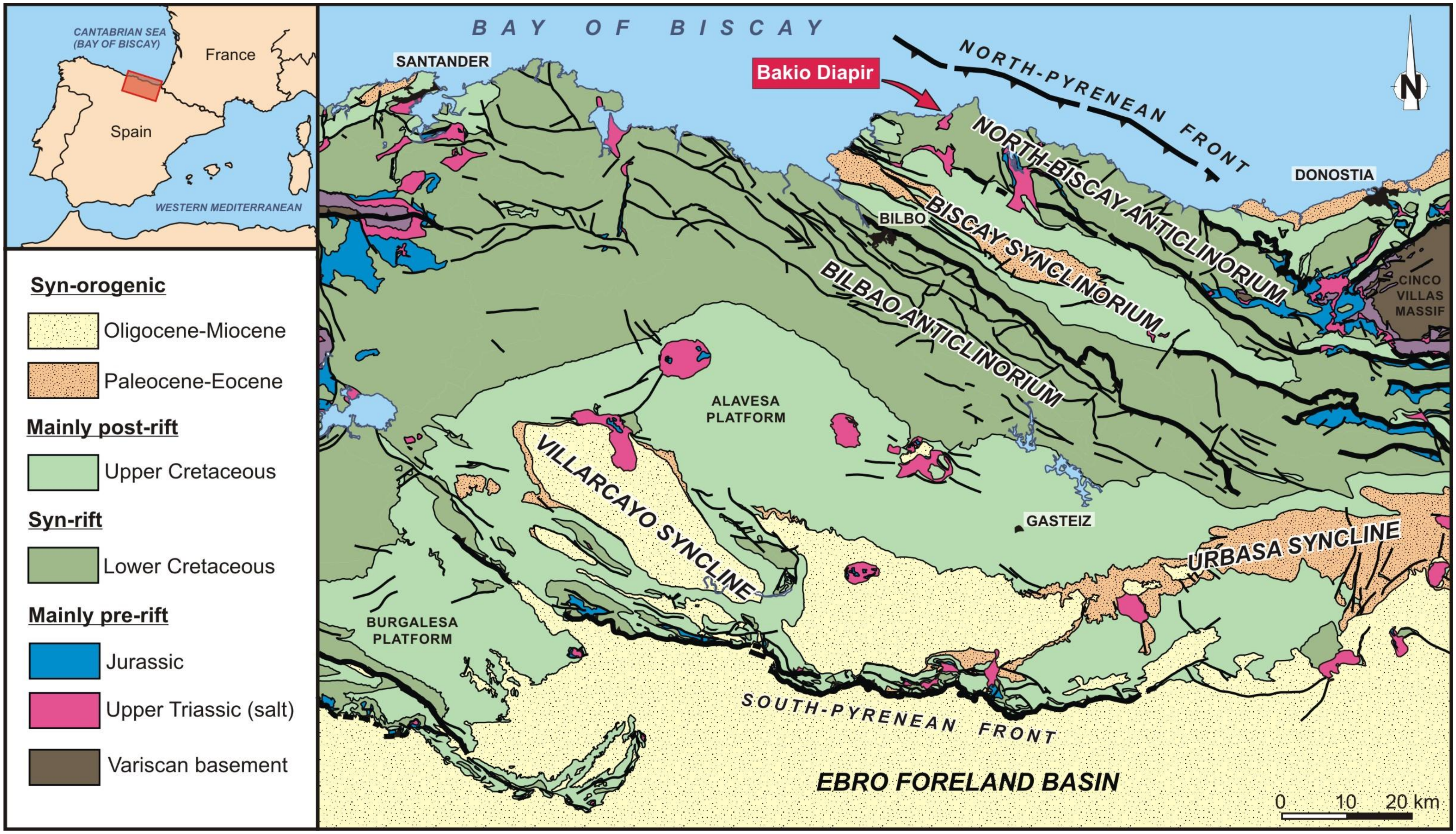

Figure 1. Location of the studied area and simplified geological map of the Basque Pyrenees with the location of the main structures that forms the Basque Arch. The Bakio Diapir is noted with a red rectangle.

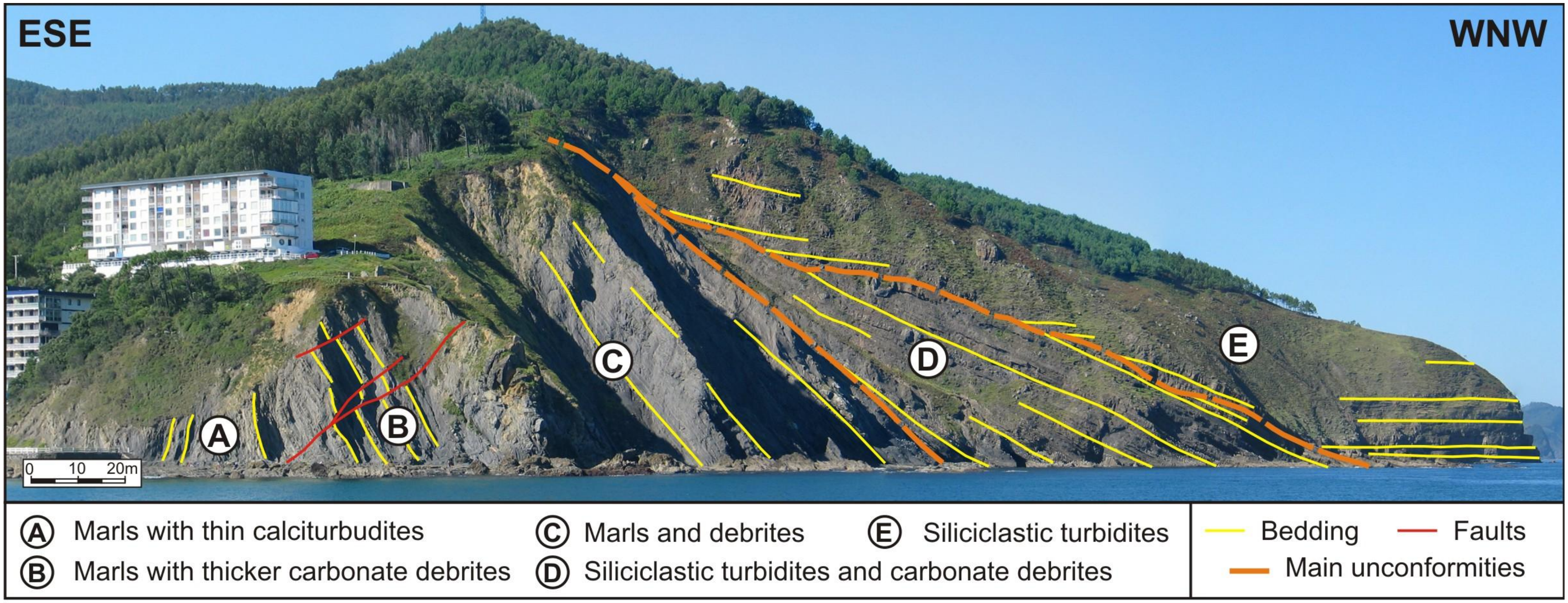

Figure 2. Panoramic view from the sea of the western flank of Bakio Diapir, showing the main structural and stratigraphic features of the Aptian to middle Albian halokinetic sequences. The western wall of the diapir is located just eastward of the image. Note the strong internal deformation of the eastern unit with vertical to overturned beds (A and B).