Paleomagnetic constraints on the kinematics of inverted passive margins with salt diapiric structures. Preliminary results from syndiapiric overburden rocks of the northern margin of the Basque-Cantabrian extensional Basin.

Control paleomagnético de la cinemática de márgenes pasivos invertidos con estructuras salinas diapíricas. Resultados preliminares en sedimentos sindiapíricos del margen norte de la cuenca extensional Vasco-Cantábrica.

E. Beamud[1,2], E. Roca[1], R. Soto[3], C. Peigney[1], E. L. Pueyo[3]

1 Geomodels UB Research Institute, Dept. de Dinàmica de la Terra i de l'Oceà. Universitat de Barcelona, 08028 Barcelona. betbeamud@ub.edu, eduardroca@ub.edu; c.peigney@ub.edu
2 Paleomagnetic Laboratory CCiTUB-Geo3BCN CSIC, 08028 Barcelona.
3 Instituto Geológico y Minero de España. Unidad de Zaragoza. C/ Manuel Lasala 44, 9ºB, 50006 Zaragoza. r.soto@igme.es, unaim@igme.es

Abstract: *Salt levels deposited prior to deformation in either passive margins or orogenic settings generate a decoupling in deformation, with differential deformation in layers above and below the salt detachment. Distribution of salt detachments controls differential shortening and formation of orogenic arcs; and widespread diapirism can generate isolated minibasins which may record vertical axis rotations during their development. Our study aims to unravel the kinematics of salt diapiric structures by means of a paleomagnetic study of a portion of the Basque Arc, in the northern margin of the Basque-Cantabrian extensional Basin, where the salt overburden appears compartmentalized by several salt walls (Bakio, Bermeo, Guernica and Mungia diapirs). In this setting, 65 paleomagnetic sites from the overburden sequence have been analyzed. Predominant anti-clockwise rotations with some clockwise and anticlockwise rotations in opposing flanks of the salt walls are observed. Fold tests reveal that some of the sites are clearly remagnetized, whereas some other sites show a prefolding magnetization. These observations are confirmed by magnetic hysteresis and back-field experiments in part of the studied rocks. Although further analyses will be necessary to explain the origin and distribution of the remagnetization, a preliminary kinematic model for the suprasalt deformation together with the underlying decoupled autochtonous materials can be established.*

Keywords: *Paleomagnetism, vertical axis rotation, salt tectonics, remagnetization, Basque-Cantabrian Basin.*

Resumen: Los niveles salinos depositados antes de la deformación, tanto en márgenes pasivos como en contextos orogénicos, producen una deformación diferencial en los niveles por encima y por debajo del despegue salino. La distribución de los despegues salinos controla el acortamiento diferencial y la formación de arcos orogénicos y el diapirismo puede generar minicuencas asociadas a rotaciones de ejes vertical durante su desarrollo. Nuestro estudio, con 65 estaciones paleomagnéticas, pretende deducir la cinemática de estructuras salinas mediante el estudio de una porción del Arco Vasco, en el margen norte de la Cuenca extensiva Vasco-Cantábrica, donde la cobertera de la sal está compartimentada por varias paredes salinas (diapiros de Bakio, Bermeo, Guernica y Mungia). Los resultados muestran rotaciones antihorarias predominantes y rotaciones horarias y antihorarias en flancos opuestos de los diapiros. Los test del pliegue revelan que algunas estaciones están remagnetizadas mientras otras muestran magnetizaciones "prefolding". Los experimentos de magnetismo de rocas en parte de las muestras estudiadas confirman estas observaciones. A pesar de que son necesarios más análisis para entender el origen y la distribución de las remagnetizaciones, es posible establecer un modelo cinemático preliminar de la deformación suprasal junto a los materiales despegados infrayacentes.

Palabras clave: Paleomagnetismo, rotación de eje vertical, tectónica salina, remagnetización, Cuenca Vasco-Cantábrica.

INTRODUCTION

The presence of salt levels deposited prior to deformation in either passive margins or orogenic settings generates a decoupling in deformation, which promotes differential deformation in layers above and below the salt detachment. The distribution and thickness of salt detachment levels controls differential shortening during thrust displacement which can lead to formation of orogenic arcs with associated vertical axis rotations. Moreover, widespread diapirism and halokinetic activity can generate isolated

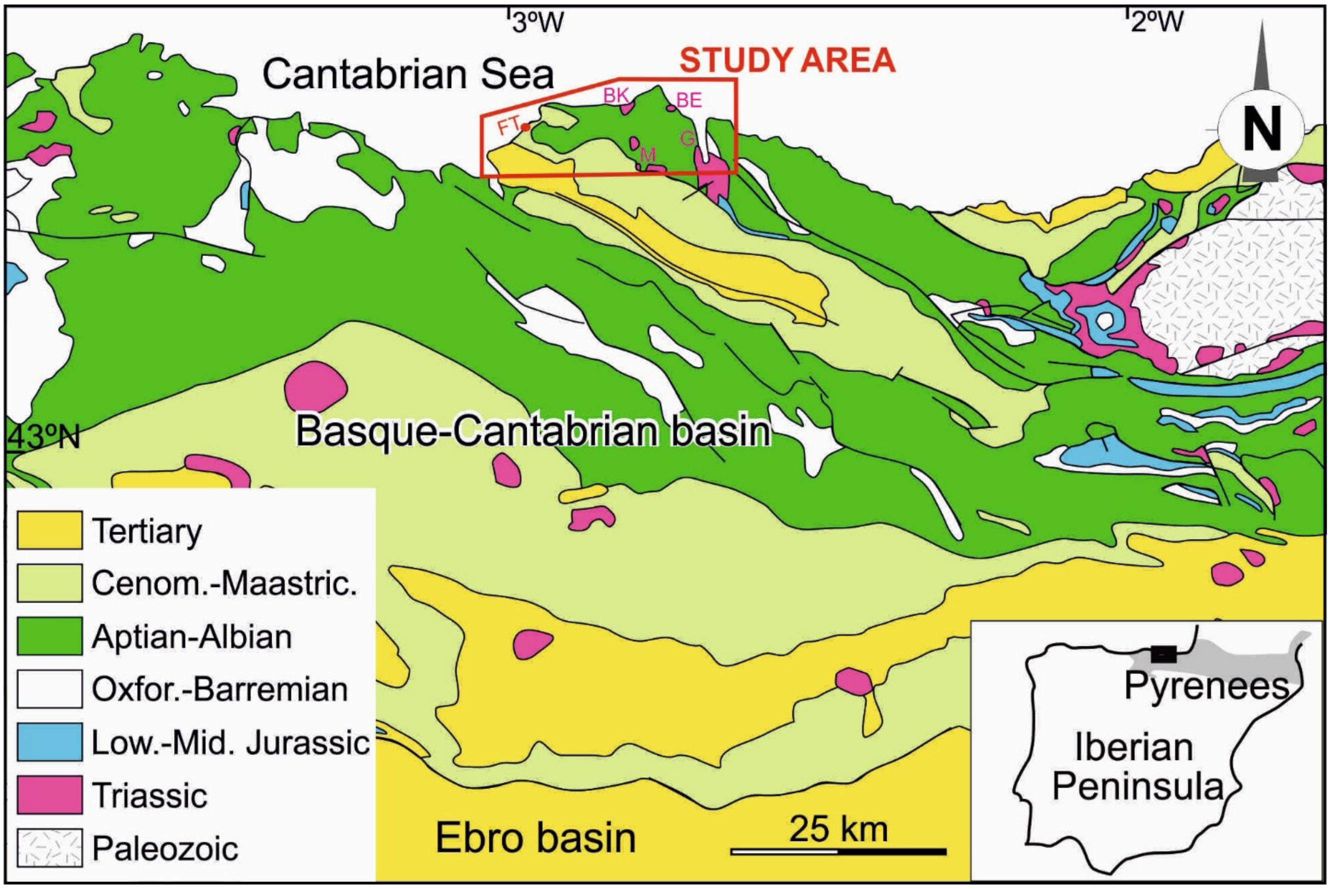

FIGURE 1. Simplified geological map of the Basque-Cantabrian Basin with location of the study area and the studied salt walls: BK: Bakio, BE: Bermeo, G: Guernica and M: Mungia. FT indicates the location of the fold test shown in Figure 3.

minibasins which record significant vertical axis rotations during their development either in extensive or contractive settings. In this work we aim to shed some light on the kinematics of salt diapiric structures by the study of a portion of the Basque Arc (Feuillée and Rat, 1971; Calvo et al, 2007), located at the northern margin of the Basque-Cantabrian extensional Basin (Figure 1). There, the salt overburden (Jurassic to Eocene in age) is displaced several km northwards and appears compartmentalized by several N-, NNE- and WNW-trending salt walls (Bakio, Bermeo, Guernica and Mungia diapirs) (Figure 1). Our paleomagnetic study is designed to detect and quantify vertical axis rotations recorded during both the extensional and later contractional reactivation of the basin margin.

GEOLOGICAL SETTING

The Basque-Cantabrian Basin is a hyperextended uppermost Jurassic to middle Cretaceous basin that formed as the result of the opening of the Bay of Biscay (García-Mondéjar et al., 1996). It was floored by an extremely thinned lithosphere with exhumed mantle, and involved a pre-rift thick Upper Triassic salt layer. This layer decoupled the extensional deformation and generated salt diapirs in both basin margins (Figure 1).

From late Santonian (Late Cretaceous), the Basque-Cantabrian Basin was inverted during the Pyrenean orogeny forming the Basque Pyrenees. The architecture of the Basque Pyrenees was largely determined by the extensional crustal structure of the precursor Basque-Cantabrian Basin and the distribution and geometry of the stretched overlying Upper Triassic salt layer (Ferrer et al., 2008; Ferrer et al., 2014). This last layer, where present, generated a thin-skinned contractional deformation with thrusts and folds that, in the northern basin margin, usually are placed over the subsalt extensional faults (Gómez et al., 2002)

In this scenario, the salt diapirs, formed during the early-middle Cretaceous at the northern margin, were partially or totally squeezed and passively transported towards the north in the hangingwall of the northern Pyrenean thrust system during Cenozoic times. Also they nucleate the suprasalt contractional deformation generating narrow stripes of variable orientations in which the overburden appears strongly deformed by tight detachment folds and minor thin-skinned thrusts.

The study area is located in the central part of this reactivated northern margin of the Basque-Cantabrian Basin (Fig. 1). Specifically, it is located at the northwestern edge of the large North-Biscay and Biscay synclinorium where this structure is well depicted. Here, the diapirs, at surface, are recorded by widespread outcrops of sub-volcanic tholeiitic rocks and red clays intruded by secondary gypsum veins; and the overburden by: a thin Jurassic carbonate *layer, thick Aptian to lower Santonian syn-diapiric carbonate to terrigenous halokinetic sequences with some thick volcanic interbeds, and upper Santonian to Eocene synorogenic deposits.*

PALEOMAGNETIC RESULTS

In this regional setting, 65 paleomagnetic sites have been sampled and analyzed in the overburden sequence. Of these, 61 sites were located in the Aptian, Albian and Cenomanian marls, marly limestones and fine grained sandstones, one in upper Albian-lower Cenomanian pillow lavas, another one in the Cenomanian basaltic rocks interstratified with marls and, finally, 2 sites were sampled in Eocene sandstones and marly limestones. Characteristic components of sites composed by sedimentary rocks are usually defined between 200-450 ºC (Figure 2) pointing to titanomagnetite or fine grained magnetite as the main remanence carrier.

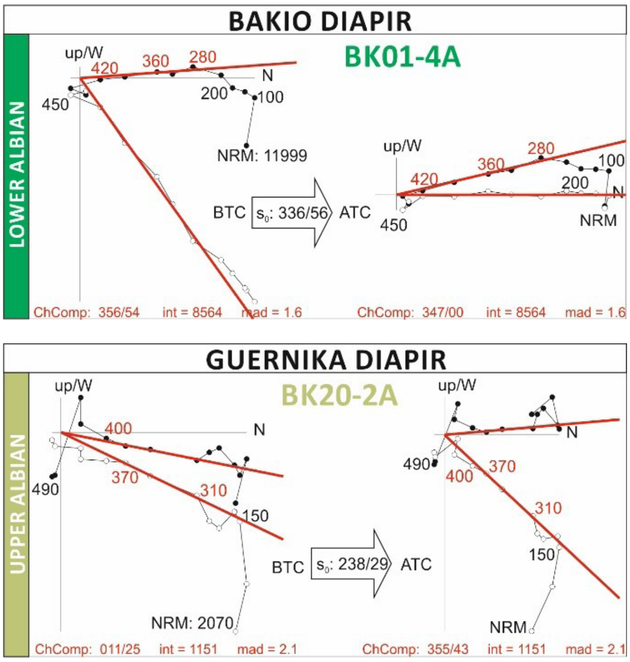

FIGURE 2. Demagnetization diagrams of representative samples of the Bakio Diapir (BK01-4) and Guernika Diapir (BK20-2a). Red line represents the characteristic component obtained for the selected range of temperatures, also indicated in red.

Mean directions at site level show predominant anticlockwise rotations with some clockwise and anticlockwise rotations in opposing flanks of the salt diapirs. All directions yield normal polarity, as expected by the age of the rocks, which (except the Eocene sites) coincide with the Cretaceous superchron C34n. However, some of the sites are clearly remagnetized as they yield negative fold tests (Figure 3), whereas some other sites show a prefolding magnetization (Figure 4).

Several rock magnetism experiments (IRM acquisition, Lowrie test, hysteresis analyses and backfield experiments) have been conducted in order to understand the remagnetization mechanism

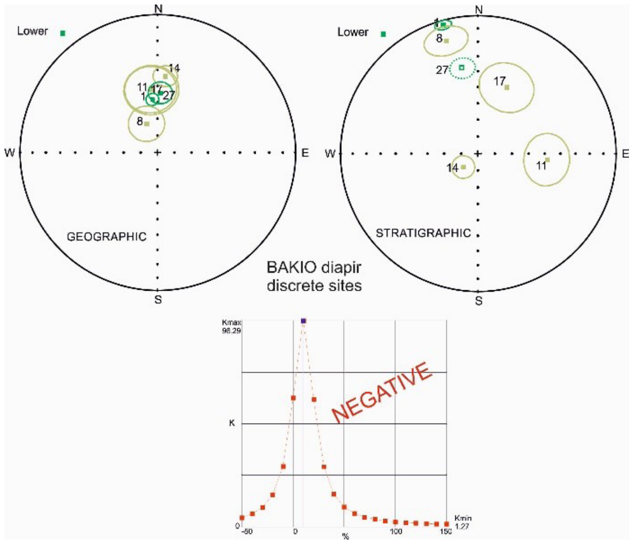

FIGURE 3. Fold test for the Aptian-Albian successions on the Bakio Diapir (BK in Figure 1). A better grouping is attained in geographic coordinates, revealing a negative fold test and a postfolding magnetization.

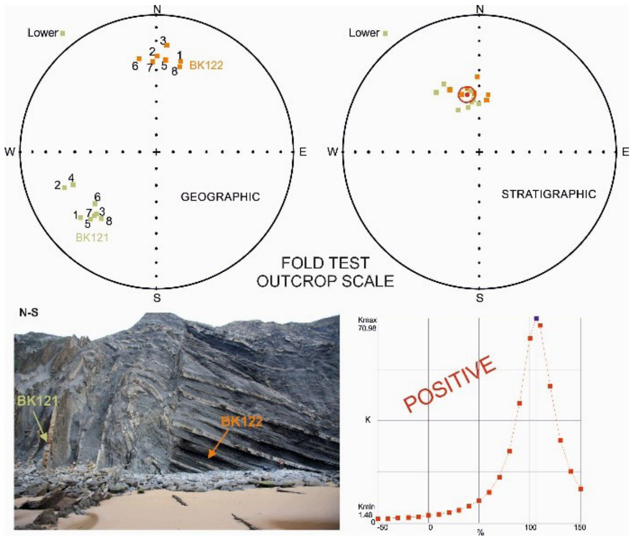

FIGURE 4. Fold test at outcrop scale (FT, in Figure 1). Sampled materials correspond to Upper Cenomanian-Coniacian marls and marly limestones. Site 121 was sampled in the northern flank of the anticline and site 122, in the southern one. A better grouping is attained in stratigraphic coordinates, revealing a positive fold test and a prefolding magnetization.

DISCUSSION

The spatial location of remagnetized rocks does not show a distinct structural pattern and further analyses will be necessary in order to explain the origin and distribution of the remagnetization. The age of the observed remagnetization is difficult to assess, since the folds affecting the studied materials were formed at separated moments by two different mechanisms:

1) Synsedimentary origin linked to the growth of the diapirs (Aptian-Albian)

2) Folds related to the Pyrenean deformation (late Santonian-middle Miocene)

Partial remagnetization has also been faced in Maastrichtian rocks from the Sopelana and Zumaia magnetostratigraphic sections, near the study area (Moreau et al., 1994; Batenburg et al, 2012). These authors observed that marls are more often affected by remagnetization in these sections, and they explain it as an effect of postdepositional selective diagenetic processes.

Although the aforementioned uncertainties, the obtained results allow establishing a preliminary kinematic model for the suprasalt deformation together with the underlying decoupled autochthonous materials, since the observed vertical axis rotations in either in situ or corrected coordinates follow the same pattern.

ACKNOWLEDGMENTS

This work has been supported by the project SALTCONBELT-CGL2017-85532-P, funded by Agencia Estatal de Investigación (AEI) and FEDER. Some of the authors are members of the consolidated research group of Geodynamics and Basin Analysis 2017SGR596 of the Generalitat de Catalunya.

REFERENCES

Batenburg, S., Sprovieri, M., Gale, A.S., Hilgen, F.J., Hüsing, S., Laskar, J., Liebrand, D., Lirer, F., Orue-Etxebarría, X., Pelosi, N., Smit, J. (2012). *Earth and Planetary Science Letters* 359-360, 264-278.

Calvo-Rathert, M., Cuevas, J., Tubía, J.M., Bógalo, M.F. y Gogichaishvili, A. (2007). *Int J Earth Sci (Geol Rundsch)* 96, 1163–1178.

Ferrer, O., Roca, E., Benjumea, B., Muñoz, J., Ellouz, N., MARCONI-Team (2008). *Marine and Petroleum Geology* 25, 714–730.

Ferrer, O., Arbués, P., Roca, E., Giles, K., Rowan, M.G., de Matteis, M. y Muñoz, J.A. (2014). *AAPG 2014 Annual Convention and Exhibition*, Search and Discovery Article #41385.

Feuillée, P., Rat, P. (1971). En: *Histoire structurale du Golfe de Gascogne*. (Debyser J, Le Pichon X, Montadert L. Eds), Technip Ed. 1.1–1.48.

García-Mondéjar, J., Agirrezabala, L.M., Aranburu, A., Fernández-Mendiola, P.A., Gómez-Pérez, I., López-Horgue, M., Rosales, I. (1996). *Geological Journal* 31,13–45.

Gómez, M., Vergés, J., Riaza, C. (2002). *Bulletin de la Societe Geologique de France* 173, 449–459.

Moreau,M-G., Cojan,I., Ory,J. (1994). *Earth and Planetary Science Letters* 123, 15–37.