5.- DIFUSIÓN CIENTÍFICA DEL EQUIPO DEL PROYECTO DURANTE LA EJECUCIÓN DEL MISMO

A continuación se exponen los trabajos que el equipo del Proyecto ha publicado durante la ejecución del mismo, que están relacionados directamente con los objetivos planteados.

En cada publicación se incluye el *abstrac* del artículo o poster.

GALINDO-ZALDÍVAR, J.; CHALOUAN, A.; AZZOUZ, O.; SANZ DE GALDEANO, C.; AMEZA, L.; **MARÍN-LECHADO, C**.; RUANO, P.; SAJI, R.; MASANA, E.; PEDRERA, A.; LÓPEZ-GARRIDO, A.C.; BARGACH, K.; **ROLDÁN-GARCÍA, F.J**.; **RUIZ-COSTÁN, A**.; BERMAKHLOUF, M.; AHMAMOU, M.; AKIL, M.; CHABLI, A. (2007). Tectónica reciente y activa en el interior de la Cordillera del Rif. Alhucemas (Marruecos): Implicaciones en la peligrosidad sísmica. 1st MAPG International Convention Conference & Exhibition-Marrakech. Octubre 2007. Marrakech.

RESUMEN

La determinación de la actividad tectónica reciente y actual en cordilleras tiene gran interés ya que está asociada a la actividad de las fallas que determinan la peligrosidad sísmica de una región. Las Cordilleras Bético-Rifeñas son cordilleras alpinas desarrolladas desde el Cretácico, en las que su relieve actual es consecuencia de la convergencia oblicua en dirección NO-SE desde el Tortoniense entre las placas Euroasiática y Africana. La deformación continúa en la actualidad y produce una sismicidad que a veces tiene consecuencias catastróficas.

En la Cordillera del Rif, las estructuras activas sismogenéticas de las zonas frontales se correlacionan bien con las estructuras tectónicas mayores observadas en campo y su comportamiento contrasta con el de las zonas interiores. La actividad sísmica se concentra esencialmente en la zona de Alhucemas, en el límite entre las Zonas Externas e Internas, región en la que el 24 de febrero de 2004 se produjo un terremoto catastrófico superficial (14 km de profundidad) con la mayor magnitud instrumental registrada en el Mediterráneo más occidental (M=6,3). El mecanismo focal y las alineaciones de epicentros indican la actividad de fallas sinistras transcurrentes de orientación N-S. Sin embargo, en las observaciones de campo no se identifica ninguna falla vertical transcurrente en la alineación de los epicentros, y por el contrario se observa la actividad reciente de fallas normales. Esta aparente contradicción puede deberse a la estratificación mecánica de la corteza, debido a la presencia de niveles de despegue.

La principal consecuencia de estas observaciones es la necesidad de realizar estudios complementarios a los propuestos por las técnicas paleosismológicas clásicas en cordilleras con estratificación mecánica, como la Cordillera Bética, donde también ha ocurrido una sismicidad catastrófica.

GALINDO-ZALDÍVAR, J.; CHALOUAN, A.; GIL, A.M.; AZZOUZ, O.; SANZ DE GALDEANO, C.; ANAHNAH, F.; AMEZA, L.; RUANO, P.; PEDRERA, A.; RUIZ, A.M.; **RUIZ-COSTÁN, A**.; **MARÍN-LECHADO, C**.; BENMAKHLOUF, M.; LÓPEZ-GARRIDO, A.C.; AHMAMOU, M.; **ROLDÁN, F.J**.; AKIL, M.; CLARA DE LACY, M.; CHABLI, A. (2008). Recent and active deformations in Internal and External Rif Cordilleras: new non permanent GPS networks. 4th TOPO-EUROPE Wokshop. 5-8 October, Madrid.

ABSTRACT

The Rif Cordilleras together with the Betic Cordilleras have formed in the western Mediterranean by the westwards motion of the Internal Zones in between the convergence region of the Eurasian and African plates. A crustal thinning stage during Oligocene- Early Miocene times formed the Alboran Sea floored by Internal Zones rocks. The present-day relief developed since the Late Miocene. At present, recent deformations are concentrated in the Betic Cordillera mainly in the Internal Zones while in the Rif Cordillera, both Internal and External zones shows seismicity and active deformations with contrasting features. Recent deformation in the frontal part of the Rif developed a fold and thrust belt located in the Prerif Ridges area. In addition to the seismicity, there are clear evidences of Quaternary deformation including vertical folded Plio-Quaternary layers of striated conglomerates and reverse faults affecting fluvial terraces of the Saïss foreland basin. Extensional deformations occur at the foreland including moderately active normal faults. A new non-permanent GPS networks with 6 sites have been installed and measured in the Fez- Sefrou region in order to quantify the shortening deformations that occur in the foreland basin and the uplift of the Prerif Ridges folds and thrusts. In the interior of the Rif and near the contact between the Internal and External zones is located the Alhoceima region that has undergone a catastrophic earthquake in February 24, 2004 (M= 6.3) with a strike-slip focal mechanism (probably N-S sinistral fault). However, rupture does not reach the surface, and recent active N-S oriented faults are normal. A crustal model with active detachment is proposed for this region. A GPS network including 6 sites have been also installed in order to understand the propagation of deep motion towards the surface in complex deformed regions. Although the study of recent structures allow to evidence a contrast at present in the deformation style of Internal and External zones, GPS networks may allow in the future to quantify the rates of these deformation that are finally realted to the Eurasia-Africa boundary.

GALINDO-ZALDÍVAR, J.; CHALOUAN, A.; RUANO, P.; AZZOUZ, O.; **MARÍN-LECHADO, C**.; PEDRERA, A.; **RUIZ-COSTÁN, A**.; ANAHNAH, F.; BENMAKHLOUF, M.; SANZ DE GALDEANO, C.; AHMAMOU, M.; LÓPEZ-GARRIDO, A.C.; AMEZA, L.; **ROLDÁN, F.J**.; CHABLI, A.; AKIL, M. (2008) Changing tectonic styles of recent and active structures in the Rif Cordillera and asymmetry in respect to the Betic Cordillera (Western Mediterranean). 33º International Geological Congress Oslo. Poster.

ABSTRACT

The Betic and Rif Cordilleras, separated by the Alboran Sea, constitute the alpine orogen that formed the Gibraltar Arc at the western Mediterranean Sea. The westwards migration up to early Miocene of the Alboran Domain, the most internal domain, determined the roughly symmetrical structure of the cordilleras between Variscan African and Iberian margins. The NW-SE convergence between Eurasian and African plates since the Tortonian is responsible for the development of the main relieves. The
area is affected by a broad band of seismicity that evidences the dispersion of the present-day tectonic activity. The distribution of the recent and present-day active structures in a S -N cross-section of the Rif Cordilleras shows a typical transition from thin skinned to thick skinned tectonics. From the foreland (Moroccan Meseta), the southern Saïss foreland basin is deformed by extensional faults, while in its northern part, reverse faults formed by the Rif propagation are observed. The frontal part of the Rif is formed by the Prerif Ridges, an active fold and thrust belt with very shallow associated seismicity and of Quaternary compression evidences. In constrast, the Rifian Internal Zones in Al Hoceima area constitute a region with probably active crustal detachments. Transcurrent basement faults produce catastrophic seismicity (M=6.4, February 24, 2004), but does not extends to surface, where transtensional and normal faults determine the geometry of the main recent basins. Northwards is located

the Alboran Sea, an area of thinned continental crust, that has undergone shortening at its boundaries since the late Miocene. In the Betic Cordillera, most of the recent and active deformation is located at the Internal Zones where the hanging walls of crustal detachments are deformed by kilometer-size late folds that determines the main features of the present-day relief. Normal and transtensional faults are the most abundant in the surface in central Betic Cordilleras, while strike-slip faults are mainly developed in their eastern part. The frontal part of the Betic Cordillera is practically
inactive. These cordilleras have undergone a stage of symmetrical deformation followed by asymmetrical tectonic activity due to the interaction of present oblique convergence and inherited arched geometry. While Rif show a typical distribution of active deformations, the Betic Cordilleras constitutes the backstop of the deformation area with concentration of compressive structures in the Internal Zones where the highest relieves are reached. In addition in the internal zones, geophysical data shows the presence of detachment levels determining that seismogenic deep faults not reach the surface and cannot be studies by classical geological and paleoseismological techniques, that only allow to characterize the shallow outcropping faults. In these regions 3D crustal models, integrating geophysical and geological data, are needed to assess the seismic hazard.

HEREDIA, J.; GONZÁLEZ, A.; RODRÍGUEZ-ARÉVALO, J.; GOLLONET, J.; **ROLDÁN, F.J**.; RUBIO, J.C. (2008). Acuífero carbonatado de la Loma de Úbeda: propuesta para una explotación sostenible basada en la modelación numérica. Simposio de Agua en Andalucía. T-II. IGME. Serie : Hidrogeología y Aguas Subterráneas, nº 25. 779-794 pp.

ABSTRACT

Olive cultivation plays a major role in the economy of the region of Úbeda. The extension of cultivated land and olive oil production have both increased strongly during the last years due to drip irrigation, using mainly groundwater pumped out of the aquifer of Loma de Úbeda. This aquifer consists of Jurasic limestone some 90 m thick and extends over 875 km^2. The aquifer is confined by Miocene marls in about 625 km^2 and reaches a depth of some 800m. In the last decade, deep boreholes have been drilled and groundwater extraction, almost absent before, has increased rapidly and strongly. Lacking a water resources exploitation plan is having a stronger impact due to the lack of a consistent conceptual model of the aquifer, because it exhibits a complex geometry, it is divided in several compartments and there is a deficient knowledge of its boundaries and the water balance (recharge and discharge). IGME, in agreement with CHG, developed numerical models of ground-water flow aimed at gaining a better understanding of the hydraulic functioning of the aquifer and at supporting groundwater management, namely addressing: 1) the identifcation of a plausible conceptual model and the estimation of a water balance in a non-altered scenario through the steady state modelling of the mean hydraulic situation of the period 1960/62–1994/95; and 2) the estimation of a water balance for a heavy exploitation scenario through the transient state modelling of the period 2000/01–2005/06. Limits to the sustainable water exploitation of the aquifer are preliminarily proposed for different sectors in the aquifer, based on the water balances that resulted from the numerical models and on the conceptual model proposed.

RODRIGUEZ-FERNÁNDEZ, J.; ROLDÁN, F.J.; AZAÑÓN, J.M.; BOOTH, G. (2007). Middle to Late Miocene Thrust and Piggy.Back Basin Development in the External Betic Chain. 1st MAPG International Convention Conference & Exhibition-Marrakech. Octubre 2007. Marrakech.

ABSTRACT

Several lines of evidence, surface geology, seismic lines and wells, show that the eastern and central external zones (east of 5º W) of the Betic chain have been affected by a piggy-back sequence of thrusts in the later part of Middle Miocene and early Late Miocene (13-10 Ma).

The piggy back thrust sequence affects the previous Mesozoic and Cenozoic sedimentary sequences as well as a remarkable brecciated sedimentary sequence mainly nourished by Triassic, Cretaceous and Tertiary soft sedimentary rocks. This ubiquitous unit has been previously cited as Guadalquivir olistrostrome, Olistostromic unit, Chaotic Subbetic units, etc. More than three thousand samples allow dating this unit as Late Langhian to Early Serravallian (15-13 Ma). These units constitute the basement of many piggy back basins formed on the thrust hangingwalls, contemporaneously with the northwest movement of them.

Sediment deposited in these piggy back basins, forming the Castro del Rio unit show clear evidences of sinsedimentary and coseismic deformation and in a general way show a fining and thickening upward sequence, from detrital or carbonatic to fine grained marly sediments. Abundant reworked fauna from Cretaceous to Early Tertiary make it difficult to date these sediments, with only a few samples providing a Late Serravallian-Early Tortonian age. The Castro del Rio Unit is also cut by thrusts that are finally sealed by Late Miocene sediments.

ROLDÁN, F.J. (2008). Las unidades olistostrómicas del Antepaís Bético. CONTEXTOS GEOLÓGICOS ESPAÑOLES. UNA APROXIMACIÓN AL PATRIMONIO GEOLÓGICO ESPAÑOL DE RELEVANCIA INTERNACIONAL. Capítulo 11. IGME. 124-131 pp.

ROLDÁN, F.J.; MARÍN, C.; RODRÍGUEZ-FERNÁNDEZ, J.; AZAÑÓN, J.M. (2008). Geometric analysis of sedimentary filling of the foreland basin (Betics, Spain). 33º International Geological Congress Oslo. SES-06 Palaeoecology, climate and chronostratigraphy. Poster.

ABSTRACT

The Guadalquivir basin is a triangular foreland basin located to the south of the Iberian Massif which extends from Sierra de Cazorla to the gulf of Cadiz. This Neogene basin developed by crustal flexure related with thrusting of the Alboran Domain over the South-Iberian paleomargin. The sedimentary record in the foredeep basin ranges from upper Tortonian to Quaternary.

Geological mapping of 24.500 km2 and the study of more than 3.000 calcareous nannoplankton and foraminifera samples has provided the spatial distribution of four different depositional sequences. In order to elaborate a geometric analysis of the distribution of these sedimentary sequences, we have combined cartographic information with the interpretation of more than 1.800 km of seismic reflection profiles. Well micropaleontological descriptions

provided by oil companies (more than 90 km) have been used to correlate depositional sequences and seismic reflectors. Well geophysical logging information allows establishing an average seismic velocity of 2750 m/s for time to depth conversion. The geometric analysis we present shows onlap sedimentation of the lower units, Tortonian and Messinian in age, on the South-Iberian paleomargin.

This way, the Tortonian unit crops out in the eastern part of the foredeep basin (sector included between Sierra de Cazorla and Mengíbar, Jaen), whereas the Messinian unit occurs in the western part (sector between Ecija, Sevilla and the gulf of Cádiz). The two upper units outcrop only in the westernmost sector (Ecija-gulf of Cádiz) and record the sedimentation between the upper Messinian and the Plio-Quaternary. Contrasting with the lower units, the upper Messinian and Plio-Quaternary units show offlap related with the upper Messinian eustatic drop. The proposed sketch permits us to visualize the depositional sequence distribution, the depth to the Iberian basement and the deformations related with crustal flexure and reactivation of Variscan faults by the Alpine Orogeny.

RUIZ-CONSTAN, A. (2007). Estructura cortical y deformaciones recientes de la transversal occidental de las Cordilleras Béticas (Marbella-Sevilla). Seminario de Investigación. Universidad de Granada. 115 pp.

CONCLUSIONES

La adquisición de nuevos datos magnetotelúricos, gravimétricos y magnéticos, combinados con los datos de sismicidad ha permitido precisar la estructura cortical de la transversal occidental NO-SE de la Cordillera Bética, entre Marbella y Sevilla. La Moho tiene una profundidad aproximada de 30- 32 kilómetros bajo el Macizo Ibérico y bajo la Cuenca del Guadalquivir y desciende progresivamente hasta más de 40 kilómetros bajo la Depresión de Ronda. Hacia el Sur probablemente la corteza se divide. La parte superior de la corteza está compuesta por los materiales que afloran en las Cordilleras Béticas mientras que la parte inferior corresponde a la prolongación del macizo Ibérico que subduce bajo el Mar de Alborán hasta profundidades de más de 120 km.

La estructura eléctrico-resistiva muestra que la corteza continental es heterogénea. La parte superior está formada por cuerpos conductores y resistivos que se correlacionan bien con la estructura geológica observada en superficie. En niveles medios y profundos de la corteza, destaca la identificación de varios cuerpos conductores. El mayor de ellos, situado bajo las Zonas Externas y Depresión de Ronda, tiene un marcado buzamiento hacia el SE, con extensión en el perfil de más de 50 km y 95 profundidades comprendidas entre 10 y 40 km. Otro cuerpo conductor de menor tamaño se localiza en la parte media-baja de la corteza, bajo la Depresión del Guadalquivir. Ambos cuerpos corresponden probablemente a rocas ígneas básicas.

El basamento sobre el que se depositaron los sedimentos neógenos de la Depresión de Ronda es heterogéneo. Mientras que su borde meridional corresponde esencialmente a calizas del Penibético que limitan la Depresión, el borde septentrional actual de los materiales neógenos situados sobre materiales de los flysch es erosivo y no constituye un límite de cuenca. Mediante gravimetría, en el basamento se detectan bloques de tamaño kilométrico de mayor densidad atribuidos a calizas jurásicas similares a las aflorantes en los relieves más meridionales. Además, la potencia mínima de los materiales triásicos debe ser de 2-2.5 kilómetros en el sector de Ronda.

Los materiales neógenos de la Depresión de Ronda reposan discordantes sobre su basamento. La deformación frágil es escasa y se reduce a pequeñas fallas locales de tamaño métrico y sistemas de diaclasas. Los pliegues tienen una distribución heterogénea localizada en el sector SO de la Depresión. Destacan el conjunto de pliegues NNE-SSO de la Sierra de las Salinas, que continua en el pliegue ONO-ESE de la Sierra de la Sanguijuela, paralelo al borde de la cuenca. Ambos pliegues se desarrollaron simultáneamente.

El pliegue de las Salinas es una antiforma que coincide con la posición del mínimo gravimétrico más pronunciado de la región, debido a que el núcleo del pliegue está constituido por los materiales triásicos. El pliegue tiene la misma geometría que los pliegues en caja del Penibético, como el de Sierra Merinos. Este pliegue se ha desarrollado, al menos, en dos etapas de deformación. En la etapa inicial, previa al depósito de los sedimentos tortonienses, se produciría una acumulación de rocas poco densas del Trias elongada en dirección NNE-SSO, paralela a las estructuras del Subbético en esta región. Estos pliegues están fosilizados por los sedimentos neógenos del borde nordoriental de la Depresión. En una etapa posterior, se produciría una reactivación local por diapirismo que desarrollaría el pliegue en caja sin vergencia definida y el pliegue de la Sanguijuela.

El índice SL no es un buen método para la determinación de la actividad tectónica en regiones con pliegues, ya que la existencia de niveles resistentes a la erosión, tales como las calcarenitas del Tortoniense, y su estructura influyen en mayor medida sobre los valores obtenidos que la actividad tectónica reciente.

La sismicidad indica que el frente montañoso es activo y las zonas afectadas por deformación actual son progresivamente más profundas hacia el SE, hasta más de 120 km de profundidad, asociadas a la corteza continental subducida. Hacia la parte meridional del perfil se observa la existencia de grandes despegues corticales a profundidades aproximadas de 5-7 y 18-20 kilómetros que buzan al SE.

Los paleoesfuerzos y esfuerzos actuales indican que se produjo una etapa de extensión en la corteza superior previa al Tortoniense. Desde el Tortoniense a la actualidad han predominado los esfuerzos compresivos regionales en dirección NO-SE, bien representados tanto en las microfallas como en los mecanismos focales localizados en el frente montañoso. Además hay heterogeneidades notables del campo de esfuerzos producidas posiblemente por permutación local de los ejes de esfuerzo. En la parte alta de la corteza, representada por la Depresión de Ronda, se identifican esfuerzos de extensión NO-SE producidos posiblemente por inestabilidad gravitatoria de la cuña orogénica. En profundidad, en la corteza subducida, los esfuerzos son mucho más variables con la presencia abundante de mecanismos focales con planos nodales subverticales y subhorizontales y de falla normal.

Los resultados anteriores muestran que, en la transversal occidental de las Cordilleras Béticas entre Marbella y Sevilla, las deformaciones recientes asociadas al la aproximación NO-SE ente Eurasia y África tienen una distribución heterogénea. Mientras que en superficie se produce esencialmente la elevación del relieve, en profundidad el acortamiento se compensa por la subducción hacia el SE de la corteza continental del Macizo Ibérico bajo el Mar de Alborán.

RUIZ-CONSTÁN, A.; GALINDO-ZALDÍVAR, J.; ANAHNAH, F.; **ROLDÁN, F.J**. (2008). Deep structure of a mountain front with olistostrome development from gravity, MT and seismicity data (Guadalquivir basin, central betic Cordilleras). 33º International Geological Congress Oslo. Poster.

ABSTRACT

The Guadalquivir basin is a Neogene foreland basin, located in the southern part of the Iberian Peninsula, bounded to the north by the Iberian Massif and to the south by the External Zones of the Betic Cordilleras. Its northern part is mainly filled by autochthonous sediments of Tortonian to Quaternary age, meanwhile the southern part is formed by Mesozoic and Cenozoic chaotic olistostromes which come from the External Zones. A N-S cross section of the central Betic Cordilleras acquiring different geophysical data (magnetotelluric, gravity and seismicity) has been performed in order to obtain information of the deep structure of the zone. Gravity and MT data determine the continuity in depth of the Iberian Massif below the foreland Guadalquivir Neogene basin and the External Zones of the Cordillera. The major relieves at the Betic Cordilleras front are constituted by limestone outcrops of several square kilometres. Geophysical data allow to determine the lack of continuity in depth of these limestones supporting that they are large olistoliths involved in a clay ductile matrix with foraminiferal fauna that extends up to Late Langhian-Early Serravallian age, and does not represent a frontal tectonic unit of the Betic Cordillera. 2D inversion of new MT soundings acquired along the N-S profile provides the first deep resistivity image of the zone that support the results obtained from gravity data. The heterogeneous initial few kilometers in depth of the profile, characterized by high variability on conductivity values, corroborate the distinctive chaotic structure of the upper part of the crust in the frontal part of the mountain range. Shallow levels are formed by large resistive bodies (Subbetic Mesozoic limestone blocks) included in a more conductive matrix (gypsum and clays). Although the northern margin of the Guadalquivir Depression is passive, the presence of olistostromes in the southern boundary evidences a main stage of tectonic activity during early-middle Miocene. Anyway, the irregular mountain front suggests a later long inactivity period. However shallow seismicity in this region points to a recent reactivation of a major detachment dipping southwards, to the Internal Zones of the Cordilleras, as consequence of the recent Eurasian-African convergence.