Interaction between sedimentation and submarine volcanism (Jurassic, Subbetic, southern Spain)

Interacción entre sedimentación y vulcanismo submarino (Jurásico, Subbético, sur de España)

J. M. Molina (*) and J.A. Vera (**)

(*) Departamento de Geología. Facultad de Ciencias Experimentales. Universidad de Jaén. 23071 Jaén (Spain)
(**) Departamento de Estratigrafía y Paleontología. Facultad de Ciencias. Universidad de Granada. 18071 Granada (Spain)

RESUMEN

Se estudia la relación entre vulcanismo submarino y sedimentación carbonatada principalmente pelágica en el margen continental pasivo que actualmente aflora en el Subbético. Existen dos grupos principales de relación entre vulcanismo y sedimentación: 1) normal o gradual, y 2) catastrófica. En el grupo normal o gradual se presentan cinco tipos desde rocas volcánicas, compuestas sólo por lavas almohadilladas hasta la única sedimentación, incluyendo siete tipos en los que coexisten ambas rocas. La intensidad de la actividad volcánica controló especialmente el tipo y distribución de estas facies sedimentarias durante el Jurásico medio-superior del Subbético Medio, en esta parte de la cuenca.

Palabras clave: vulcanismo submarino, sedimentación pelágica, Jurásico, Subbético.

Geogaceta, 29 (2001),142-145
ISSN: 0213683X

Introduction

In southern Spain Middle-Upper Jurassic submarine volcanic rocks appear, interbedded between pelagic sediments, corresponding to deposits in the Southern Iberian Continental palaeomargin. These deformed materials, currently form part of one of the units (Median Subbetic) of the External Zones of the Betic Cordillera. The outcrops are very well exposed, allowing us to study clearly the relationship between submarine basic volcanic rocks, mainly pillow lavas, and the Jurassic sediments, especially pelagic, that are interbedded or that overlie them.

The first description of pillow lavas in these volcanic rocks was carried out by Fontboté and Quintero (1960). In subsequent works, their petrological and geochemical characteristics have been analysed (Comas *et al.*, 1986; Puga *et al.*, 1988, 1989; Portugal *et al.*, 1995; Morata *et al.*, 1996; Vera *et al.*, 1997), defining a transitional to alkaline affinity for the basic magmatism. Intercalations of pelagic carbonate rocks within the volcanic rocks have been described (Comas *et al.*, 1981) and the ages of the lava flows have been dated from ammonites of the overlying and underlying materials (García-Yebra *et al.*, 1972) or from radiometric dating (Puga *et al.*, 1988). Vera *et al.* (1997) described shallow water carbonate deposits (oolitic limestones) and karstification surfaces on volcanic edifices, that would correspond to Jurassic guyots.

Previous papers on the relationship between pelagic sedimentation and submarine volcanism are relatively scarce. Garrison's publications (1972, 1973, 1974) continue to be the most complete on this topic. Studies of modern ocean floor provide valuable data, but in a different context, since commonly they are mainly observations of oceanic ridges. The studied region in this paper was an area within a passive continental margin in which the volcanism and the pelagic sedimentation coexisted for much of the Middle-Upper Jurassic.

The main object of this paper is to describe and classify the types of relationships between submarine volcanic rocks and the related pelagic sediments. Processes and models explaining their genesis were presented in Molina and Vera (1999, 2000).

Geologic and stratigraphic setting

The studied rocks belong to the Subbetic in the External Zones of the Betic Cordillera (Fig. 1). The Subbetic corresponds to materials deposited during the Mesozoic and much of the Tertiary, in a wide portion of the Southern Iberian Continental palaeomargin, characterized by the dominance of the pelagic facies from the Middle Liassic. Within this domain, palaeogeographic domains of smaller range have been differentiated, chiefly according to their subsidence rates (García-Hernández *et al.*, 1980, 1989; Vera, 1981, 1988). The volcanic rocks are present exclusively in one of these smaller domains named Median Subbetic.

They are basic volcanic rocks very rich in potassium, whose original magma was generated in the upper mantle and extruded on the sea floor after passing through a thick continental crust (Vera *et al.*, 1997). They are three main types: 1) pillow lava flows, 2) hydroclastites and pillow-breccias, and 3) sills, dykes and small laccoliths. All these three main types may occur together, but the pillows are typically more abundant in the upper part of the volcanic edifice. Pillows have spherical, ellipsoidal or tubiform shape and vary from decimetres to several metres in diameter. As a consequence of repeated tectonism, volcanic activity and erosion by marine currents numerous unconformities occur within the volcano-sedimentary sequences. These volcanic rocks are intercalated in pelagic limestones and marls with ammonites which allow precise dating.

The thickness of the volcanic rocks and their age varies from some areas to others within the same palaeogeographic unit, with a maximum thickness of 700 m in the Alicún de Ortega area. An extreme case are the volcanic flows only some meters thick between sediments of the

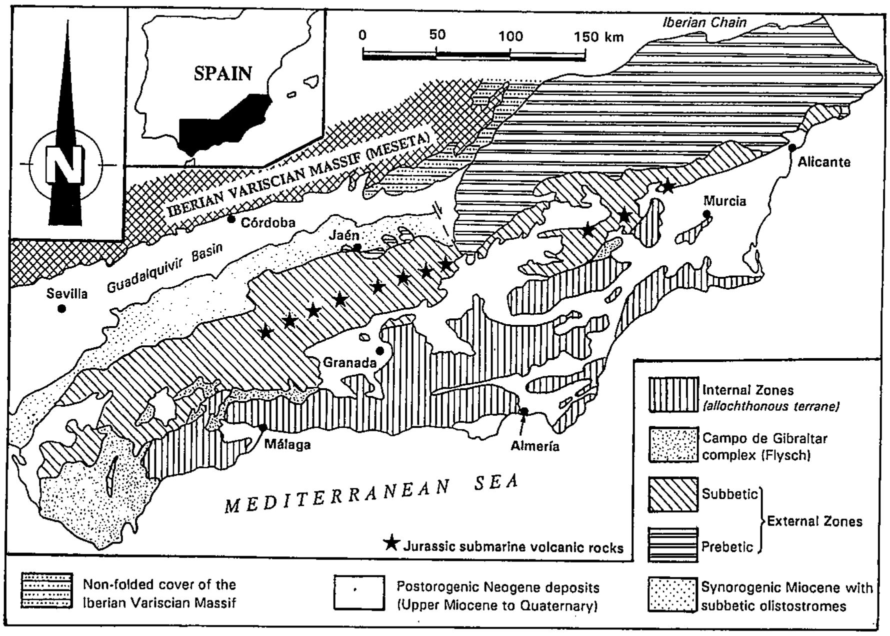

Fig. 1.- Geological setting of the study area. The Jurassic submarine volcanic rocks occur in the Subbetic (External Zones of the Betic Cordilllera).

Fig. 1. Localización geológica del área estudiada. Los principales afloramientos de rocas volcánicas submarinas jurásicas aparecen en la Zona Subbética (Zonas Externas de la Cordillera Bética).

same ammonite biozone. The opposite extreme case would be that of some volcanic flows between pelagic sediments, with ammonites of several stages, that constitute volcanic edifices some hundreds of metres in height.

Very locally volcanic flows are interbedded in materials of Toarcian age. Most submarine volcanism in the Subbetic basin occurred in Middle Jurassic time, (Aalenian and Bajocian especially). During Late Jurassic, the volcanism continued but was more local. A few submarine volcanic flows are Cretaceous.

Petrological and morphological types

We have differenciated seven types (Table 1). These types can be distributed in two main groups according to their genetic nature described before: 1) as normal or gradual relation of the volcanism against the sedimentation (types A to E), or 2) as catastrophic deposits (types F and G).

Normal relation of the volcanism versus sedimentation (Types A, B, C, D and E)

We have distinguished also two main sets (Table 1) mainly according to the abundance and the position or relation of the sediments with the volcanic rocks. The first set (types A, B and C) corresponds to pillow lavas and related pelagic sediments located between them. The second set (types D and E) are the sediments deposited on volcanic edifices covering them and marking the end of the volcanism.

Type A) Pillow lavas without pelagic sediments. They are made by volcanics without sedimentary rocks. The volcanic rocks have a pillow lava structure with radial and/or concentric cracks, and variable size, changing their major diameter between 20 and 200 cm, with average values of 60 cm. Their shape is also variable, but dominating the flat bottoms and the convex tops. Frequently they present deformations linked to the adaptation to the underlying pillows. Only drusy calcite cement (radiaxial fibrous mosaic sparite) appears in the voids between pillow lavas. The pillow lavas have abundant vacuolas with a diameter size between 0.5 and 2 mm.

Type B) Pillow lavas with pelagic sediments. We have not recognized well consolidated sediment older than enclosing basalt pillows, but only unconsolidated sediment more or less contemporaneous with the volcanic flows (Fig. 2, B1, B2, B3). We differentiate three subtypes according to the relative abundance of the pelagic sediment against the pillow lavas and their morphology.

a) *Subtype B-1 of interpillow and intrapillow limestones.* The pelagic limestones and marly limestones, are minoritary sediments in small cavities between the pillows not completely surrounding it, or in individual pillows. We differentiate three kinds in this subtype B-1:

B-1a) They occur as small bodies mainly with an approximately triangular characteristic shape, with flat or gently concave-down tops and pointed or arched-down lower boundaries. Correspond to sediment percolated "in situ" and deposited between the voids of pre-existing pillows. When there are bioclasts (mainly "filaments"), the main characteristic is the presence of parallel horizontal lamination or "sandglass" lamination. The average size is between 10 cm and 40 cm in the longest distance.

B-1b) Intrapillow limestones. Micritic sediment filling radial and concentric cracks in the interior of individual pillows. The filled cracks are some millimetres to some centimetres in thickness, so they are not abundant in relation to the total volume of pillows.

B-1c) Sediments associated to irregular and brecciated pillows. It is pelagic sediment incorporated to the movement of the pillows, related to "irregular" or brecciated pillows, generally without lamination, but in some cases with deformed laminae. The breccia pillows have very angular clasts in a matrix of pink pelagic limestone. In some cases the sediment appears squeezed between the deformed pillows.

b) Subtype B-2 (B2 in Fig. 2). It corresponds to pelagic limestones that appear completely surrounding more abundant single pillows or mounds of pillows.

c) Subtype B-3 (B3 in Fig. 2). They are isolated pillow lavas in the more abundant pelagic limestones. The pillows are well rounded and their size is between 20 and 80 cm.

All the pelagic rocks belonging to this type B are pink and red micritic limestones (mudstones) or marly limestones locally with abundant "filaments" and other bioclasts (wackestone and packstone) frequently with parallel lamination and in some cases adapting its shape to an irregular bottom. The pelagic sediments have no metamorphism or exceptionally a very low thermal metamorphism. This alteration is not clearly shown in thin section by the microscope but it is usually shown by changes in color (pale pink, yellow or brown), apparently due to reduction of iron oxides and chloritization of clay minerals. Only in some cases the interpillow pelagic limestones show deformed shapes that suggest the pillows moved over plastic masses of unconsolidated wet sediments.

Type C) Stratiform sedimentary levels. They have irregular bottoms adapting to the convex-up shape of the pillows and flat tops (Fig. 2C). According to their morphology they can be:

Subtype C-1) Discontinuous sedimentary levels, less than several meters in horizontal length and less than 1 m thick.

Subtype C-2) Partially continuous (more than several metres) or continuous sedimentary levels. They are generally less than 5 m in thickness, but they can reach up to 40 m. In some of these levels synsedimentary faults and folds and abundant slumps have been observed.

These sedimentary levels are pelagic limestones and marly limestones, mainly mudstone and locally wackestone and packstone with "filaments", radiolaria, globigerinids and bioclasts. These facies do not present clear or important differences with the described before for the type B but, exceptionally, mainly in the upper part of the thicker interbeds, peloidal packstone and grainstone appear, in some cases showing hummocky cross-stratification. They have frequently horizontal parallel lamination of algal origin and in some places elemental sequences finishing in their upper part with intensively bioturbated (*Chondrites* and burrows) surfaces. Locally very well preserved belemnites appear.

Type D (Guyot type) (Fig. 2D). Limestones appear capping volcanic edifices more or less flat in their tops. According to the present outcrops we can deduce a minimum extension between 5 and 10 square kilometres. This limestones are mainly oolitic and peloidal grainstones. They also contain oncoids, aggregate grains, foraminifera (*Nautiloculina, Protopeneroplis, Trocholina, Pfenderina, Valvulina*), calcareous algae (mainly *Dasycladaceae*), crinoids and solitary corals. Other microfacies abundant in the lower part of these sedimentary sequences are packstone and/or wackestone with bioclasts (mainly "filaments" and sponge spicules), peloids and some radiolaria. They appear over the volcanic rocks with until 70 m in thickness and according to their facies and age they belong to the Camarena Fm (Molina and Vera, 2000).

This facies distribution shows a shallowing-upward sequence on the formation scale, which also appears on a smaller scale (2 to 5 m thick), with cycles of peloidal wackestone in the lower part changing gradually in the upper part to oolitic grainstones, showing karstification features at the top. Hummocky cross-stratification (HCS) is abundant primarily in the lower part of the formation. Parallel lamination, marked by alternative peloidal and bioclastic laminae, is also frequent. Nodular and bedded chert appear in some beds. In the lower part of the stratigraphic sections, also there are intraformational breccias, synsedimentary faults, slumps and soft-sediment deformation structures. At the bottom of the formation beds with flat tops and irregular bottoms occur, related to the topographical irregularities of the underlying volcanic rocks, in many cases pillow lavas.

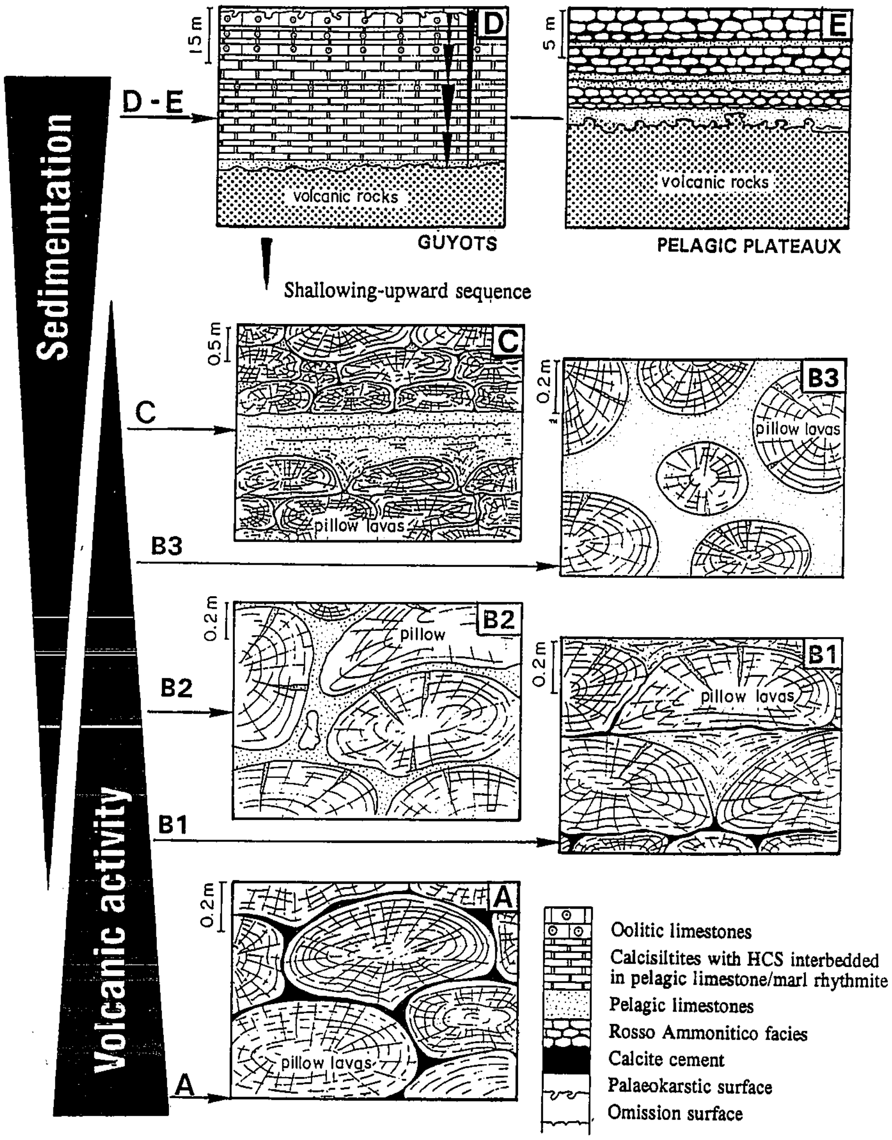

Fig. 2.- Normal o gradual types A to E, disposed according to the importance of volcanism against sedimentation. These different kinds of relationships models between the analysed pelagic and volcanic rocks are obtained from photographs and sketches drawn on the studied outcrops. They are described in the text and synthesized in table 1. Also two models of fossilization of the volcanic edifices (guyots and pelagic plateaux) are included (Types D and E).

Fig. 2.- Tipos normales o graduales A a E, dispuestos de acuerdo con la importancia del vulcanismo respecto a la sedimentación. Estos diferentes tipos de modelos de relación han sido obtenidos a partir de fotografías y esquemas dibujados sobre los afloramientos estudiados. Se describen en el texto y resumen en la tabla 1. También se incluyen dos modelos de fosilización de los edificios volcánicos (guyots y plataformas pelágicas, tipos D y E).

Type E (Pelagic plateau type) (Fig. 2E). Red pelagic limestones and marly limestones (mudstone and wackstone) with abundant "filaments", brachiopoda and other bioclasts, in some places with parallel lamination. They are dominant in the lower part of the sequence directly over the volcanic rocks. In some outcrops typical Rosso Ammonitico facies appear, with a characteristic irregular bottom covering the underlying pillow lavas, and locally with pyroclasts in the pelagic rocks. This relation was recognized previously by Comas *et al.* (1981) in other localities.

Catastrophic and related deposits (Types F and G)

Type F) Sedimentary slided blocks (olistoliths) in the volcanic rocks. They are blocks more than 15 m in length and until 3 m thick, composed mainly by oolitic and/or peloidal grainstone-packstone limestones, as those described in the guyot type. In some cases they have angular volcanic clasts.

Type G) Pyroclastic rocks, breccia-pillows (including the hydroclastic rocks) and neptunian dykes.

Subtype G-1) Pyroclastic lutites,

NORMAL OR GRADUAL TYPES

Volcanic rocks and associated pelagic limestones (types A to C, see Fig. 2)

Type A.-Pillow lavas without pelagic sediments.

Type B.- Pillow lavas with pelagic sediments

Subtype B-1.- Interpillow and intrapillow limestones (minoritary sediments)

B-1a.- Interpillow limestones

B-1b.- Intrapillow limestones

B-1c.- Sediments associated to irregular deformed and brecciated pillows

Subtype B-2.- Pelagic limestones surrounding more abundant pillows

Subtype B-3.- Isolated pillow lavas into the more abundant pelagic limestones

Type C.- Stratiform sedimentary levels interbedded between pillow lavas

Subtype C-1.- Discontinuous sedimentary levels

Subtype C-2.- Partially continuous or continuous sedimentary levels

Sedimentary rocks on volcanic edifices (types D and E, see Fig. 2)

Type D.- *Guyot type* (with shallowing-upward sequences, including oolitic limestones and palaeokarstic surfaces)

Type E.- *Pelagic plateau type* (with pelagic, marly limestone and limestone Rosso Ammonitico facies)

CATASTROPHIC TYPES

Type F.- Sedimentary slided blocks (olistoliths) in the volcanic rocks

Type G.- Pyroclastic rocks, breccia pillows and neptunian dykes.

Subtype G-1.- Pyroclastic lutites, arenites (mainly volcanic ashes) and/or breccias (including breccia pillows).

Subtype G-2.- Neptunian dykes (pelagic sediments in cracks of volcanic rocks)

Table 1.- Classification of the relationship between the studied sedimentary and submarine volcanic rocks.

Tabla 1.- Clasificación de las relaciones entre las rocas sedimentarias y volcánicas submarinas estudiadas.

Table 1.- Classification of the relationship between the studied sedimentary and submarine volcanic rocks.

Tabla 1.- Clasificación de las relaciones entre las rocas sedimentarias y volcánicas submarinas estudiadas.

arenites and/or rudites (including breccia pillows). The lutites and arenites are mainly volcanic ashes appearing in all the analysed localities. The breccias are composed of angular clasts with 12 cm of average size of basalts (mainly fragments of pillows) and pelagic limestones (mudstone).

Subtype G-2) Neptunian dykes. They are pelagic sediments (mudstone or bioclastic wackestone) filling cracks in volcanic rocks. They have a thickness between some millimeters and some centimeters.

Conclusions

Exposures of the sedimentary rocks related with submarine volcanism in a passive continental palaeomargin (Jurassic, Median Subbetic) demonstrate a variety of ways in which sedimentation is affected and modified by submarine volcanism. Seven main types of relationship between sedimentary and volcanic rocks have been established and described. Submarine volcanic edifices in their interaction with the pelagic sedimentation tend to be areas in which the very irregular reliefs developed by the volcanism, act against the possibilities of the normal deposition of the shallow pelagic sedimentation, but in some cases favouring the growth of very interesting shallow carbonate facies, with the rise of guyots. In these special submarine volcanic areas it is not possible to take in account the typical trends of the sea level global change curve. In this area during the Middle and Late Jurassic the volcanic control of the sedimentary supply and environments clearly overprint the effects of sea-level change and subsidence. Volcanism was an important factor in controlling in a complex way the timing and facies architecture of these carbonate deposits and the location in time and space of the related sedimentary discontinuities.

Acknowledgements

This study is part of the results obtained in the Research Projects PB-96-0429 and PB-96-1430 which are financed by the DGES.

References

Comas, M.C., Olóriz, F. and Tavera, J.M. (1981): *Rosso Ammonitico Symposium Proceedings, Roma, Tecnoscienza,* 113-136.

Comas, M.C., Puga, E., Bargossi, G.M., Morten, L. and Rossi, P.L. (1986): *N. Jb. Geol. Paläeont. M.* 1986 (7): 385-404.

Fontboté, J.M. and Quintero, I. (1960): *Not. Com. Inst. Geol. Min. España,* 60: 85-90.

García-Hernández, M., López-Garrido, A.C., Martín-Algarra, A., Molina, J.M., Ruiz-Ortíz, P.A. and Vera, J.A. (1989): *Cuad. Geol. Ibérica,* 13: 35-52.

García-Hernández, M., López-Garrido, A.C., Rivas, P., Sanz de Galdeano, C. and Vera, J.A. (1980): *Geol. Mijnb.*, 59: 155-168.

García-Yebra, R, Rivas, P. and Vera, J.A. (1972): *Acta Geol. Hisp.,* 7: 133-137.

Garrison, R.E. (1972): *Jour. Geol.,* 80: 310-322.

Garrison, R.E. (1973): *Geol. Soc. Amer. Bull.,* 84: 583-594.

Garrison, R.E. (1974): *Pelagic Sediments: On Land and under the Sea.* Inter. Assoc. Sediment., Spec. Pub., 1: 367-399.

Molina, J.M. and Vera, J.A. (1999): *Libro Homenaje a José Ramírez del Pozo.* A.G.G.E.P. Madrid, 91-106.

Molina, J.M. and Vera, J.A. (2000): *Geogaceta,* 27: 107-110.

Morata, D.A., Puga, E., Demant, A. and Aguirre, L. (1996): *Geogaceta,* 20: 576-578.

Portugal, M., Morata, D.A., Puga, E., Demant, A. and Aguirre, L. (1995): *Estudios Geol.,* 51: 109-118.

Puga, E., Fliert, van de J.R., Torres-Roldán, R.L. and Sanz de Galdeano, C. (1988): *Estudios Geol.,* 44: 47-59.

Puga, E., Portugal, M., Díaz de Federico, A., Bargossi, G.M. and Morten, L. (1989): *Geodinamica Acta,* 3 253-266.

Vera, J.A. (1981): *Programa Internacional de Correlación Geológica, Real Academia de Ciencias Exactas, Físicas y Naturales,* Madrid, 2, 129-160.

Vera, J.A. (1988): *Rev. Soc. Geol. España,* 1: 373-391.

Vera, J.A., Molina, J.M., Montero, P. and Bea, F. (1997): *Terra Nova,* 9:163-166.

Preguntas de J. P. Calvo a los autores.

1) En el trabajo se alude a la situación de los diferentes tipos de depósitos en relación con los edificios volcánicos ¿Se dispone de datos sobre la estructura de estos edificios?

2) Podrían los autores indicar la publicación (o publicaciones) dónde se han presentado y discutido los ambientes paleogeográficos en que se desarrolla el vulcanismo de la región?

Respuestas

En primer lugar agradecemos al Prof. Dr. José Pedro Calvo Sorando el interés mostrado por nuestro trabajo al hacernos estas interesantes preguntas.

La primera pregunta, nos parece tiene dos partes, una relativa a la situación de los depósitos en los edificios volcánicos y otra relacionada con la estructura del edificio.

En cuanto a la situación de los diferentes tipos de depósitos respecto al edificio volcánico habría que diferenciar entre los antiguos sedimentos y actualemente rocas sedimentarias ligadas a los tipos normales o graduales (tipos A y E) y los correspondientes a los tipos catastróficos (tipos F y G). Entre los del primer grupo los tipos A, B y C se encontrarían distribuidos de forma dispersa principalmente en el interior de los edificios volcánicos, mientras que los tipos D y E siempre se encontrarían cubriendo las partes más altas de estos edificios, marcando el final de las etapas importantes de vulcanismo en los distintos sectores. En cuanto a los depósitos de tipo catastrófico, el tipo F y subtipo G1 estarían ligados principalmente a las zonas de pendiente y pie de pendiente en los bordes de los edificios volcánicos próxima al margen de los mismos y en las áreas de pendiente que los bordearían, donde sería más propicio el desarrollo de fracturación.

Respecto a la estructura de los edificios volcánicos, estos están compuestos como se indica en el apartado del marco geológico y estratigráfico por tres tipos de rocas volcánicas y subvolcánicas, siendo las lavas almohadilladas generalmente más abundantes en la parte superior de los edificios. Hay que tener presente que la actividad volcánica más o menos intensa y discontinua, la tectónica y la erosión por corrientes submarinas, todas ellas variando en intensidad a lo largo del tiempo, habrán sido las responsables del desarrollo y desmantelamiento continuado de estos edificios volcánicos, lo que les daría formas de elevaciones topográficas submarinas bastante irregulares y complejas. Esta morfología es difícil de precisar en general en el caso de los tipos A a C, principalmente por la alteración que presentan las rocas volcánicas en los afloramientos. En el caso de los edificios situados debajo de los depósitos de tipo D y E podemos deducidr que tendrían formas de tronco de cono de planta más o menos irregular, pero estos edificios como se indica en el trabajo sería entre 5 y 10 kilómetros cuadrados, y su altitud sobre el fondo marino de varios centenares de metros, teniendo en cuenta que los máximos espesores de rocas volcánicas, encontrados en el área de Alicún de Ortega, son de unos 700 m, por lo que probablemente no se sobrepasaría este desnivel topográfico en el fondo volcánico submarino del área estudiada.

Como contestación a la segunda pregunta, entre los trabajos más recientes que tratan sobre los ambientes paleogeográficos en que se desarrolló este vulcanismo y subvolcanismo jurásico podemos destacar por orden de antigüedad los de Comas *et al.* (1986), Vera *et al.* (1997), Molina y Vera (1999, 2000 a, b) y Molina *et al.* (1999). Excepto los dos últimos (cuyas citas bibliográficas se añaden) todos aparecen en las referencias bibliográficas del trabajo.

Otras referencias citadas en la respuesta:

Molina, J. M. y Vera, J. A. (2000b): *Geogaceta*, 27: 111-114.

Molina, J. M., O'Dogherty, L., Sandoval, J. y Vera, J.A. (1999): *Palaeogeogr. Palaeoclimat. Palaeoecol.*, 150: 309-330