Preliminary report of seepage mound occurrences in Spain. Comparison with carbonate mounds from the Amargosa Desert, western USA

Informe preliminar sobre el reconocimiento de depósitos de tipo 'seepage mound' en España. Comparación con montículos carbonáticos del Desierto de Amargosa, oeste de Estados Unidos

J. P. Calvo (*), M.I Pozo(**) and B. F. Jones (***)

(*) Dpto Petrología y Geoquímica, Univ.Complutense, 28040 Madrid
(**) Dpto Q.A., Geología y Geoquímica, Univ.Autónoma, 28049 Madrid
(***) US Geological Survey, Reston VA 22092, USA

ABSTRACT

Seepage mounds are domic-like structures formed by seepage and discharge of groundwater that occur associated with linear fault zones. Two seepage mound occurrences are described from Miocene continental formations in Spain and their features are compared with previously described deposits in Amargosa Desert, western USA. Emphasis is made on the deformation of overlying lacustrine sediments due to the upward growth pressure of the mounds which provides evidence of the mechanism of mound formation.

RESUMEN

Los seepage mounds son depósitos de geometría dómica debidos a flujo y descarga de aguas subterráneas, estando su posición relacionada con zonas lineales de fractura. Describimos en este trabajo dos ejemplos de este tipo de estructura, reconocida por primera vez en nuestro país en formaciones continentales de edad Mioceno (cuencas de Madrid y Las Minas de Hellín). Sus rasgos son comparados con los observados en seepage mounds del Desierto de Amargosa, Plioceno, oeste de Estados Unidos. El modelo de formación propuesto para estas estructuras tiene en cuenta el efecto de deformación sobre sedimentos lacustres suprayacentes debido a la presión de crecimiento hacia arriba de los montículos.

Key-words: *seepage mounds, fault zones, continental carbonate, Neogene*

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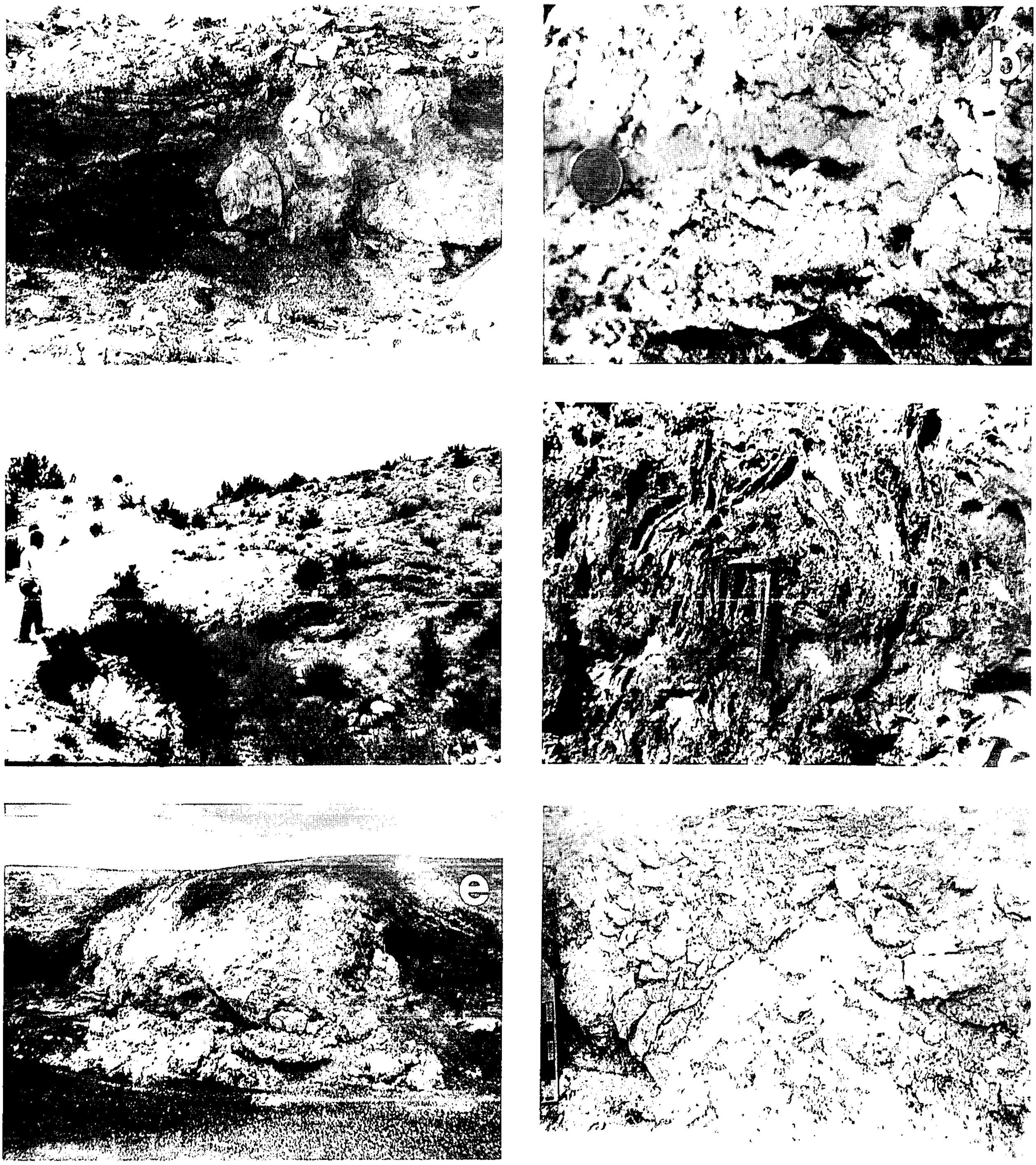
Introduction

Mound springs are defined as accumulations of mineral matter, generally carbonate, with a convex-up (domic) geometry that form in locations where groundwaters emerge, probably under artesian conditions, at the land surface. The distribution of outflow *loci* is related to basement irregularities, commonly faults which constrain groundwater pathways as well as the specific features of the springs. A variety of spring carbonate and/or silica deposits, either related to thermal or lower temperature waters, have been described in recent environments. Most common spring carbonate deposits result from cool freshwater tufas (Pedley, 1990), which locally form mounds at the mouth of the springs. Spectacular tufa mounds differing in both geometry and internal structure from the aforementioned tufas are associated with older and recent deposits of Pyramid, Walker, and Mono lakes, western USA (Council and Bennett, 1993; Benson, 1994) and elsewhere (e.g. some Bolivian lakes, *J.M.Rouchy, personal commun.*, 1995). In addition to these occurrences, other type of mound deposits related to the discharge of groundwater (i.e. seepage mounds) can be recognized. Our examples come from Tertiary formations in Spain (Upper Neogene of the Madrid and Las Minas basins) as well as from the Pliocene sedimentary record of the Amargosa Desert (California-Nevada). In this paper we offer a preliminary report of these occurrences with a brief description of the seepage mound deposits. Emphasis is given to the fracture systems that constrained the location of the mounds.

Seepage mound description

Malcovadeso area, central part of the Madrid Basin

Carbonate deposits interpreted as seepage mounds have been observed in quarries near the village of Esquivias, Toledo province. They occur at the contact between two upper Neogene (Vallesian) units consisting of shallow lacustrine mudstone and carbonate with interbedded paleosols and laminated marlstone, carbonate and diatomite deposited in a deeper lake (Units I and II of Bellanca *et al.*, 1992), respectively. At least four seepage mounds have been detected in the quarried area. The mounds consist of steep-sided masses of carbonate that push up the overlying beds (laminated marlstone and carbonate) (Fig.1a). In the sections, size of the mounds ranges



1-4 m in height, 2-6 m in width. Carbonate in the mounds is white and massive, though in close-up view it displays a speleanlike fabric characterized by an extensive void network and a brecciated texture (Fig.1b). Voids are usually flattened and veneered by drusy calcite mosaics. Carbonate composition is mainly low magnesian calcite. Under the microscope, the carbonate consists of crumb-like to dense micrite which is widely disrupted by calcite spar veins . This texture shows large voids which are partially cemented by calcite.

In general, the Miocene units cropping out in the Malcovadeso are horizontal. However, local folding and thrusting of the lacustrine beds appeared as a striking feature (Leguey *et al.*, 1985) that never received a reliable explanation. By comparison with the other study cases described in this paper (see below), we suggest that local deformation of the Miocene sediments in Malcovadeso was related to the building of the carbonate mounds. Observation on aerial images indicated that the mound occurrences were linked with N 100 E faults.

Moharque area, Las Minas Basin

Las Minas Basin is a tectonic half-graben structure located in the Prebetic area, SE Spain (Elizaga, 1990). The basin was filled by a 500 m thick succession of upper Neogene (Vallesian-Turolian) lacustrine sediments which consist mainly of laminated marlstone and varve-like

Fig. 1a.- Seepage mound in Malcovadeso. Note the irregular, domic morphology of the carbonate deposit. Laminated marlstone and limestone beds belonging to Unit II of Bellanca *et al.* (1992) are pushed up by the mound (centre of the photograph). Heigth of the mound in the outcrop, 3 m.
Fig.1a.- **Seepage mound** ***en Malcovadeso. Nótese la morfología dómica e irregular del depósito carbonático. Las capas de calizas y margas de la Unidad II de Bellanca et al. (1992) aparecen deformadas por el montículo (parte central de la fotografía). La altura de éste es de 3 m***

Fig.1b.- Close-up view of a seepage mound in Malcovadeso. A speleanlike fabric, outlined by flattened voids and calcite drusy veneers is one of the outstanding feature of the carbonate. Diameter of scale coin 2.5 cm.
Fig.1b.- Aspecto de detalle de un **seepage mound** ***en Malcovadeso. La fábrica de carácter espeleotémico, caracterizada por huecos planos y rellenos parciales de calcita*** **drusy,** ***es el rasgo más sobresaliente del carbonato. Diámetro de la moneda, 2'5 cm.***

Fig.1c.- Deformation of lacustrine sediments at the contact with a seepage mound deposit in Moharque, Las Minas Basin.
Fig.1c.- Aspecto del contacto entre el **seepage mound** ***y los depósitos lacustres adyacentes en Moharque, Cuenca de Las Minas. Obsérvese la deformación de estos últimos por efecto de la construcción del montículo.***

Fig.1d.- Internal structure of the seepage mound in Moharque. Strongly deformed beds and a very open void framework form the core of the mound. Hammer for scale, 33 cm.
Fig.1d.- Aspecto de la estructura interna del **seepage mound** ***analizado en Moharque. Obsérvese la fuerte disturbación de capas y la fábrica con amplios huecos que caracterizan el interior del montículo.***

Fig.1e.- General view of a seepage mound in Carson Slough, Amargosa Desert. The mound promotes deformation of the overlying lacustrine beds. Mound in the photograph is about 3 m high and 6 m wide.
Fig.1e.- Aspecto general de un **seepage mound** ***en Carson Slough, Desierto de Amargosa. El montículo deforma claramente las capas lacustres suprayacentes. La altura del montículo es de unos 3 m y su longitud en el afloramiento de unos 6 m.***

Fig.1f.- Close-up view of a seepage mound in Amargosa. The carbonate displays a typical brecciated texture and a massive appearance. Bars in the scale in inches.
Fig.1f.- Aspecto de detalle de un **seepage mound** ***en Amargosa. El carbonato presenta aspecto masivo y textura brechoide. Las barras en la escala corresponden a pulgadas.***

carbonate beds. The seepage mounds have been recognized north-west of the village of Las Minas. The biggest mound is located in Moharque, close to the volcanic vent of Cerro del Monagrillo (Bellon *et al.*, 1981). The mound can be observed both in plan view and cross sectional outcrops. On aerial images, it is seen to be clearly aligned with a SW-NE fault that delimits the northern part of the outcrop. The mound is approximately 140 m long, 30 m wide, and the maximum observed height is about 8 m. Other smaller seepage mounds have been recognized in the area. In all cases the mounds have steep sides and the contact with adjacent marls and limestones is sharply defined (Fig.1c).

The internal structure of the Moharque mounds is very typical and consists of strongly deformed and brecciated thin limestone beds that are extensively silicified (Fig.1d). The whole core of the mound displays this type of structure. The varve-like lamination in the limestone beds is quite similar to that of the lacustrine limestones that infill the basin. In close view, the deposit is characterized by a very open void framework resulting in a speleanlike fabric, even more impressive here than in the Malcovadeso outcrops. Under the microscope, the carbonate texture consists of spar calcite and dolomite mosaics cemented and/or replaced by quartz.

Comparison with carbonate mounds from the Amargosa Desert

The Amargosa Desert is an intermontane basin in the western part of the Basin and Range province (California-Nevada boundary) of the western USA. Pliocene deposits in the area have been described by Papke (1970), Khoury *et al.* (1982), and Hay *et al.* (1986). Carbonate mounds in the Amargosa Desert were first described in detail by the latter authors, who pointed out the linkeage of the mound occurrences with linear zones of groundwater discharge throughout the Pliocene. Source rocks for the Amargosa springs were dolomite and volcanics. The present authors recognized several of these carbonate mounds in Carson Slough, east-central part of the Amargosa Desert. In this area, the mounds occur as white, massive carbonate bodies that deform and push up the overlying sediments (Fig.1e). They are 4-5 m high whereas their width ranges from a few meters to several tens of meters. The composition of the mound carbonate is mainly dolomite with variable amount of calcite and silica. The fabric of the carbonate is commonly brecciated or nodular (Fig.1f) and displays a typical void network, though spaces between nodules and/or fragments of carbonate are usually plugged with marl. Locally, the uppermost part of the mounds shows abundant accumulation of concretionary silicified carbonate.

Discussion and conclusions

In spite of some compositional and textural differences among the carbonate mound deposits recognized in Malcovadeso, Moharque and Amargosa, they have several main features in common, which indicate they formed in a similar pattern. In all cases the mounds display a typical domic morphology which is accompanied by deformation, folding and shearing of the overlying sediments. An internal structure derived from strong brecciation and disruption of the carbonate, as well as by an open void framework (spelean fabric) is a common feature in the three study cases. In addition, silicification of the carbonate is a widespread feature in the Moharque and Amargosa mounds.

Our interpretation of the processes leading to the formation of the mounds is based on the linkeage of the mound occurrences with linear fault zones. This is clearly established in the Amargosa (Hay *et al.*, 1986) and in Las Minas, whilst it is deduced from larger regional observation for the Malcovadeso occurrences. The faults constrained both groundwater flow pathways and the zones where groundwater seeped upward, resulting in the formation of the mounds (Fig.2). The increase in volume of the resulting sedimentary body is outlined by the folded and brecciated internal structure of the mounds, which in turn exhibit a very open void framework. The deformation of lacustrine sediments contouring the mounds was due to the upward growth pressure derived from this volume increase. An unsolved question in the pattern concerns the accumulation of new mineral matter in the mounds. In Moharque, this accumulation might be low, as the mounds consist mostly of deformed

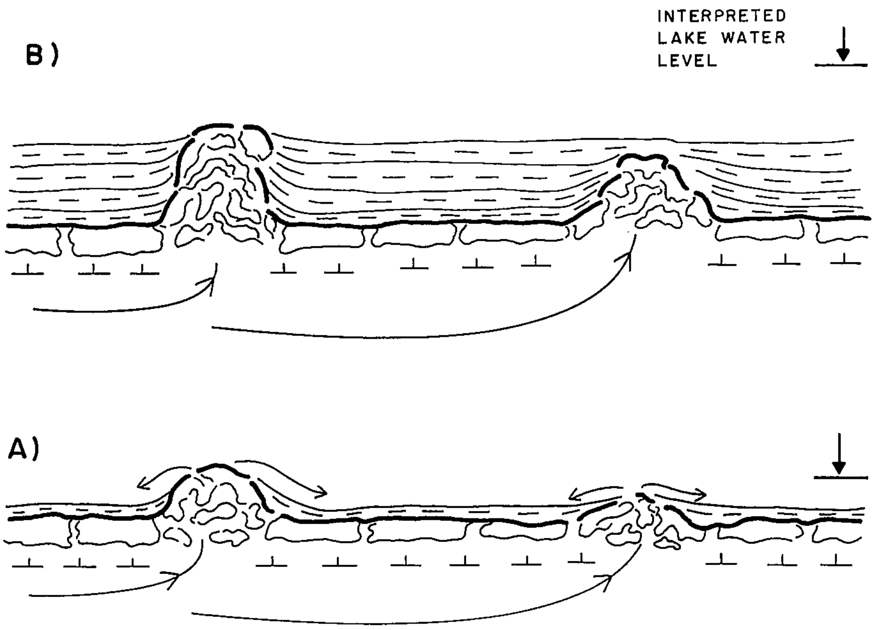


Fig.2.- Idealized sketch for modelling the formation of the seepage mounds analyzed in this paper. A) Initial stage of mound development, B) Final stage of mound growth with local disturbation of the complete overlying sequence.

Fig.2.- Modelo idealizado de formación de* seepage mounds *a partir de los ejemplos descritos en este trabajo. A) Etapa inicial del desarrollo de los montículos, B) Etapa final.

lacustrine beds wherein the original micrite has been either transformed to spar dolomite and/or calcite or pervasively silicified. Additional calcite is recognized as drusy mosaics veneering voids. The Malcovadeso and Amargosa occurrences do not show such conclusive evidence, the mounds displaying a more massive appearance. Hay *et al.* (1986) pointed out that dolomite, accompanied by variable amount of sepiolite and other Mg-rich clays, was deposited by seepage groundwater in the Amargosa mounds, but they did not evaluate the extent to which these new mineral phases were incorporated into the mounds. Our observations in Carson Slough, Amargosa, seem to indicate that dolomite and silica formed from seepage groundwater, thus contributing to the growth and induration of the mound deposit. This effect is not so clear in Malcovadeso, where calcite is the only mineral found in the mounds. The homogeneous structure recognized within the mound occurrences in Malcovadeso may be due either to huge accumulation of carbonate precipitated from the seepage waters or perhaps it reflects the original massive texture of the sediments affected by the outflowing waters.

Finally, the time at that the mounds started to grow merits some comments. In all cases, the formation of the mounds lead to deformation of the overlying beds. As can be clearly observed in Malcovadeso, the growth of the mounds deformed lacustrine laminated marlstone and limestone deposited in relatively deep lake conditions (Bellanca *et al.*, 1992) and deformation affects locally the complete package of beds (Fig.2). Consequently, we interpret that the discharge of groundwater through the mounds was an effective mechanism for water supply resulting in lake expansion. A similar situation is recognized in Amargosa, where the domic growth of the mounds affected overlying lacustrine mudstone and carbonate beds. This is envisaged as an alternative mechanism to that proposed by Hay *et al.* (1986) for carbonate mounds in Amargosa and by Hay & Stoessell (1984) for similar deposits in Amboseli, Kenya. In both locations, they characterized the mounds as caliche breccias related to the development of paleosols.

To conclude, the carbonate mounds recognized in Malcovadeso, Moharque, and Amargosa are interpreted as seepage mounds that were related to groundwater discharge throughout fault linear zones. This resulted in the growth of domes in which strongly brecciated carbonate and silica deposits occur. In some cases, as in Malcovadeso and Amargosa, feeding of water would account for the expansion of the lacustrine environment where mounds formed. Modern counterparts of these seepage mounds have been documented from coastal lakes of SE Australia (Handford *et al.*, 1984). The present paper is the first report of seepage mound deposits in Spain.

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