Unusual twinning features in large primary gypsum crystals formed in sait lake conditions, Middle Miocene, Madrid Basin, Spain: palaeoenvironmental implications- reply

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We are thankful for Shearman's comments on our paper (Rodriguez-Aranda et al., 1995) as they provide the opportunity to reinforce several of the points that led us to the interpretation of these twinned gypsum crystals as an exception to the classical Mottura's rule. We consider it is worthy to take into account the suggestions placed by D. Shearman in order to enlarge an useful debate regarding the palaeoenvironmental implications of this type of gypsum occurrence.

We believe that most of Shearman's misgivings on our interpretation of the twinned gypsum in the Madrid Basin corne from his uncertainty on the correct tectonic position of the succession in which gypsum deposits occur. Consistent with this idea, if the succession is overturned the problem is over, but if the polarity is normal we have a problem as the twinned crystals stand with their reentrants directed downwards from the depositional surface, just the opposite of Mottura's observation. In the case this latter statement is right, D. Shearman suggests an alternative mode! to explain this particular gypsum occurrence by proposing the growth of the gypsum crystals from the underside of rafts of organic matter or crusts of other salts floating in the brine.

Our statement that the Middle Miocene succession near Driebes (eastern part of the Madrid Basin) has not been overturned at ail is sup- ported by the authors large experience in the geology of the basin (Calvo et al., 1989, 1990; Ordózez et al., 1991; Alonso-Zarza et al., 1992; Sanz et al., 1995; amongst other publications), detailed mapping of the area (San José, 1975; Rodriguez-Aranda, 1995), and evidence provided by oil exploration (AMOSPAIN, SHELL) during the seventies and eighties (Querol, 1989). More- over, no doubt exists in the Spanish geology cul- ture that Middle Miocene successions in the large continental Tertiary basins of the Iberian Penin- sula (Madrid, Duero, and Ebro basins) have not undergone strong tectonic disturbance (see Friend and Dabrio, 1995, for a review). In the study area, thrusting associated with the uplift of the Al- tamira Range located 15 km far from Driebes took place during the Late Oligocene- Early Miocene (Vegas and Banda, 1982; De Vicente et al., 1995). Additional data supporting the normal polarity of the Driebes section concerns the recognition of sequences belonging to the Miocene Intermediate Unit (Aragonian-Vallesian) overlying the Lower Aragonian gypsum as well as minor features dealing with the sequential arrangement of facies (see p. 126 in Rodríguez-Aranda et al., 1995). Orientation of root bioturbation developed downwards from some bed surfaces is also common.

Thus, our interpretation of the twinned gypsum crystals showing downwards reentrant angles in the Madrid Basin has been carried out on the clear and solid base that the gypsum deposits are in a normal stratigraphie position. Consequently we have tried to explain the specific features of this type of gypsum and propose a growth pattern for such an unusual fabric. We also considered the hypothesis of a secondary origin through the replacement of more soluble minerais, e.g. glauberite, in fact an abundant minerai within the Miocene sequences in the basin. In contrast with the reported features that have been found to be characteristic of the replacement of glauberite by large gypsum crystals (Ortf Cabo et al., 1995), the Driebes gypsum does not include any ghosts or relies of a former minerai, whereas such relies are locally observed within other types of gypsum from the Madrid Basin. The primary origin of the gypsum is evidenced by both the reworking of crystals in beds of coarse clastic gypsum interbedded with maris (Almoguera area) and dissolutional features at the top of some gypsum beds. Even if these features could be also consistent with a syndepositional diagenesis, that would not change significantly the final interpretation.

There are many other indications of a syndepositional gypsum growth as the presence of cloudy aggregates of anhydrite crystals and the distribution of sedimentary particles with respect to the crystal fabric. The burial depth of the Miocene formation, which remained Jess than 100 m, cannot explain the processes of partial dehydration leading to the development of anhydrite that must be interpreted by early diagenetic processes taking place in the depositional environment. As indicated in the diagrammatic sketch of our article (fig. 6 in Rodriguez-Aranda et al., 1995), the sedimentary particles are trapped along the vertical planes of crystal intergrowth and lie on the surface of the {111} bipyramids which are affected by microdissolutional features.

Ali the aforementioned data can be shown as evidences for a primary syndepositional growth and it is beyond doubt that these gypsum crystals are twinned, so that we had no alternative but to explain the crystal formation by processes that do not respect the classical Mottura rule. Taking only into account considerations about the direction of growth of sub-crystals in the twins, Shearman questions this interpretation and propose to consider that the crystals grew downwards suspended from the undersides of rigid rafts of organic matter or crusts of other salts floating in the surface of the brine. We thank him for this suggestion, which is consistent with some observations from several coastal lagoons in the Mediterranean (Cornee et al., 1992) and elsewhere (Handford, 1991), but we do not believe it is a working mechanism in our case taking into account both the size and weight of the gypsum crystals. Besides, it is difficult to understand such an accumulation of big gypsum crystals with no evidence of breaking or bending of the crystals and no deformation of the marly soft substrates on which they could fall.

On the other hand, the objections placed by D. Shearman to the growth pattern that we proposed for the Christmas-tree gypsum, especially that concerning relationships among sub-crystals, suggest a nice subject of discussion. We think that Shearman's divergence dealing with the arrangement of the sub-crystals derives from the fact that he considers the growth pattern of the Christmas-tree gypsum to be similar to that of the classical selenite. On the contrary, we argue in the paper that the direction of faster growth of the crystals is different in the two cases, as indi- cated by the dimensions of the Christmas-tree gypsum crystals (p. 127, second paragraph, in Rodríguez-Aranda et al., 1995; Fig.1). Christ- mas-tree crystals are elongated horizontally ac- cording to the b-axis, which in many cases repre- sents the maximum length (10-30 cm, or even more) of the crystals. By their side, crystals in classical selenite are elongated vertically accord- ing to the c-axis. In this way, the intergrowth of

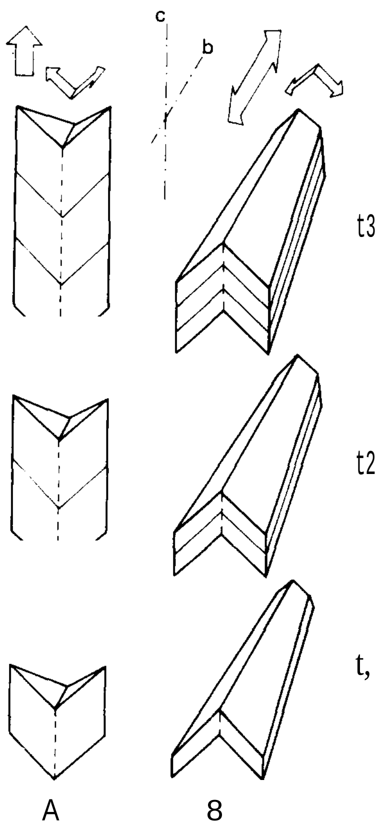

Fig. 1. Comparison of crystal growth patterns in classical selenite (A) and Christmas-tree gypsum (B). Arrows indicate main directions of growth in each case; *t*> t_2 and t_3 indicate successive crystallization stages. The directions of the crystallographic axes c and *b* are drawn in the uppermost part of the sketch.

sub-crystals in the Christmas-tree gypsum is mainly developed horizontally and laterally due to a higher growth rate of the {010} faces (actually the {020} faces, Heijnen and Hartman, 1991) and the {120} and {100} faces. In this pattern, the growth of the {111} faces would be slow and accompanied by a discontinuous development of the Christmas-tree crystals in the vertical direction. Provided the regularity of the intervals of the outlines of {111} on the plane (010) (fig. 3 in Rodríguez-Aranda et al., 1995), we interpret that discontinuities of vertical growth could be seasonal. For illustrating this growth pattern we can calculate that in a single step of growth a twinned crystal could develop 0.7 cm along the c-axis (vertical), 20 cm along the b-axis (horizontal) and 8 cm according to the [101] direction, so 4 cm lateral to each side of the twin plane (Fig. 1).

The same as Shearman, we also noticed that the base of the subcrystals were not moulding the top of the underlying ones, in apparent contradiction with the classical ideas about the modalities of crystal growth. However, the evidence that these crystals were primary and grew in situ led us to consider these relations between subcrystals as depositional. Thus, lacking of moulding between sub-crystals is interpreted to result from the development of microdissolution processes followed by further epitaxial crystallization. Microdissolution processes took place in periods of episodic, probably seasonal, dilution of the lake brine. As the brine reached gypsum supersaturation, the new sub-crystals would start to grow in optical continuity, rapidly developing from the twin plane along the b-axis and according to the [101] direction. At the same time the underlying sub-crystals, previously affected by microdissolution, would regain growth slowly along the c-axis (vertical), that is the only available space for gr9wing. The growth of these underlying sub-crystals results in formation of {111} faces with hexagonal outlines in sections eut parallel to the (100) plane. However, the overlying crystals, growing faster than the lower ones, interlocked then aborting the development of the hexagonal pattern of the {111} faces. The resulting morphology is observable in sections parallel to the twin plane (100) that display a mosaic of quasihexagonal-quasipentagonal traces (figs. 4B and 5 in Rodrfguez-Aranda et al., 1995), so that the sub-crystals are interlocked in the directions of faster growth. According to this pattern, the number of sub-crystals must not be the same in the successive arrays. Only when microdissolution has not been effective there is moulding between the stacking sub-crystals and so the sections eut parallel to the twin plane exhibit sub-crystals that are properly hexagonal. On the contrary, when moulding is not recognized the surfaces between sub-crystals could represent either the crystals-brine interface or simply the basal morphology of an array of sub-crystals growing from the twin plane. In this pattern, we do not discard that the original fabric of the Christmas-tree gypsum had some porosity that has been plugged by later epitaxial gypsum.

To conclude, in this reply we have tried to refine our interpretation on the crystallographic pattern exhibited by the Christmas-tree gypsum which is clearly differentiated from the classical selenite. We are forced indeed to propose an alternative mode! in view they do not show the same features that the latter one. Anyway this mode! takes into account that the tectonic and sedimentological characteristics are quite well established and consequently the relationships among sub-crystals have to be interpreted in terms of in situ crystal growth, even if the interpretation shows some variation with that classically proposed.

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