

Answer to the comment of Casas et al. about González Acebrón et al.'s (2011) paper

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The comment of Casas et al. concerns the paper published by González-Acebrón et al. (2011) and refers mostly to their model for the structural and thermal events in the sedimentary record (Late Jurassic–Early Cretaceous) from the Cameros Basin. Their model differs significantly from the interpretations previously published by Mas et al. (1993), Guimerà et al. (1995, 2004) and Mas and Salas (2002). Their main concern appears to be the difference of opinion about the previously published structural evolution of the basin, not the results of our new study. Rather than debate the earlier, more appropriate papers, they have chosen this our marginally related paper to air their different view of the structural interpretations. Our paper did not concern evidence for interpretations of the structural evolution of this basin, which had already been published and peer-reviewed. We clearly stated that we had excluded their model for consideration relative to our new data, why we had done so, and referred to the appropriate peer-reviewed literature. Thus, we must question whether this is

the appropriate venue for airing such a debate. It appears their comment should have been aimed at some other paper with a very different focus.

As Casas et al. have pointed out, the Cameros Basin represents “one of the best-known and controversial basins in the Iberian microplate”. The Cameros Basin is atypical of the different Mesozoic basins of Iberia by its very high sedimentation and subsidence rates, generating a stratigraphic sequence of more than 9,000 m from Tithonian to Early Albian. In addition, sediments were affected by low-grade metamorphism. Given the controversial nature of this basin, it is inevitable that such debates occur, but more appropriate venues have been used in the past, going back almost 20 years.

In their comment we appreciate that Casas et al. consider that we have produced *invaluable data about the thermal evolution of the basin... and an important contribution to the understanding of the post-sedimentary, pre-inversion processes...* We agree with their opinion that our research will *undoubtedly add new evidence to the knowledge of hydrothermal processes in general and particularly to the paleothermal evolution of the basin*. Where we disagree with them is that we have (1) inappropriately omitted references and (2) made interpretations without prior consideration of their model. Their model had already been evaluated and rejected in multiple previously published papers, more appropriate for debating the differences between both structural models (e.g., Mas et al. 1993; Guimerà et al. 1995; Mas et al. 2003; Omodeo-Salè et al. 2011). It is on this basis that the synclinal basin model (SBM) of Casas et al. was rejected. We had no intention of inappropriately extensive repetition of data and arguments already in the literature, in our paper. Again, our paper was not an appropriate venue for that. Below, we reply to each of their comments.

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Inappropriate references

We have to disagree with the Casas et al. assertion that referencing was not appropriate. They apparently have taken the point of view that we should have rehashed all of the literature on the debate on the structural evolution of the basin, even though that was not the focus of our paper. As an example of our point, in their paper on the structure of the Cameros Basin (Casas et al. 2009), we did not necessarily expect them to reference all previous studies concerning the stratigraphy and basin structure in the Cameros Basin. Had they been practicing what they were preaching, they would have cited Mas et al. (2002, 2003, 2004) and Guimerà et al. (2004). The paper at which their comment is directed (González-Acebrón et al. 2011) gave a fair airing to their views considering the focus of the paper. Several paragraphs in the sections of “Introduction”, “Basin formation” and “Metamorphic processes and studied sections” are dedicated to introduce the idea of burial, dynamo-thermal metamorphism and to discuss the model that Casas et al. maintain to explain the Cameros Basin configuration. In these sections, the following of their papers are referred to (Casas-Sainz and Simón-Gómez 1992; Casas-Sainz and Gil-Imaz 1998; Mata et al. 2001; Casas et al. 2009; Del Río et al. 2009), which adequately summarized the appropriate material for those discussions.

In addition, Casas et al. make the following assertions in relation to referencing, and we respond to each in sequence:

1. Casas et al. write that up to date, the only thorough studies of the small-scale extensional structures (namely tension gashes and microfaults) at the basin scale within the Cameros basin have been carried out by Guiraud and Seguret (1985).

In our opinion, this comment makes no sense in relation to our paper. In our paper, we never mentioned that our work attempted to be a thorough study of small-scale extensional structures in the Cameros Basin or that we had been the first to do so.

2. Casas et al. write that it is not justified to reject the syncline basin model.

Multiple publications have criticized the SBM proposed by Casas et al. on the basis of mechanical flaws. These publications question that extension was produced by the action of a normal fault dipping southward and located in the Upper Triassic deposits to produce a “simply” synclinal basin fill, as Casas et al. suggest (Casas-Sainz and Simón-Gómez 1992; Casas-Sainz 1993; Mata et al. 2001; Casas et al. 2009; among others). Those studies disprove their hypothesis because of the presence of marine Jurassic rocks constituting the substratum throughout the basin (e.g.,

Mas et al. 1993, 2003; Guimerà et al. 1995; Omodeo-Salè et al. 2011). In addition, geological mapping and seismic profiles (Mas et al. 1993; Guimerà et al. 1995) reveal that architecture of the basin infill consists of a lateral juxtaposition of depositional sequences where depocentres were located to the north and overlapped the Jurassic substratum. This was interpreted as a consequence of the southward displacement of the hanging wall including the earlier depositional sequences (e.g., Mas et al. 1993, 2003; Guimerà et al. 1995; Omodeo-Salè et al. 2011). The data and arguments to reject the SBM idea have been published previously. It would have been inappropriate to restate all of these in González-Acebrón et al. (2011).

3. Casas et al. write that the term “hydrothermal metamorphism” is used inappropriately. They propose that this term should be used to describe the alteration of oceanic crust and that it is used in incorrectly in González-Acebrón et al. (2011) to describe metamorphism in the Cameros Basin.

Hydrothermal metamorphism is defined following the recommendations from the International Union of Geological Sciences Subcommittee on the Systematics of Metamorphic Rocks (Fetters and Desmons 2007). It is a “type of metamorphism of local extent caused by hot H₂O-rich fluids. It is typical of local extent in that it may be related to a specific setting or cause”. Thus, no restriction to the use of this term to the oceanic crust exists, and so the use of hydrothermal metamorphism for the Cameros Basin is completely correct.

A priori rejection of the Syncline Basin Model

Casas et al.’s comment points out their main concern with González-Acebrón et al. (2011) is its *a priori* rejection of the SBM. We agree that we rejected this hypothesis at the outset of our discussion, but do not agree that it is a cause of concern. The syncline model for Cameros Basin was rejected on the basis of an extensive literature using data other than that presented in González-Acebrón et al. (2011). There is no reason to consider a disproven hypothesis without some real reason. One merely is required to refer to it and explain why it is not being considered. That is how deductive scientific reasoning makes progress, through rejection of hypotheses. The reasons for rejection of the SBM hypothesis can be summarized from the literature as follows:

1. There is no evidence to assume the presence of a major extensional fault at the northern boundary of the basin, mainly because the marine Jurassic substratum appears

to be continuous throughout the basin. This continuity is maintained even after the basin inversion (Mas et al. 1993, 2003; Guimerà et al. 1995; Omodeo-Salè et al. 2011).

2. There is northward migration of successive depositional sequences and depocentres, manifested by their onlap onto the pre-basin Mesozoic substratum and onlap onto the northern border of the basin (Mas et al. 1993, 2003; Guimerà et al. 1995; Omodeo-Salè et al. 2011).
3. There is a progressive spatial evolution of facies in depositional sequences, from proximal areas of deposition (i.e., coarse-grained deposits in alluvial fan systems) at the southern areas to distal facies (i.e., lacustrine) at the northern areas of the basin (i.e., Urbión Gr.; Enciso Gr.; Oliván Gr.). There is no evidence for an active source of sediments in the northern area (Alonso and Mas 1993; Mas et al. 2003).
4. There is evidence of non-prograde hydrothermal alteration (Alonso-Azcárate et al. 1995; Barrenechea et al. 1995, 2000, 2001). These authors considered the composition and permeability of sediments as main factors that control the alteration. This fact produces thermal inversion across sections in the depocentre areas (Mantilla-Figueroa et al. 1998, 2002; Barrenechea et al. 2001) and postrift age (Casquet et al. 1992).

The four summarized observations above are used to disprove a “simply” extensional synclinal basin model. In the literature, we have offered an alternative hypothesis consisting of superimposition of sedimentary sequences but with consistent depocenter migration to the north. This hypothesis explains data summarized above and supports the idea that sedimentary infill was the consequence of syn-sedimentary hanging-wall displacement to the South. Thus, the Cameros Basin can be considered as an extensional ramp syncline basin, formed on a south-dipping ramp associated with a buried horizontal extensional fault several kilometers deep (Mas et al. 1993, 2003; Guimerà et al. 1995; Omodeo-Salè et al. 2011).

On the basis of the comment of Casas et al., it is clear that they still consider the syncline basin model to be viable. It is valuable for the readers to see two such differing interpretations can arise. The explanation is related to differences in basic mapping and stratigraphic analysis that can be summarized with the following key points:

1. As explained earlier, there is one essential observation that is the key to understand the two differing interpretations. Casas et al. do not recognize or consider the onlap of the Enciso Gr. (including Leza Fm.) on the northern border of the basin, as demonstrated by Guimerà et al. (1995) and Mas et al. (2002; its Fig. 2b).

2. Furthermore, Casas et al. (2009) consider that the Oncala Gr. crops out along the northern border of the basin and dipping southward (see Fig. 3a from Casas et al. 2009), but it is the Enciso Gr. that is found.
3. In addition, Casas et al. consider “the existence of continuous outcrops of the syn-rift sequence all along the northern basin border”. We think this observation is in error and leads to significant misinterpretations. The mapping used by Casas et al. (Mata et al. 2001; Villalaín et al. 2003; Casas et al. 2009) corresponds to an old geological concept of the sedimentary record of the basin, possibly obtained from the publications of the Spanish Geological Maps, especially those of Munilla (no. 242), Enciso (no. 280) and Cervera del Río Alhama (no. 281) from the MAGNA serie (IGME 1981, 1982, 1990, respectively).
4. The more recent stratigraphic framework of the Cameros Basin can be analyzed in several newer publications (Mas and Salas 2002, p. 285; Mas et al. 2003, 2004, p. 506. All of these publications demonstrate that the Oncala Gr. does not crop in the northern part of the basin, as Casas and co-authors maintain. The carbonate units cropping out in this area correspond to the Leza Fm., a lithosome included in the Enciso Gr., recently dated by Suárez et al. (2010) as Barremian-Aptian. We speculate that Casas and co-authors may have confused this carbonate formation with carbonates from Oncala Gr. This speculation is backed up by observing Fig. 3a and b in Casas et al. (2009).
5. Another problem with the mapping of Mata et al. (2001), Villalaín et al. (2003) and Casas et al. (2009) is that they do not recognize the onlap of the main sedimentary units (Oncala Gr., Urbión Gr., Enciso Gr. and Oliván Gr.) over the Mesozoic substratum in the northern area of the basin as a result of the migration of depocenters to the north. This onlap can be observed clearly along the northern border of the basin, where depositional sequences 1 + 2, 3 and 7 onlap progressively over the Jurassic substratum (Fig. 1 in González-Acebrón et al. 2011). This onlap is not recognized in Fig. 3 from Casas et al. (2009), which offers a scheme that greatly differs from our detailed mapping of stratigraphic units.
6. Casas et al. have pointed that seismic reflection data “unequivocally” support their SBM, referencing the publications by Casas-Sainz and Gil-Imaz (1998) and Casas et al. (2009). However, these authors forgot the seismic interpretations of Guimerà et al. (1995) where a seismic reflection analysis clearly support the progressive northward onlap of depositional sequences over marine Jurassic deposits at the basin substratum (Fig. 6 of Guimerà et al. 1995).

Thus, the issues with the stratigraphic, mapping and seismic observations summarized above can clearly lead to an incorrect model for basin evolution. Once such model is proposed, as Casas et al. have pointed out, one can find paleomagnetic data (Villalaín et al. 2003), mineral assemblages and fluid inclusion microthermometry (Mata et al. 2001), and even some of the seismic observations (Casas et al. 2009) that are consistent with it. Consistency with a hypothesis does not prove it to be correct, however. As summarized in the foregoing, other observations can disprove it.

Finally, the comment of Casas et al. offers a last figure with two cross sections trying to express the two opposing basin models proposed for the Cameros Basin. Unfortunately, Casas et al., represent our model incorrectly. We have already published the correct relationship in Fig. 12 of González-Acebrón et al. (2011) and do not see why that would modify our view and represent it as ours. The extensional ramp-flats configuration that we propose is not at a continuous level that extends toward the north. In contrast, the northern flat connects with the normal listric faults outside the Cameros Basin toward the north. These normal faults are responsible of the configuration of satellite basins located between the Cameros Basin and the Vasco-Cantabrian Basin at the north of the Iberian plate.

Comment on thermal data

Casas et al. question the position of samples from González-Acebrón et al. (2011) within the basin (gray star in Fig. 12). We must say that the stratigraphic location of the samples is absolutely correct: they correspond to the Tera Gr., and thus, their position in Fig. 12 is completely well supported.

On the other hand, in several papers, several authors (e.g., Mata et al. 2001) have tried to demonstrate “the close relation between paleotemperatures and the position within the stratigraphic sequences” as a prograde sequence. Casas et al. use this paleotemperature data as support for their SBM and disproof of our model for hydrothermal metamorphism (e.g., Mata et al. 2001). Oddly, Mata et al. (2001) supported a mixed hypothesis with a prograde sequence overprinted by syn to retrograde hydrothermal events; thus, the hydrothermal metamorphism is in some way accepted by these authors.

Furthermore, an analysis of the position of samples for paleotemperature analysis in the stratigraphic framework used in Mata et al. (2001) shows that they are not part of a local vertical succession (Fig. 2A and B in Mata et al. 2001). Their oldest samples (T1 to T4 from the Tera Gr.) were collected close to the El Pegado anticline, where hydrothermal alteration processes reach the anchizone-epizone boundary (i.e., Barrenechea et al. 2001; Mantilla-

Figuroa et al. 1998, 2002). In contrast, their younger samples (Urbión and Oliván Gr.) were collected far away representing a vertical sample succession, but shifting laterally more than 25 km. On the basis of this fact, an incorrect prograde sequence was deduced.

Comments about the age of the metamorphism are not justified as far as the age obtained by Del Río et al. (2009) by SHRIMP U-Pb dating on authigenic monazites (99 ± 2 My) is inside the age range of Casquet et al. (1992) by K-Ar in authigenic illites (108-86 My).

In addition, Casas et al. argue that chlorite is not a reliable geothermometer. In our paper, geothermometric data from chlorites are cited together with illite crystallinity from Mantilla-Figuroa (1999) and Barrenechea et al. (2001). Both types of data point to equivalent temperatures. We considered useful to refer the chlorite data in order to show all the available geothermometers in the study area, independently of its level of reliability.

Casas et al. consider that almost 400 m is a thin sedimentary sequence (Fig. 11 of González-Acebrón et al. 2011) to calculate thermal gradients among fracture fillings. However, in our work, we have demonstrated that variations in paleotemperature data in veins crossing this sedimentary thickness exist. Thus, we can accept these gradients. In addition, changes in gradient between both sections evidence the hydrothermal metamorphism.

Casas et al. comment that in this case “it seems admissible for the authors to consider sedimentary bodies to be superimposed in the vertical”. This sentence makes no sense and indicates a scale confusion of these authors between the architecture of sedimentary bodies in the local analyzed area and the architecture of depositional sequences in the whole basin.

Finally, González-Acebrón et al. (2011) do not propose three hydrothermal events as Casas et al. stated. Only two thermal events are proposed in this paper.

Conclusion

In conclusion, we would like to thank Casas et al. (2009), Villalaín et al. (2003) and Mata et al. (2001) for the quality data they have provided toward understanding the Cameros Basin. We believe that their criticism that we did reference all of the discussion of the debate on the Cameros Basin is misplaced. They have projected this structural debate onto a paper of much different focus and scope. We add that the scientific method is one of disproof of hypotheses. Their basin model has been disproven in prior publications. The fact that some data are consistent with this discredited model does not make it correct. Finally, we appreciate Casas et al.’s compliments on the detailed petrographic and geothermometric data we have produced. We disagree with

their SBM, but we agree with them that there is much yet to be done to fully understand this complex system. Our work has shown and characterized two different hydrothermal events of Cretaceous and Eocene age. But a more detailed petrographic study integrating various structural elements, geothermometry and thermochronometry will undoubtedly result in this already complex story evolving further.

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References

- Alonso-Azcárate J, Barrenechea JR, Rodas M, Mas R (1995) Comparative study of the transition between very low grade metamorphism and low grade metamorphism in siliciclastic and carbonate sediments. Early Cretaceous, Cameros Basin (North Spain). *Clay Miner* 30:407–419
- Barrenechea FJ, Rodas M, Mas R (1995) Clay mineral variation associated to diagenesis and low grade metamorphism of early cretaceous sediments in the Cameros Basin, Spain. *Clay Miner* 30:89–103
- Barrenechea FJ, Rodas M, Frey M, Alonso-Azcárate J, Mas JR (2000) Chlorite, corrensite and chlorite-mica in Late Jurassic fluviolacustrine sediments of the Cameros Basin of Northeastern Spain. *Clay Clay Miner* 48(2):56–265
- Barrenechea FJ, Rodas M, Frey M, Alonso-Azcárate J, Mas JR (2001) Clay diagenesis and low-grade metamorphism of Tithonian and Berriasian sediments in the Cameros basin. *Clay Miner* 36(3):325–333
- Casas AM, Villalain JJ, Soto R, Gil-Imaz A, del Río P, Fernández G (2009) Multidisciplinary approach to an extensional syncline model for the Mesozoic Cameros Basin (N Spain). *Tectonophysics* 470:3–20
- Casas-Sainz AM (1993) Oblique tectonic inversion and basement thrusting in the Cameros Massif (Northern Spain). *Geol Acta* 6(3):202–216
- Casas-Sainz AM, Gil-Imaz A (1998) Extensional subsidence, contractional folding and thrust inversion of the Eastern Cameros Basin, Northern Spain. *Geol Rundsch* 86:802–818
- Casas-Sainz AM, Simón-Gómez JL (1992) Stress field and thrust kinematics: a model for the tectonic inversion of the Cameros Massif (Spain). *J Struct Geol* 14(5):521–530
- Casquet C, Galindo C, González-Casado JM, Alonso A, Mas R, Rodas M, García E, Barrenechea JF (1992) El metamorfismo en la Cuenca de Los Cameros. *Geocronología e implicaciones tectónicas*. *Geogaceta* 11:22–25
- Del Río P, Barbero L, Mata P, Fanning CM (2009) Timing of diagenesis and very low-grade metamorphism in the eastern sector of the Sierra de Cameros (Iberian Range, Spain): a U-Pb SHRIMP study on monazite. *Terra Nova* 21:438–444
- Fetters D, Desmons J (2007) *Metamorphic rocks: a classification & glossary of terms*. Cambridge University Press, Cambridge
- González-Acebrón L, Goldstein RH, Mas R, Arribas J (2011) Criteria for recognition of localization and timing of multiple events of hydrothermal alteration in sandstones illustrated by petrographic, fluid inclusion, and isotopic analysis of the Tera Group, Northern Spain. *Int J Earth Sci* 100:1811–1826
- Guimerà J, Alonso A, Mas R (1995) Inversion of an extensional-ramp basin by a newly formed thrust: the Cameros Basin (N Spain). In: Buchanan JG, Buchanan PG (eds) Basin inversion. Geological Society Spec. Publ. 88:433–453
- Guimerà J, Mas JR, Alonso A (2004) Intraplate deformation in the NW Iberian Chain: mesozoic extension and Tertiary contractional inversion. *J Geol Soc Lond* 161:291–303
- Guiraud M, Seguret M (1985) A realising solitary overstep model for the late Jurassic-early cretaceous (Wealdian) Soria strike-slip basin (Northern Spain). *SEMP Special Publ* 37:159–175
- IGME (1981) Mapa geológico de Enciso (no. 280)
- IGME (1982) Mapa geológico de Cervera del Río Alhama (no. 281)
- IGME (1990) Mapa geológico de Munilla (no. 242)
- Manilla-Figueroa LC (1999) El metamorfismo hidrotermal de la Sierra de Cameros (La Rioja-España): Petrología, Geoquímica, Geocronología y contexto estructural de los procesos de interacción fluido-roca. Ph.D. Thesis UCM, 361 pp
- Manilla-Figueroa LC, Casquet C, Mas JR (1998) Los paleofluidos del Grupo Oñcalá, Cuenca de Cameros (La Rioja, España): Datos de inclusiones fluidas, isótopos de oxígeno y SEM. *Geogaceta* 24:207–210
- Manilla-Figueroa LC, Casquet C, Galindo C, Mas JR (2002) El metamorfismo hidrotermal cretácico y Paleógeno de la Cuenca de Cameros (Cordillera Ibérica, España). *Zubía. Instituto de Estudios Riojanos* 14:143–154
- Mas JR, Salas R (2002) Lower cretaceous in the Iberian Basin. In: Gibbons W, Moreno T (eds) *Geology of Spain*. Geol. Soc. Lon., pp 284–288
- Mas JR, Alonso A, Guimerà J (1993) Evolución tectono-sedimentaria de una cuenca extensional intraplaca: la cuenca finijurásica-eocretácica de Los Cameros (La Rioja-Soria). *Rev Soc Geol Esp* 6(3-4):129–144
- Mas JR, Benito MI, Arribas J, Serrano A, Guimerà J, Alonso A, Alonso-Azcárate J (2002) La Cuenca de Cameros: desde la extensión finijurásica-eocretácica a la inversión terciaria—implicaciones en la exploración de hidrocarburos. *Zubía. Instituto de Estudios Riojanos* 14:9–64
- Mas JR, Benito MI, Arribas J, Serrano A, Alonso A, Alonso-Azcárate J (2003) The Cameros basin: from late Jurassic-early cretaceous extension to tertiary contractional inversion—implications of hydrocarbon exploration. In: AAPG international conference and exhibition. Barcelona, Spain (geological field trip 11)
- Mas JR, García A, Salas R, Meléndez A, Alonso A, Aurell M, Bádenas B, Benito MI, Carenas B, García-Hidalgo JF, Gil J, Segura M (2004) Segunda fase del rifting: Jurásico Superior-Cretácico Inferior. In: Vera J (ed) *Geología de España*. Sociedad Geológica de España, Instituto Geológico y Minero, 884 pp
- Mata MP, Casas AM, Canals A, Gil A, Pocovi A (2001) Thermal history during Mesozoic extension and tertiary uplift in the Cameros Basin, northern Spain. *Basin Res* 13:91–111
- Omodeo-Salè S, Arribas J, Guimerà J, Mas R, López V, Quijada IE, Suárez-González P (2011) The architecture of depositional sequences in an inverted rift basin: tectonic controls and genetic insight (the late Jurassic-early cretaceous Cameros basin, N Spain). 28th IAS meeting of sedimentology 2011, Zaragoza, Spain (abstracts book: 445)
- Suárez P, Quijada E, Mas JR, Benito MI (2010) Nuevas aportaciones sobre la influencia marina y la edad de los carbonatos de la Fm. Leza en el sector de Préjano (SE de La Rioja). Cretácico Inferior, Cuenca de Cameros. New contributions to the marine influence and the age of the Leza Fm carbonates in the Préjano area (SE La Rioja). Lower cretaceous, Cameros Basin. *Geogaceta* 49:7–10
- Villalain JJ, Fernández-González G, Casas AM, Gil-Imaz A (2003) Evidence of a cretaceous remagnetization in the Cameros Basin (North Spain): implications for basin geometry. *Tectonophysics* 377:101–117