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Discussion of LAYA *et al.* (2021), Dissolution of ooids in seawater-derived fluids - an example from Lower Permian re-sedimented carbonates, West Texas, USA [*Sedimentology* 68(6), 2671-2706] [*]

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Abstract: This discussion reassesses earlier interpretations of calcareous turbidites from the subsurface Spraberry Formation of the Happy Field (Garza County, NW Texas). It is based on routine petrographic analyses with a standard microscope. The succession of diagenetic products in this deep water setting were a little initial cementation by low magnesian calcite (LMC) and then the partial or complete leaching of both aragonite and high magnesian calcite (HMC) allochems facilitated by the presence of a residual primary intergranular porosity. This contradicts LAYA *et al.*'s (2021) claim that cementation left no residual intergranular porosity so further leaching of the ooids would not have been possible. Instead the study made for this discussion with the same thin sections found residual primary intergranular porosity remains as evidenced by some of their photomicrographs. Most thin sections with porous grainstones have 1) collapsed molds that exhibit evidence of little initial cementation and 2) measured permeability values that range from some mD to some tens of mD. Isopachous LMC cements occur in almost all thin sections lining the margins of most intergranular pores. As these cements do not fully fill the pores, there is permeable well-connected residual primary porosity with no significant LMC cement in the secondary moldic porosity. Compaction affects the allochems and, where these are partially leached, intergranular and moldic porosities. Dissolution of aragonite (a major component) and HMC (possibly a minor component) was probably not coeval. The order of paragenetic sequence of this discussion study was: 1) LMC cementation; 2) aragonite leaching facilitated by oxidation of the organic matter in the "biocrystals" of bioclasts and oolitic cortices; 3) compactional brecciation, which was first mechanical, and then chemical causing local collapse of the molds of some of the largest pores. It was governed by cementation initially in a shallow burial diagenetic setting and then leaching whereas chemical compaction marks a slightly deeper burial diagenetic setting. The final event was marked by oil migration into the Happy Field reservoirs, freezing the calcium carbonate diagenesis. The theory of LAYA *et al.* (2021) of the leaching of ooids in directly "seawater-derived fluids" is unsupported by the paragenetic sequence described above.

Key-words:

- NW Texas;
- Permian;
- ooids;
- oomolds;
- cementation;
- dissolution;
- compaction

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[*] *While it is standard practice to publish a discussion in the journal in which the original article was published, along with a response by the authors, the editor-in-chief of* Sedimentology *declined to do so.*

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Résumé : *Commentaires sur* L*aya* et al. *(2021) : "Dissolution of ooids in seawater-derived fluids - an example from Lower Permian re-sedimented carbonates, West Texas, USA" [*Sedimentology *68 (6), 2671-2706].-* Cette réévaluation d'une des interprétations antérieures des turbidites calcaires de la Formation Spraberry dans le champ pétrolier de Happy (comté de Garza, nord-ouest du Texas) est fondée sur des analyses pétrographiques de routine avec un microscope standard. La succession de modifications diagénétiques que nous avons reconnues dans ces dépôts en eaux profondes comprend une cimentation initiale relativement limitée par une calcite faiblement magnésienne suivie de la dissolution partielle ou complète des éléments figurés initialement composés d'aragonite et de calcite très magnésienne ; cette dissolution a été facilitée par la présence d'une porosité intergranulaire primaire résiduelle. Nos observations contredisent l'affirmation de Laya *et al.* (2021) selon laquelle la cimentation n'a laissé aucune porosité intergranulaire résiduelle, ce qui impliquerait qu'aucune dissolution ultérieure des ooïdes n'aurait été possible. Au lieu de cela, l'étude que nous avons réalisée à partir des mêmes lames minces a révélé qu'une porosité intergranulaire primaire résiduelle est encore présente comme en attestent d'ailleurs certaines photos de ces auteurs. La plupart des lames minces avec des faciès granulaires poreux montrent des vides de dissolution effondrés bordés par le ciment initial peu développé et affichent des valeurs de perméabilité mesurées comprises entre quelques mD (millidarcy) et quelques dizaines de mD. Les ciments isopaques en calcite faiblement magnésienne sont observés dans presque toutes les lames minces, où ils tapissent les bords de la plupart des pores intergranulaires. Comme ces ciments ne remplissent pas complètement les pores, il existe toujours une porosité primaire résiduelle bien connectée et donc accompagnée d'une perméabilité certaine ; de plus, on note la quasi absence de ciment en calcite faiblement magnésienne dans les vides de dissolution, *i.e.*, dans la porosité secondaire. La compaction affecte les éléments figurés et, lorsque ceux-ci sont partiellement dissous, les vides de dissolution mais aussi les espaces intergranulaires. La dissolution de l'aragonite (une composante majeure) et celle de la calcite très magnésienne (peut-être une composante mineure) n'ont probablement pas été contemporaines. La chronologie relative de la séquence paragénétique définie ici a dû être la suivante : 1) cimentation par une calcite faiblement magnésienne ; 2) dissolution de l'aragonite facilitée par l'oxydation de la matière organique dans les "biocristaux" des bioclastes et des cortex oolithiques ; 3) formation d'une brèche d'écrasement, par compaction d'abord mécanique, puis chimique provoquant l'effondrement local des microcavités correspondant à certains des plus grands pores. L'ensemble des processus a donc été régi par une phase de cimentation réalisée initialement dans un contexte diagénétique d'enfouissement peu profond, suivie par une phase de dissolution, alors que la compaction chimique correspond à un cadre diagénétique d'enfouissement nettement plus profond. L'épisode final marqué par la migration des hydrocarbures dans les réservoirs carbonatés du champ pétrolier de Happy signe l'arrêt de la diagenèse de ces carbonates. La théorie de Laya *et al.* (2021) d'une dissolution des ooïdes dans les "fluides" directement "dérivés de l'eau de mer" n'est pas étayée par la séquence paragénétique décrite ci-dessus.

Mots-clefs :

- nord-ouest du Texas ;
- Permien ;
- ooïdes ;
- moules de dissolution d'ooïdes ;
- cimentation ;
- dissolution ;
- compaction

1. Introduction

The title of Laya *et al.*'s (2021) paper claims to document the unlikely case of (1) the "Dissolution of ooids in seawater-derived fluids". On the basis of geochemical arguments, the authors also improbably conclude that (2) there is "a marine origin" for "the prominent equant low magnesium calcite cement textures" they observed (Laya *et al.*, 2021, p. 2771/1). This discussion recognizes that geochemical arguments are dependent on models and subjective. From experience (*e.g.*, Granier, 2019, *versus* Eichenseer *et al.*, 1999; Charollais *et al.*, 2013, and Granier *et al.*, 2014, 2016, *versus* Godet *et al.*, 2016) and because any chosen model depends on personal choice, it is easy to argue that any genuine geochemistry dataset is subject to emotive interpretations and so difficult to substantiate. For this discussion, rather than focusing on subjective abstract chemical models, we use simple observations of petrographic microfabrics. Our critique proposes that their paper is based on erroneous and/or biased interpretations of the data presented. For instance, "cementation and leaching cannot be coeval because both processes require fluids with discrete pH" (see Kendall, 2005; Granier *et al.*, 2022), a requirement that blatantly contradicts the synchronicity hypothesis defended by Laya *et al.* (2021). As a result, most Laya *et al.*'s statements will be proven to be incorrect.

2. Material and methods

The first author (BRCG) used a Wild Heerbrugg M5A binocular microscope for routine petrographic analysis of a temporary loan (2 weeks only) of 40 thin sections (Fig. 1) from the Happy Spraberry oil field in the Garza County (NW Texas, USA). That represented 25% of the thin sections (161) used by Laya *et al*. These thin sections were probably made from horizontal or vertical plugs taken from cores of 7 wells (Lott 19#2-6 and 19#10-11) as suggested by a notch

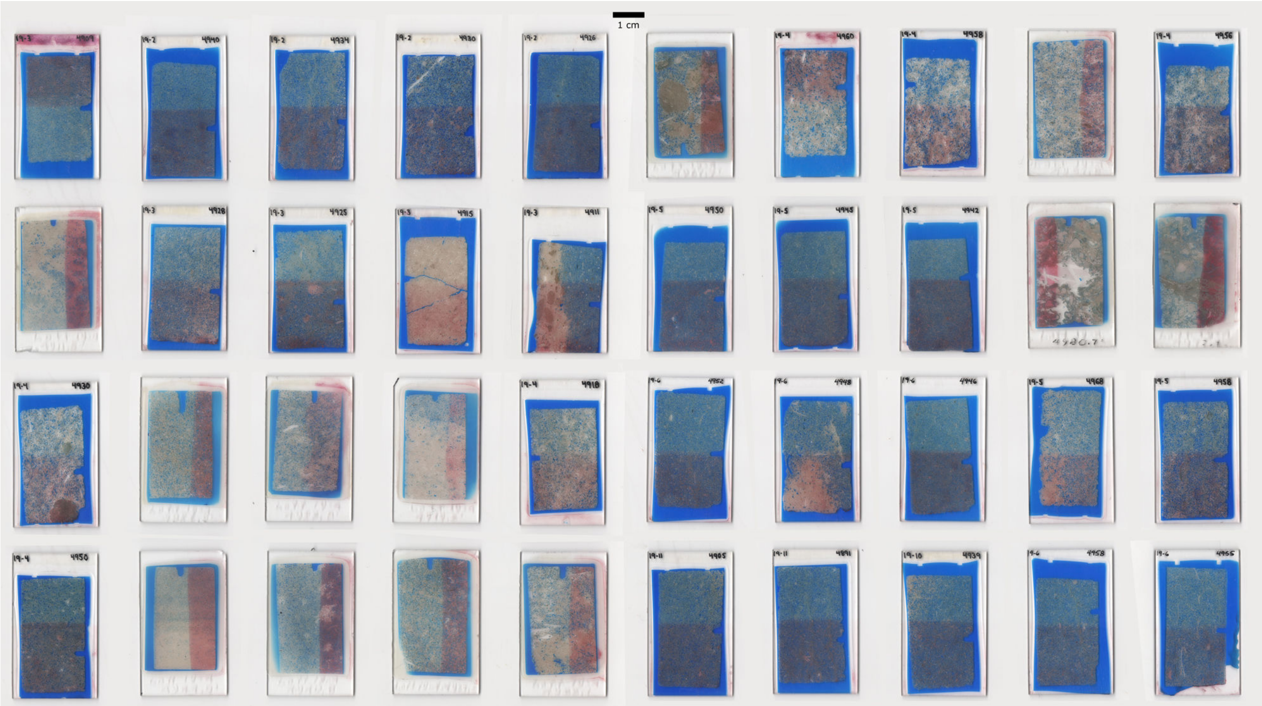

Figure 1: The limited set of 40 thin sections studied to support this discussion and the detailed description of which is given in Appendix.

indicating the top of each slide. The core plug chips were impregnated with blue epoxy prior to the final cut, which helps visualizing the porous network. One third to half of the thin section surface is stained with Alizarin, which proved to be useless considering the limited amount of dolomite in the rock samples. Photomicrographs of the material were taken in both reflected (with a white card, FOLK, 1987) and transmitted lights with a Nikon D3100 camera mounted on the microscope. Because there was no slide cover, the best photomicrographs were obtained with the thin section immersed in tap water.

3. Summary petrographic description of the material revised

The detailed petrographic descriptions of the thin sections are summarized in the form of a table given in Appendix. Thirty-seven out of forty thin sections mostly display grainstone texture corresponding to grainy calcareous turbidite facies; the remaining thin sections correspond to a debris flow facies with large lithoclasts. In the grainy facies, the allochems are mostly bioclasts and ooids. A significant number of the grains were leached and remained as empty molds whereas some others were cemented and fewer recrystallized.

Among the bioclasts, crinoid ossicles are up to 10% of the grains (Pl. 1, figs. l-m; Pl. 2, figs. a-d) but syntaxial overgrowths on these remains have unexpectedly a rather limited extension (Pl. 2, figs. c-d). Bivalvia shells are up to 10% of the grains and molds whereas gastropod shells are rare (Pl. 2, figs. e-g). Those primarily that were composed of aragonite only are commonly found as empty elongated angular molds and micritic envelopes (Pl. 1, figs. af, ai), sometimes as partly or fully cemented molds and micritic envelopes (Pl. 1, figs. ag-ah, aj). Similar observations can be made on former aragonite layers of those Bivalvia shells which had a dual LMC and aragonite composition. Among the foraminifers, the tests of the primitive Miliolata that were made of HMC are commonly leached (Pl. 1, figs. ak-an). The identification of many rounded molds as oomolds may be incorrect because they do not retain a nucleus (Pl. 1, figs. b, j-m; Pl. 2, figs. b-d) or any cortical layer (Pl. 1, figs. a, c-i, v-w). These rounded molds could be remnants either of bioclasts or peloids. Some ooids were not leached, but partly or fully recrystallized. Contrary to the claims of LAYA *et al.* (2021) there is no evidence either that any ooid was ever micritized because micritization would have erased the concentric structures that remain visible in most recrystallized oolitic cortices (Pl. 1, figs. n-q, t-u, z-ae).

Besides the secondary moldic porosity after ooids or bioclasts, the porous network comprises a significant volume of intergranular porosity, which is merely a residual primary porosity. Intergranular porosity is common in the majority of the thin sections studied, in porous grainstones. It was clearly underestimated by LAYA *et al.* (2021), specifically when they use this argument to discard their first scenario (see below). Its absence in tight grainstones is related to centripetal drusy LMC cementation, late dolomite and late celestine cements. Solution seams are common in the grainy facies (Pl. 2, figs. h-o; Pl. 3, figs. k, o-p), often observed next to collapsed moldic pores or to residual intergranular pores.

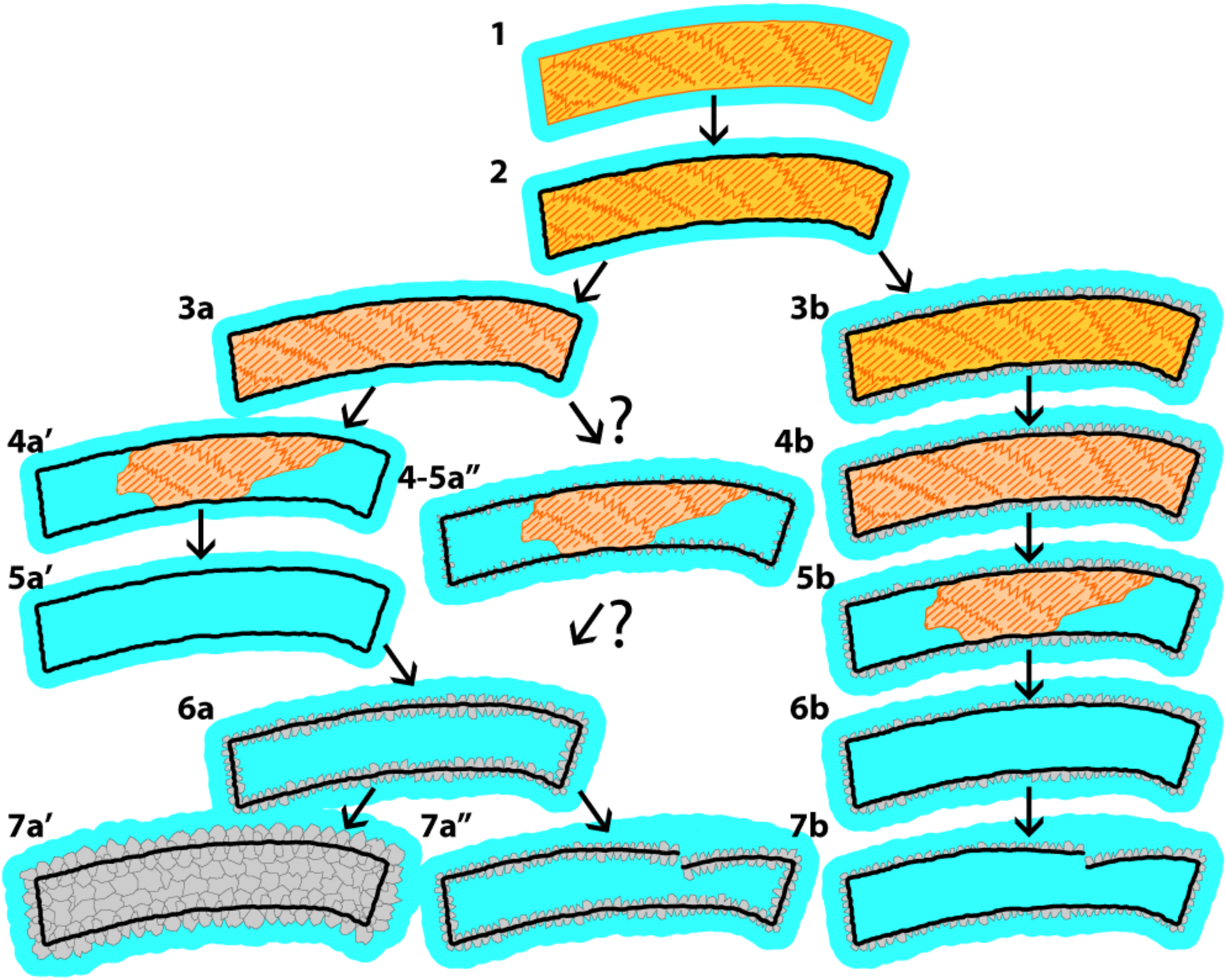

Figure 2: This illustration uses as its template a hypothetical paragenetic sequence of that follows the potential paths of diagenesis of an originally aragonite Bivalvia fragment (modified from Shearman, circa 1977, unpublished) . The figure illustrates three models for the paragenetic sequence of a formerly aragonite bioclast. The end product of the right path is a broken micritic envelope, weakly cemented on its outer side only: 1 -> 2 -> 3b -> 4b -> 5b -> 6b -> 7 b. In this path the micritic envelope is not a prerequisite but used for the purposes of this illustration. The end products of the left path are either a fully cemented micritic envelope (or a fully cemented mold): 1 -> 2 -> 3a -> 4a' -> 5a' -> 6a -> 7 a', or a broken micritic envelope (or a broken mold), weakly cemented on both its inner and outer sides: 1 -> 2 -> 3a -> 4a' -> 5a' -> 6a -> 7 a". The replacement of steps 4a'-5a' by 4-5a" corresponds to the original unpublished drawing of Shearman. It is not clear whether the transition 3a -> 4-5a" represents a single episode with coeval leaching and LMC cementation (the authors do not agree with this interpretation, see text) or two discrete episodes with leaching first and cementation second. Similarly, it is not clear either whether the transition 4-5a" -> 6a represents a single episode with coeval leaching and LMC cementation (the authors do not agree either with this interpretation, see text) or two discrete episodes with leaching first and cementation second.
Caption: 1) aragonite skeletal fragment; 2): micritic envelope; 3a, 4b) oxidation of the organic framework; 3b) isopachous LMC cementation; 4a', 5b) partial leaching of the aragonite bioclast; 5a', 6b) complete leaching; 6a) isopachous LMC cementation; 7a') drusy LMC cementation; 7a", 7b) breakage of the envelopes.

4. The three scenarios discussed by Laya *et al.* (2021)

The reasoned arguments of Laya *et al.* (2021, p. 2789/19) explore three key potential models for the oolitic Spraberry reservoirs:

"(1) if complete cementation of interparticle porosity between ooids had occurred, permeability would have been sufficiently reduced that fluid flow would have been minimized as would have the likelihood of subsequent dissolution; alternatively,

(2) if dissolution occurred prior to cementation, oomolds despite having thin micritic envelopes would likely have collapsed in the very shallow subsurface".

Laya *et al.* (2021) discarded both of them related to the order and relative "timing of the dissolution and precipitation", and settled a third mechanism:

"(3) if coeval dissolution and cementation occurred in a manner where partial cementation reduced but did not eliminate fluid flow, additional aragonite dissolution and calcite cementation could have occurred".

They concluded that "The last possibility is the most likely to explain the textures observed in thin sections from Happy Field" (LAYA *et al.*, 2021). However, on the basis of a review of their material, this conclusion proves to be wrong, which is unfortunate since it forms the keystone of their hypothesis title, *i.e.*, "Dissolution of ooids in seawater-derived fluids".

LAYA *et al.* (2021) promptly dismissed their first scenario because they precluded "complete cementation of interparticle porosity between ooids", hence a permeability that was almost nil, potentially impeding acidic fluids to reach the aragonitic or HMC oolitic cortices.

To test the other two scenarios, we use the SHEARMAN model, redrawn here (Fig. 2) after a sketch from his unpublished "Laboratory Handbook of Carbonate Petrography". It illustrates paragenetic sequences commonly observed after a formerly aragonite bioclast. The original SHEARMAN's sequence should be restricted to the single path from an original skeletal fragment to a broken micritic envelope, weakly cemented on both its inner and outer sides: 1 -> 2 -> 3a -> 4-5a" -> 6a -> 7 a". It is noteworthy mentioning that it is not clear in the original SHEARMAN's sequence whether the transition 3a -> 4-5a" represents A) a single episode with coeval aragonite leaching and LMC cementation, or B) two discrete episodes with leaching first and cementation second. Similarly, it is not clear either whether the transition 4-5a" -> 6a represents C) the continuation of the single episode with coeval aragonite leaching and LMC cementation (see above), or again D) another two discrete episodes with leaching first and cementation second. The succession of four or more alternating episodes: 1) leaching, 2) cementation, 3) leaching, 4) cementation, etc., does not appear very realistic.

Our Figure 2 corresponds to an expanded version of the genuine SHEARMAN model because it includes other paths and end products. For instance, the left path (1 -> 2 -> 3a -> 4a' -> 5a' -> 6a) would be more realistic. Its end products can be either A) a fully cemented micritic envelope 7a', B) a broken micritic envelope, weakly cemented on both its inner and outer sides 7a", or C) a fully cemented broken micritic envelope (not shown). As a live analogue to steps 2 -> 3a -> 4a' -> 5a', one can imagine the fate of a wrapped sugar piece dropped in a hot cup of tea.

Recrystallization *sensu stricto* is not included in our Figure 2 because it is a particular path from the fact that it is not generating any secondary porosity. On the opposite, according to SHEARMAN (unpublished), "replacement of aragonite by calcite in a closed system should results in an increase in the volume of the solid phase of approximately 8%". Recrystallization *sensu stricto* corresponds to the "dissolution" of aragonite or HMC and their *in situ* coeval "replacement" by a LMC mosaic (*e.g.*, WARDLAW *et al.*, 1978; SALLER, 1992; GRANIER, 2019). Organic ghosts remaining visible in the replaced ooid cortices (*e.g.*, GRANIER & LAPOINTE, 2022) or shells (Pl. 2, figs. p-q) offer tangible evidence of this diagenetic process.

In the specific case of the Happy Spraberry reservoirs, the left path of Figure 2 would match LAYA's second scenario with LMC cementation in both intergranular pores and moldic pores. The option of LAYA *et al.* (2021) to discard it is merely based on their assumption that "micritic envelopes would likely have collapsed". Although we cannot agree upon their latter conclusion, this second scenario should be abandoned because most oomolds and micritic envelopes do not display LMC cement on both their inner and outer sides, but only on their outer side.

Finally, as a third and last hypothesis, LAYA *et al.* (2021) postulate that both leaching of aragonite oolitic cortices and LMC cementation occurred synchronously in seawater-derived fluids. This they see as a supposed single fluid with a given composition and a unique pH. However, because cementation --reducing primary porosity-- and leaching --generating secondary porosity-- require fluids with discrete pH, their contemporaneity should be excluded (GRANIER *et al.*, 2022). This point irrevocably contradicts LAYA's third hypothesis of "coeval dissolution and cementation" in the Happy Spraberry reservoirs. Moreover, a micritic envelope would never behave as a permeable membrane selectively controlling aragonite leaching on its inner side and LMC cementation only on its outer side.

To sum up, all three scenarios of LAYA *et al.* (2021) are incorrect. We defend below the alternative, a new scenario.

5. Fourth scenario and conclusion

In the upper Spraberry Formation (Lower Permian) of Texas, LAYA *et al.* (2021) claimed that cementation left no residual intergranular porosity and a further leaching of the ooids would not have been possible. However, the premise of that assertion is impossible:

1. as illustrated in their own photomicrographs (LAYA *et al.,* 2021: Figs. 5.B, 7.A, 7.C, 8.A-B),
2. as observed in most thin sections with porous grainstones (Pl. 3, figs. a-h; GRANIER *et al.*, 2022, Pls. 1-3, third columns),
3. because collapsed molds (Pl. 3, figs. i-l) in thin sections of porous grainstones are evidence for a weak cementation, thus for the occurrence of residual primary intergranular porosity (GRANIER *et al.*, 2022, Pls. 1-3, first and second columns), and
4. because measured permeability values for these same samples range from some mD to some tens of mD (see Appendix; HAMMEL, 1996; LAYMAN, 2002; GENTRY, 2003; MAZINGUE-DESAILLY, 2004).

In the porous grainstones of the Happy Spraberry reservoirs, isopachous LMC cements are observed in almost all thin sections (Pl. 3, figs. a-h), mostly on all sides of most intergranular pores (and also in intragranular pores, if any, *e.g.*, Pl. 2, figs. e-g). Because these cements do not fully fill the pores, there is still some residual primary porosity, well connected, hence with some permeability, but no significant LMC cement in the secondary moldic porosity. Note that the micritic envelope is not a prerequisite in this case. Compaction affects 1) the allochems, 2) their residue in the case of a partial leaching, 3) the cement, as well as 4) intergranular and 5) moldic porosities. As for the case studied here GRANIER *et al.* (2022) figured out a sequence of events very similar to that of CONLEY (1977) for the Plattsburg Limestone (uppermost Carboniferous) of Kansas: "Solution of some pisoliths followed precipitation of first-generation cement and preceded compaction" (*op.cit.*, p. 561). This leads us to defined a fourth scenario roughly matching the right path of Figure 2: 1 -> 2 -> 3b -> 4b -> 5b -> 6b -> 7b.

Because dissolution of aragonite (a major component) and HMC (possibly a minor component) are probably not coeval, the summary paragenetic sequence will be drawn hereafter as a simplified scenario:

1. LMC cementation;
2. aragonite leaching, depending on the degree of oxidation of the organic matter in the "biocrystals" (those of the bioclasts and of the oolitic cortices);
3. local collapse of some largest pores (mainly molds), *i.e.*, compactional brecciation (first mechanical, second chemical).

In the above paragenetic sequence, cementation first and leaching second should be considered as shallow near surface burial processes in a deep water setting because they precede chemical compaction that is the mark a slightly deeper burial diagenetic environment. Finally, the migration of oil into these reservoirs froze further calcium carbonate diagenesis.

This fourth and last scenario is so far the only valid paragenetic sequence for the grainy calcareous turbidites that form some Happy Spraberry flow units. It implies that, contrary to the opinion of LAYA *et al.* (2021), the theory of the leaching of ooids in "seawater-derived fluids" is unsupported.

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Bibliographic references

AHR W.M. & HAMMEL B.S. (1999).- Identification and mapping of flow units in carbonate reservoirs: An example from the Happy Spraberry (Permian) Field Garza County, Texas USA.- *Energy Exploration & Exploitation*, London, vol. 17, nos. 3-4, p. 311-334.

CAROZZI A.V. (1961).- Distorted oolites and pseudoolites.- *Journal of Sedimentary Petrology*, Tulsa - OK, vol. 31, no. 2, p. 262-274.

CHAROLLAIS J., CLAVEL B., GRANIER B., BUSNARDO R. & CONRAD, M.A. (2013).- Discussion of the paper by GODET *et al.* 2011, entitled "Reconciling strontium-isotope and K-Ar ages with biostratigraphy: the case of the Urgonian platform, Early Cretaceous of the Jura Mountains, Western Switzerland" (Swiss Journal of Geosciences, 104, 147-160).- *Swiss Journal of Geosciences*, vol. 106, no. 3, p. 559-567. DOI: 10.1007/s00015-012-0112-6

CLAYTON J.L. (2011).- Stratigraphy and reservoir architecture of a Permian toe-of-slope ooid fan, Happy (Spraberry) Field, Garza Co., Texas.- Master, University of Texas at Austin, 90 p.

CLAYTON J.L. & KERANS C. (2013).- Reservoir compartmentalization of a deep-water ooid fan, Happy Field, Permian Basin. *In*: VERWER K., PLAYTON T.E. & HARRIS P.M. (eds.), Deposits, architecture, and controls of carbonate margin, slope and basinal settings.- *SEPM Special Publication*, Tulsa - OK, vol. 105, p. 359-383.

CONLEY C.D. (1977).- Origin of distorted ooliths and pisoliths.- *Journal of Sedimentary Petrology*, Tulsa - OK, vol. 47, no. 2, p. 554-564.

CUSHMAN J.A. & WATERS J.A. (1928).- Some Foraminifera from the Pennsylvanian and Permian of Texas.- *Contributions from the Cushman Laboratory for Foraminiferal Research*, Sharon - MA, vol. 4, p. 31-55.

EICHENSEER H.T., WALGENWITZ E R. & BIONDI P.J. (1999).- Stratigraphic control on facies and diagenesis of dolomitized sequences (Pinda Group, Albian, offshore Angola).- *AAPG Bul-*

letin, Boulder - CO, vol. 83, no. 11, p. 1929-1958.

FOLK R.L. (1987).- Detection of organic matter in thin-sections of carbonate rocks using a white card.- *Sedimentary Geology*, vol. 54, no. 3, p. 193-200.

GENTRY M.D. (2003).- Applications of artificial neural networks in the identification of flow units, Happy Spraberry Field, Garza County, Texas.- MSc Thesis, Texas A&M University, College Station - TX, 162 p. URL: https://oaktrust.library.tamu.edu/handle/1969.1/1604

GODET A., DURLET C., SPANGENBERG J.E. & FÖLLMI, K.B. (2016).- Estimating the impact of early diagenesis on isotope records in shallow-marine carbonates: A case study from the Urgonian platform in western Swiss Jura.- *Palæogeography, Palæoclimatology, Palæoecology*, vol. 454, p. 125-138.

GRANIER B. (2019).- New stratigraphic and genetic model for the dolomitic Cretaceous Pinda reservoirs in Angola. Part II - Compelling arguments against early dolomitization and early leaching.- *Carnets Geol.*, Madrid, vol. 19, no. 4, p. 47-70. DOI: 2042/69773

GRANIER B., BARBIN V. & CHAROLLAIS J. (2014).- Significance of partial leaching in calcareous ooids: The case study of Hauterivian oolites in Switzerland.- *Carnets Geol.*, Madrid, vol. 14, no. 22, p. 471-481. DOI: 10.4267/2042/56045

GRANIER B., CLAVEL B. & CHAROLLAIS J. (2016).- Comments on "Estimating the impact of early diagenesis on isotope records in shallow-marine carbonates: A case study from the Urgonian platform in western Swiss Jura" by A. GODET *et al.* [Palæogeography Palæoclimatology Palæoecology 454 (2016) 125-138].- *Carnets Geol.*, Madrid, vol. 16, no. 17, p. 417-429. DOI: 10.4267/2042/61385

GRANIER B.R.C. & LAPOINTE Ph. (2022).- The KALKOWSKY Project - Chapter III. Significance of primary radial fabrics associated with ancient partly leached or recrystallized calcareous ooids.- *Carnets Geol.*, Madrid, vol. 22, no. 5, p. 149-160. DOI: 10.2110/carnets.2022.2205

GRANIER B.R.C., KENDALL C.G.St.C. & VACHARD D. (2022).- The KALKOWSKY Project - Chapter IV. Case study of the Happy Spraberry oil reservoirs in NW Texas (with a micropaleontologic and biostratigraphic supplement): Collapsed molds should not be treated as a category of distorted ooids.- *Carnets Geol.*, Madrid, vol. 22, no. 8, p. 311-332. DOI: 10.2110/carnets.2022.2208

HAMMEL B.S. (1996).- High-resolution reservoir characterization of the Permian (upper Leonardian) Spraberry Formation, Happy Spraberry Field, Garza County, Texas.- Unpublished MS Thesis, Texas A&M University, College Station - TX, 156 p.

KENDALL C.G.St.C. (2005).- Lecture 6: Cementation & diagenesis.- Geol 751: Carbonate petrography, University of South Carolina, Columbia - SC, 118 slides. URL: http://www.sepmstrata.org/CMS_Files/CarbonateDiagenesis.ppt

LAYMAN J.M. II (2002).- Porosity characterization utilizing petrographic image analysis: Implications for identifying and ranking reservoir flow units, Happy Spraberry Field, Garza County, Texas.- MSc Thesis, Texas A&M University, College Station - TX, 103 p. URL: https://oaktrust.library.tamu.edu/handle/1969.1/399

MAZINGUE-DESAILLY V.P.G. (2004).- Assessing the influence of diagenesis on reservoir quality: Happy Spraberry Field, Garza County, Texas.- MSc Thesis, Texas A&M University, College Station - TX, 69 p. URL: https://oaktrust.library.tamu.edu/handle/1969.1/27

SALLER A. (1992).- Calcitization of aragonite in Pleistocene limestones of Enewetak Atoll, Bahamas, and Yucatan - An alternative to thin-film neomorphism.- *Carbonates and Evaporites*, vol. 7, no. 1, p. 56-73.

SHEARMAN D.J. (circa 1977, unpublished).- Laboratory handbook of carbonate petrology.- Imperial College, London, 55 p.

WARDLAW N., OLDERSHAW A. & STOUT M. (1978).- Transformation of aragonite to calcite in a marine gasteropod.- *Canadian Journal of Earth Sciences*, Ottawa, vol. 15, no. 11, p. 1861-1866.

WILKINSON B.H., BUCZYNSKI C. & OWEN R.M. (1984).- Chemical control of carbonate phases: Implications from Upper Pennsylvanian calcite-aragonite ooids of southeastern Kansas.- *Journal of Sedimentary Research*, Tulsa - OK, vol. 54, no. 3, p. 932-947.

Plates

Plate 1: a, c-g) Partly leached oolitic cortices; b, j-k) leached cortices of superficial ooids with an echinoid spine each as their nuclei; h-i) partly leached, then collapsed oolitic cortex; l-m) leached cortex of an ooid with a crinoid ossicle as its nucleus; n-q, t-u, z-ae) recrystallized oolitic cortices; r-s) oolitic lithoclast; v-w) partly leached and collapsed oolitic cortex; x-y) partly leached and collapsed oolitic cortex; af, ai) LMC drusy cement in former micritic envelopes; ag) empty molds; ah) empty mold (top) and micritic envelope (bottom); aj) empty micritic envelopes; ak-an) foraminifers with leached tests, originally HMC tests: ak) *Praeneodiscus* spp.; al) *Planiinvoluta heathi* (CUSHMAN et WATERS, 1928); am) *Endothyra* sp.; an) *Glomomidiella* sp.
References: a, f) well Lott 19#10, sample 4939'; b, al-am) well Lott 19#2, sample 4940'; c, e, an) well Lott 19#3, sample 4928'; d, aa, ag) well Lott 19#4, sample 4933.1'; g) well Lott 19#4, sample 4926.9'; h-m) well Lott 19#2, sample 4934'; n-o) well Lott 19#4, sample 4911.5'; p-s, u-w) well Lott 19#4, sample 4918'; t) well Lott 19#3, sample 4915'; x-y) well Lott 19#11, sample 4905'; z) well Lott 19#4, sample 4930'; ab) well Lott 19#4, sample 4937.5'; ac) well Lott 19#4, sample 4956'; ad-ae) well Lott 19#4, sample 4960'; af) well Lott 19#4, sample 4919.3'; ah) well Lott 19#6, sample 4948'; ai-aj) well Lott 19#5, sample 4968'; ak) well Lott 19#3, sample 4925'. Transmitted light: a-h, j, l, n, p, r, t-v, x, z-an; reflected light: i, k, m, o, q, s, w, y. All photomicrographs have the same scale (scale bar = 250 µm).

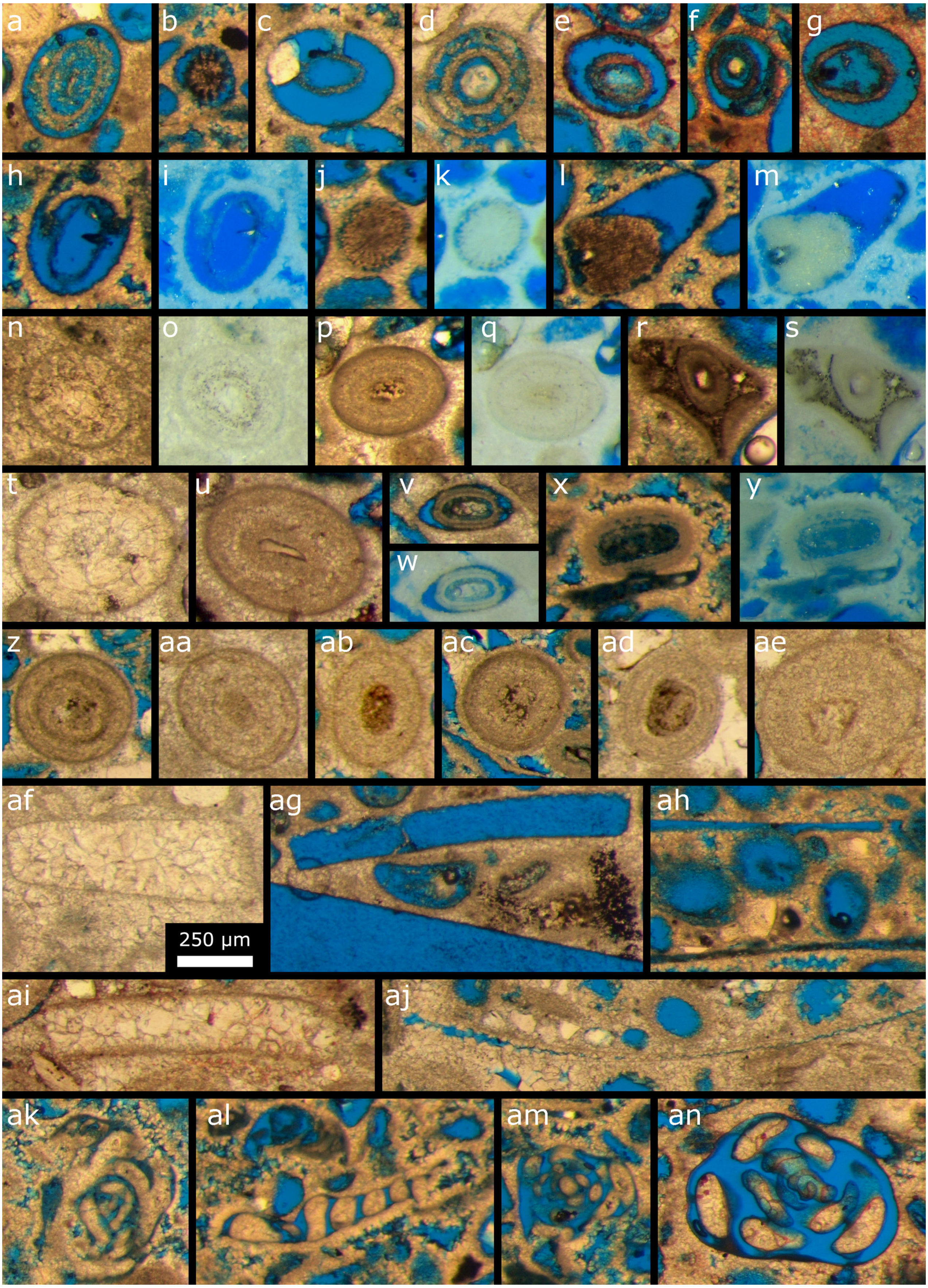
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Plate 2: a-d) Crinoid ossicles: a) articulate junction of two successive ossicles; b) transverse section of an ossicle as the nucleus of a leached ooid; c) oblique section of an ossicle in a leached ooid; d) random section of an ossicle in a leached ooid; c-d) syntaxial LMC owergrowths fill part of the collapsed mold; e-g) gastropods: intragranular and intergranular pores are partly cemented whereas the moldic pores are not much, if any; h-o) solution seams passing laterally to pores; p-q) goniatite section: p) detail of the LMC replacement of the formerly aragonite shell with brownish organic ghosts.

References: a) well Lott 19#6, sample 4948'; b) well Lott 19#4, sample 4940.8'; c) well Lott 19#5, sample 4945'; d) well Lott 19#5, sample 4950'; e) well Lott 19#2, sample 4930'; f) well Lott 19#6, sample 4955'; g) well Lott 19#6, sample 4958'; h-o) well Lott 19#4, sample 4911.5'; p-q) well Lott 19#4, sample 4958'. Transmitted light: a-h, j, l-m, p-q; reflected light: i, k, n_o. All photomicrographs have the same scale (scale bar = 250 µm), except q (scale bar = 2.5 mm).

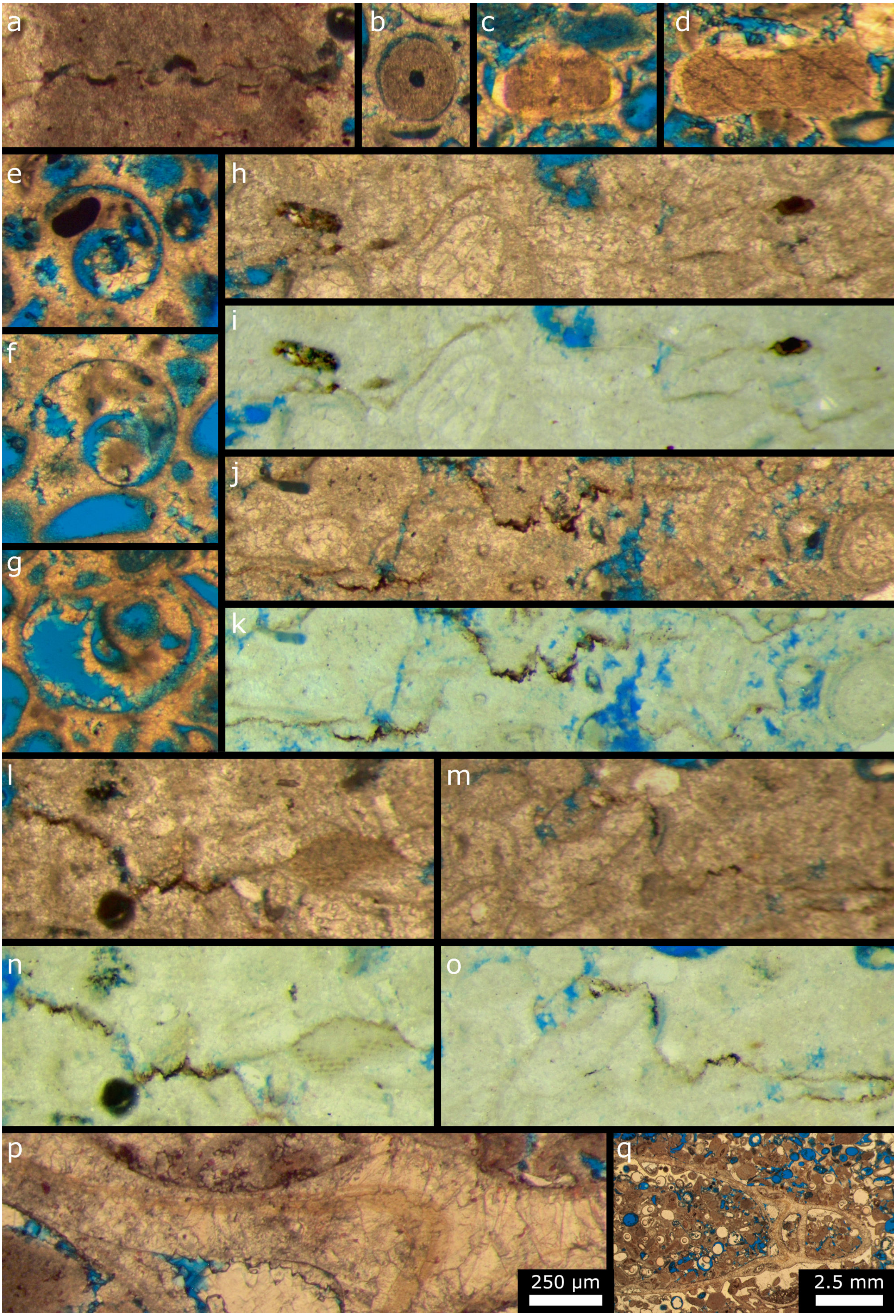
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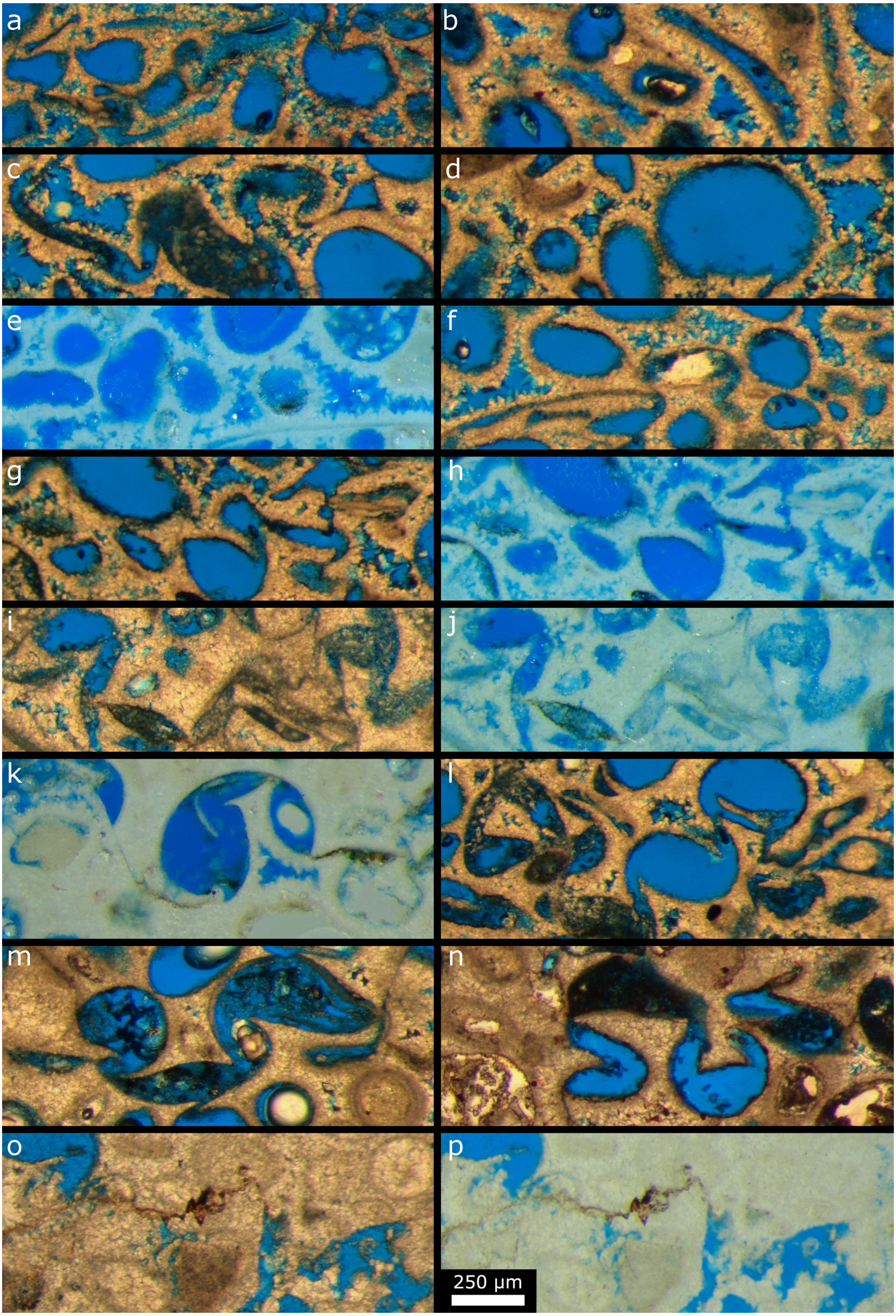
Plate 3: a-h) residual primary intergranular porosity with saw-tooth outlines and secondary moldic porosity with neat outlines; i-j) zig-zag pattern *sensu* CAROZZI (1961); k) "elephantine (trunk-to-tail)" *sensu* WILKINSON *et al.* (1984); l) silcrow (§) pattern *sensu* CAROZZI (1961); c, m-n) chains of collapsed molds of partly leached allochems (? ooids); k, o-p) pressure-solution seam passing laterally to collapsed molds.
References: a) well Lott 19#2, sample 4926'; b) well Lott 19#2, sample 4930'; c-j, l) well Lott 19#2, sample 4934'; k, m-n) well Lott 19#4, sample 4918'; o-p) well Lott 19#4, sample 4911.5'. Transmitted light: a-d, f-g, i, l-p; reflected light: e, h, j-k, p. All photomicrographs have the same scale (scale bar = 250 µm)..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Appendix

Table: Summary description of the limited set of 40 thin sections studied.

Well	core depths	allochems											porous netw.					porosity	permeability	comments:
	(True Vertical Depth) H = horizontal plug V = vertical plug	ooids (+ ? oomolds)	extraclasts	foraminifers	bryozoans	crinoids	brachiopods	pelecypods	*Tubiphytes*	ostracods	gastropods	Gymnocodiaceae	intergranular	moldic	collapsed molds	solution seams	visual permeability (estimates)	(Layman, 2002; Gentry, 2003; Mazingue-Desailly, 2004)		r = rare c = common a = abundant sp = spine ++ = whole shell st = stylolites
19#02	**4926' (H)**	c	r	r	r	c	r (sp)	c	-	r	-	-	c	c	c	r	K	**24.1%**	**39.0 mD**	grainst.
19#02	**4930' (H)**	a	r	r	r	c	r (sp)	c	-	-	r	-	c	a	-	-	K	**28.5%**	**47.0 mD**	grainst., cemented fracture
19#02	**4934' (H)**	a	-	r	r	r	r (sp)	c	-	-	-	-	c	a	c	r	K	**25.1%**	**124.0 mD**	grainst.
19#02	**4940' (H)**	a	r	r	r	c	r (sp)	c	-	r	-	-	c	a	c	r	K	**22.2%**	**6.2 mD**	grainst. (100% calcite)
19#03	**4909' (H)**	c	-	r	r	c	r (sp)	c	-	r	-	-	c	c-	c	r	K	**21.7%**	**20.0 mD**	grainst. (100% calcite)
19#03	**4911' (H)**	c	a	r	c	c	-	c	r	-	r	-	c	c	r	r	1 tight, 1 K	**23.4%**	**16.0 mD**	2 facies (floatst., grainst.), silicification (3%)
19#03	**4915' (H)**	c	r	r	r	c	r (sp)	c	r	-	?	?	-	-	-	-	tight	**23.9%**	**12.0 mD**	grainst., silicification
19#03	**4925' (H)**	c	r	r	c	c	r (sp)	c	-	r	r	-	c	c	r	r	low K	**21.4%**	**23.0 mD**	grainst., silicification (17%)
19#03	**4928' (H)**	c	r	r	r	c	-	c	-	r	-	-	r	c	r	-	low K	**6.6%**	**0.1 mD**	grainst., silicification (10%)
19#04	**4911.5' (V)**	a	-	r	r	c	-	r	-	-	-	r	r	r	r	r	low K	**16.4%**	**9.4 mD**	grainst.
19#04	**4918' (H)**	a	r	r	r	r	r (sp)	c	-	-	-	-	r	c	c	r	low K	**28.4%**	**9.3 mD**	grainst.
19#04	**4919.3' (V)** (1)	a	r	r	-	r	r (sp)	c	r	r	-	?	r	c	c-	r	1 tight, 1 K	**22.1%**	**4.7 mD**	2 facies (grainst.): 1 calcite cemented
19#04	**4923.8' (V)**	a	-	r	-	r	-	c	-	r	-	r	c-	c	r	r	low K	**23.5%**	**12.0 mD**	grainst., celestine (patches)
19#04	**4926.9' (V)**	a	r	r	r	r	-	c	-	r	-	-	r	c	r	r	? low K	**28.5%**	**2.9 mD**	grainst., calcite cemented
19#04	**4930' (H)**	a	a	r	r	r	r (sp)	c	-	-	?	?	r	c	r	-	almost tight	**18.7%**	**2.6 mD**	grainst., celestine (57%)
19#04	**4933.1' (V)**	a	-	r	-	r	-	c	-	r	r	?	r	c	r	r	almost tight	**20.5%**	**5.5 mD**	3 facies (grainst.): 1 calcite cemented, 1 celestine
19#04	**4937.5' (V)**	a	r	r	r	r	-	c	r	r	r	-	r	c	c-	r	? low K	**26.4%**	**3.4 mD**	grainst., calcite cemented
19#04	**4940.8' (V)**	a	-	r	-	c	r (sp)	c	-	r	-	-	c	c	c-	r	? low K	**16.6%**	**1.2 mD**	grainst., celestine (patches)
19#04	**4944.9' (V)**	r	-	c	-	r	-	?	-	-	-	-	r	r	-	-	almost tight	**14.7%**	**7.6 mD**	grainst., very finely grained
19#04	**4950' (H)**	c	r	r	-	r	r (sp)	r	r	r	-	-	c	c	r	r	K			grainst., finely grained
19#04	**4956' (H)**	a	r	r	-	r	r (sp)	r	-	r	r	-	r	r	r	r	almost tight			grainst., *Pseudovermiporella,* celestine
19#04	**4957.5' (V)** (2)	a	r	r	-	r	r (sp)	c	r	r	r	-	r	r	r	r	almost tight	**20.9%**	**3.2 mD**	grainst., celestine
19#04	**4958' (H)**	a	-	r	r	-	r (sp)	c	-	r	-	-	r	r	r	r	almost tight			grainst., Goniatite, ? cayeuxia, celestine (28%)
19#04	**4960' (H)**	a	r	r	r	r	-	c	-	r	r	?	r	r	r	r	almost tight	**16.6%**	**7.9 mD**	grainst., celestine
19#04	**4961.7' (V)** (3)	c	a	r	a	r	r (sp)	c	a	r	-	?	r	c-	r	r	? low K	**22%**		floatst. (2 facies) with grainst. matrix, silicification, ?? Goniatite, sponge spic.
19#04	**4972.9' (V)** (4)	-	a	r	a	c	r (sp) ++	c	a	r	-	-	M	r	-	st.	tight	**18%**		floatst. (2 facies) with silty mudst. (?) matrix, borings, silicification
19#04	**4980.7' (V)**	-	a	r	a	r	r (sp) ++	c	a	r	-	-	M	r	-	st.	tight	**11%**		floatst. with silty mudst. matrix, borings, corals
19#05	**4942' (H)**	c	r	r	r	c	r (sp)	c	-	r	-	-	c	c	c	r	K	**26.4%**	**23.9 mD**	grainst., finely grained
19#05	**4945' (H)**	c	-	r	r	c	r (sp)	c	-	r	-	-	c	c	c	r	K	**5.6%**	**1.3 mD**	grainst., finely grained
19#05	**4950' (H)**	c	-	r	r	c	r (sp)	c	-	r	-	-	c	c	r	r	K	**25.1%**	**17.5 mD**	grainst., finely grained
19#05	**4958' (H)**	a	r	r	-	r	r (sp) ++	c	-	r	-	-	c	c	c	r	? low K	**31.3%**	**39.1 mD**	grainst. (100% calcite)
19#05	**4968' (H)**	a	r	r	r	r	r (sp) ++	c	-	r	r	-	c	c	c	r	low K	**23.3%**	**12.3 mD**	grainst., silicification (20%)
19#06	**4946' (H)**	a	r	r	r	c	r (sp)	c	-	r	-	-	c	c	c	r	K	**16.3%**	**1.4 mD**	grainst.
19#06	**4948' (H)**	a	r	r	-	r	r (sp) ++	c	-	r	-	-	c	c	r	r	low K	**21.2%**	**11.6 mD**	2 facies (grainst.): 1 calcite cemented, silicification (100% calcite)
19#06	**4952' (H)**	a	r	r	-	c	r (sp)	c	-	r	-	-	c	c	c	r	K	**21.4%**	**8.8 mD**	grainst. (100% calcite)
19#06	**4955' (H)**	a	r	r	r	r	r (sp) ++	c	-	r	r	-	c	c	c	r	K			grainst.
19#06	**4958' (H)**	a	r	r	r	c	r (sp)	c	-	-	r	-	c	c	c	r	K	**19.3%**	**3.2 mD**	grainst. (100% calcite)
19#10	**4939' (H)**	a	r	r	-	c	r (sp)	c	-	r	-	-	c	c	r	-	K	**28.5%**	**43.5 mD**	grainst.
19#11	**4891' (H)**	c	r	r	-	c	r (sp) ++	c	-	-	-	-	c	c	c	r	K	**33.3%**	**5.0 mD**	grainst.
19#11	**4905' (H)**	c	-	r	-	c	-	c	-	r	-	-	c	c	c	r	K	**29.9%**	**31.4 mD**	grainst.

(1) Clayton, 2011, Fig. 3.4.A
(2) Laya *et al.*, 2021, Figs. 5.D, 9
(3) Clayton, 2011, Fig. 3.6.C; Laya *et al.*, 2021, Fig. 5.F
(4) Laya *et al.*, 2021, Fig. 5.H