Lophiostroma schmidtii (NICHOLSON)
THE MOST ENIGMATIC PALAEOZOIC STROMATOPOROID: TAXONOMY, GROWTH & DIAGENESIS
& comparisons with some of its friends

PART 1 of 2

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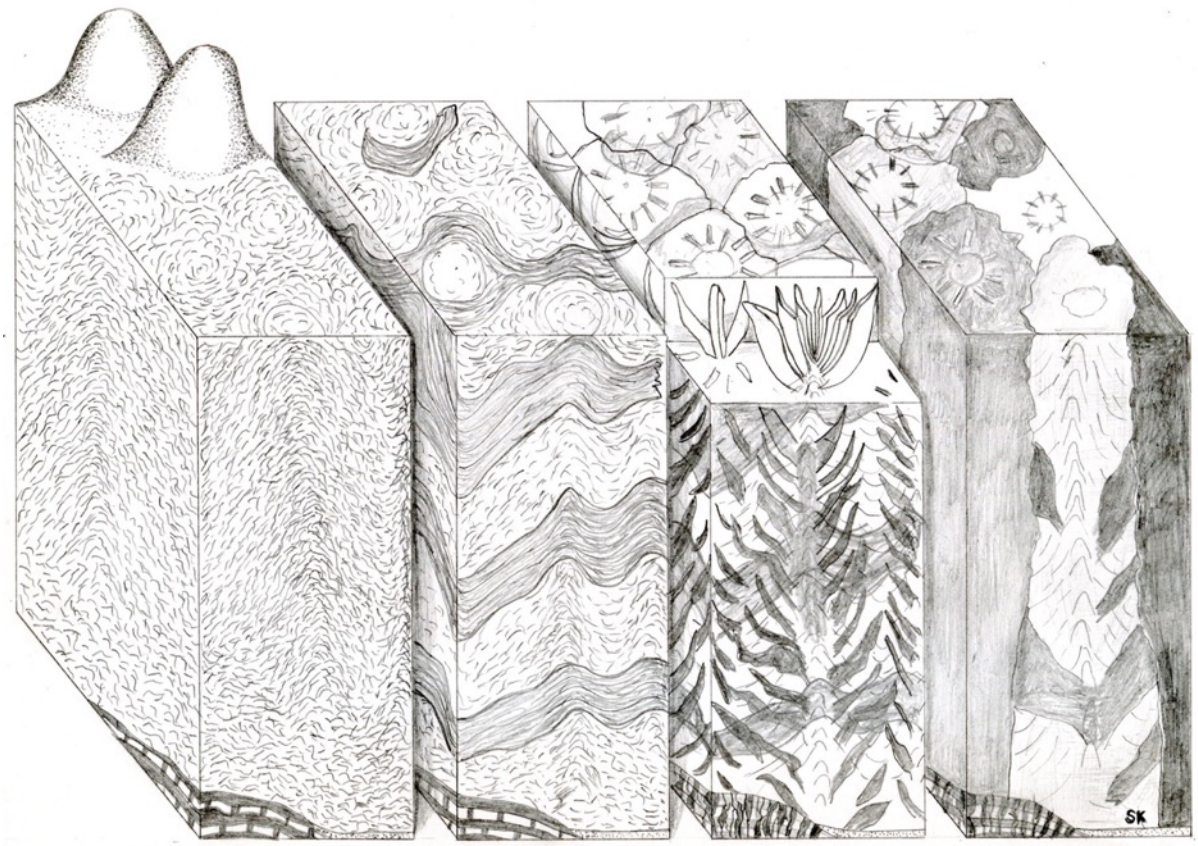

Reconstruction of structure and diagenesis of *Lophiostroma schmidtii* [this picture is repeated later with caption]

They say you shouldn't judge a book by its cover, and in this case by its title; this apparently highly specialised account contains a lot of basic knowledge and questions about stromatoporoids

An atlas of images from the Hemse group, Ludlow, Silurian, in the Kuppen peninsula biostromes, eastern Gotland, Sweden; and some other Silurian samples from Gotland and UK

This document is a compendium of annotated images and interpretations intended as a palaeontological and sedimentological research tool

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SUMMARY

The name ‘stromatoporoid’ is derived from Greek linguistic roots containing *stroma* (meaning layer) and *poros* (meaning pore); so stromatoporoids should have layers with pores (the pores are called galleries in stromatoporoid terminology). However, such a coarse definition can apply to lots of fossils, so it is therefore necessary to have some qualification to class a fossil as a stromatoporoid. Stromatoporoids essentially comprise a complex and highly variable layered calcium carbonate skeletal network of horizontal and vertical elements secreted by soft tissue lost in decay and no cases of exceptional preservation are known. Only the carbonate skeleton remains. But there is substantial evidence that stromatoporoids were sponges and there really isn’t any question about this nowadays. Nevertheless, there is one fossil classed as a stromatoporoid which shows a layered structure, in which there is very poor evidence of pores; in almost all cases it is seen a solid mass of calcite in which there is some evidence of very thin overlapping plates, that are difficult to see, even in well-preserved samples. In almost all cases these plates are obscured or lost in diagenetic overprinting. The layered structure is highly organised into tight wavy up-and-down layering with coinciding peaks and troughs to give the impression of laterally-contiguous vertical pillar-like elements that extend all the way through the skeleton and emerge at the top surface as tiny hills called papillae; hence the surface is covered with evenly-spaced papillae. Thus, in vertical section the structure is made of coinciding wavy lines; in transverse section these are expressed a mass of equally-spaced approximately circular marks overprinted by diagenetic calcite with irregular polygonal margins as a compromise of boundaries of crystals that grew in mutual competition for space. The fossil is called *Lophiostroma*, and its inclusion within the stromatoporoids is contested. Furthermore, it also lacks the characteristic astrorhizae that nearly all (but interestingly not all) stromatoporoids possess, that are the key evidence of their sponge affinity. Astrorhizae are seen in transverse sections as bifurcating channels originating from a central hole; and bifurcations are progressively narrower the further away from the central hole; they are the water-collecting system of the exhalent currents of the sponge, that drew water into the centre of the astrorhiza for expulsion at the stromatoporoid surface. In vertical section, astrorhizae form partial tubes that pass through short distances of vertical section, and the bifurcating channels are seen in vertical cross section merging with the pores (galleries) of the stromatoporoid network. But in its simple organisation of rather obscure very thin overlapping plates *Lophiostroma* does not have astrorhizae.

So, 1) why is *Lophiostroma* classed with the stromatoporoids, and 2) is it a fossilised sponge? The answer to the first question is, essentially, that its layered structure doesn’t look like corals, or bryozoa that are abundant in the rocks containing stromatoporoids; and *Lophiostroma* is common in some outcrops that contain stromatoporoids (and corals and bryozoa). Furthermore, the layered structure of *Lophiostroma*, highly visible in the field is easily imaginable as a stromatoporoid, but the problems that emerge under the microscope in plane-polarised light (PPL) mean that its structure doesn’t fit with other stromatoporoids. However, the story is very different in cross-polarised light (XPL) where the diagenetic overprinting revealed in XPL is very similar to all other stromatoporoids, and provide a good reason to keep *Lophiostroma* with the stromatoporoids. The

answer to the second question is that it is really anybody's guess, you can choose whether or not this is a sponge; however, you have to be logical in your choice. *Lophiostroma* doesn't demonstrate the concept of individuals seen in corals and bryozoa and thus possesses a well-integrated clonal skeleton, rather than a colonial one, as do normal stromatoporoids, and, as do sponges!

This atlas of *Lophiostroma schmidtii* (the type species which represents almost all occurrences of *Lophiostroma*) focusses on the common occurrence of this peculiar fossil in the Silurian of Gotland, Sweden, and is designed to explore its structure and growth, and contrasts with other stromatoporoids; this atlas drills deep into the nature of its structure and highlights the essence of stromatoporoids in the contrasts displayed. Growth form and taxonomy of *Lophiostroma* are described in literature, but in this atlas an additional aspect is dealt with in detail for the first time – the diagenesis of *Lophiostroma*. *Lophiostroma* exhibits a peculiar kind of diagenetic recrystallisation that, as mentioned above, is seen in all stromatoporoids but rarely seen in other fossils; as far as I know, it is not known in corals, or bryozoa. In 2021 in a collaborative study (Kershaw et al. 2021, in the journal Facies), it was named "fabric-retentive recrystallisation" that forms a kind of diagenetic calcite called Fabric-Retentive Irregular Calcite (FRIC); you will see FRIC appearing throughout the many photos in this document.

FRIC in stromatoporoids shows the diagenetic alteration of the skeleton passes with optical continuity into the cement present in the galleries (the pores between the skeletal elements in stromatoporoids); this optical continuity means that the crystals of diagenetic structure affecting the skeleton pass into the galleries as the same crystals! It is very weird in carbonate sedimentology and its mechanism is not known – it is an area for future research. Well, here's the exciting bit – there are growth interruption spaces within the solid mass of *Lophiostroma*; the FRIC of that solid mass passes with optical continuity into the calcite cement that fills those spaces, just exactly like it does in normal stromatoporoids. This doesn't happen in corals, or in bryozoans, in those fossil groups the crystal structure of the skeletal elements stops sharply at the edges and does not pass into the pore space within the fossil skeleton. *Lophiostroma* in diagenesis behaves like all other stromatoporoids, a good reason to retain it within that group of fossils. It is also worth noting that *Lophiostroma* has differences in diagenesis from other stromatoporoids, that seem to be unique to *Lophiostroma*; these are described in this document, for, as far as I know, the first time.

You might wonder why *Lophiostroma* is worth studying in detail, given that it is a bit of an oddball fossil; well, it allows comparisons with normal stromatoporoids and with other fossils, and thus provides a perspective on these various fossil types in palaeobiology, palaeoecology and diagenesis. Another reason, perhaps not so scientific, is that if the thin sections are prepared carefully, *Lophiostroma* shows an incredibly beautiful and intricate structure that is a delight to stare at, while trying to work out its scientific value.

Thus, putting the evidence together, *Lophiostroma:*

1) grew like a stromatoporoid (it encrusted other fossils but it was also able to grow happily on sediment substrates just like stromatoporoids did);
2) it lived in the same environments as stromatoporoids (shallow marine reefal and associated non-reefal carbonate-rich sedimentary systems), and
3) it has a comparable diagenetic character (FRIC) to stromatoporoids.

Hence, until someone comes up with a better idea, it is currently quite satisfactory to leave *Lophiostroma* in with the stromatoporoids, although it remains an outsider and is enigmatic.

As part of this atlas, a section is devoted to **taxonomic** description of *Lophiostroma schmidtii* (*Ls*), in which a correction is made to published descriptions. Literature descriptions state that *Ls* contains a kind of cone-in-cone type of architecture in its skeleton; this is shown to be incorrect and is instead a 3-dimensional crystal fan structure made of upwardly-diverging calcite crystals forming a cone shape, rather than nested solid cones. However, studies using cathodoluminescence (CL) illustrated in this atlas show that this 3D crystal fan structure is actually part of the diagenetic modification of the original structure and does not impact on the taxonomic diagnosis.

Comparisons are made with some stromatoporoids that grew along with *Lophiostroma schmidtii* (*Ls*) and there is a section towards the end that addresses similarities and differences with some taxa that look a bit like *Ls*. Included within those comparative taxa are two samples that derive from the history of study of stromatoporoids, described by the famous H. Alleyne Nicholson and Mary Johnson; these two taxa have caused problems for stromatoporoid-ologists and in a recent monograph (Kershaw et al. 2021, Palaeontographical Society Monograph), I thought that these two taxa were finally sorted out. However, subsequent to the monograph publication, this atlas of *Lophiostroma schmidtii* has involved a much more detailed appraisal of this fossil, and it turns that the story of those two older taxa is more complicated; this is all described at the end of this atlas, and if you care about these things you may be left breathless with wonder.

Finally, nearly all the samples of *Ls* covered in this atlas come from one outcrop, from which I have a nice collection of material. The samples show a lot of similarity, but also individual differences, particularly with respect to their diagenesis. So throughout this compendium you will see lots of similar-looking things, but if you have interest and patience to plough through all of it you will see the value in appreciating small-scale variations that help understand the processes taking place, both when the organisms were alive, and then later, in diagenesis.

The outcrop is a set of stacked biostromes in the middle Ludlow (Silurian) Hemse Group that occupy several tens of square km in the eastern peninsula of Gotland, Sweden, where there must be billions of stromatoporoids preserved. It is likely the most stromatoporoid-rich deposit in the world and one of the palaeontological wonders of the world. These beds are almost flat-lying, dipping very gently to the southeast along with the rest of Gotland's strata, so the biostromes must have had little topography, and developed in an environment rather like a giant lagoon. So how did such a huge tight concentration of stromatoporoids develop? In this atlas is also presented some evidence to address that question, and shows there is some preservation of gypsum in both the sediment and as replacements within the stromatoporoids, as calcite-after-gypsum pseudomorphs. I propose that the Hemse Group biostromes grew in conditions of raised salinity and it is in that condition that the stromatoporoids thrived and took over almost all the sea floor space. Nevertheless, there are also tabulate and rugose corals present in the biostromes, along with the stromatoporoids, so if raised salinity is a viable explanation then the corals must have been able to withstand it too. Very strangely, however, there are almost no cases of algae preserved in these biostromes; this is exceedingly odd because all other reefal occurrences on Gotland have evidence of fossil algae. There must be an explanation and raised salinity is one avenue of investigation. Put this idea another way: because of the large area of flat sea floor in a shallow marine, low energy environment, then if there wasn't evaporation to raise salinity in this area, what other explanations can be made to account for the very odd high-density accumulation of stromatoporoids in this area? This is an area of open research that no doubt will be tested in upcoming decades.

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SECTION 1:
INTRODUCTION

1.1. Just what are stromatoporoids and why do they matter ? (includes aspects related to Lophiostroma schmidtii)

Stromatoporoids are the skeletal fossils of benthic organisms and are beautiful and intriguing fossils; they initiated as thin layers of calcium carbonate skeletal secretions on the ancient sea floor and accumulated layer-by-layer into sheets, domes, rounded bulbs, columns, branches, irregular masses, and could get very big, several metres across in some cases. In the appropriate circumstances they accumulated in enormous numbers to develop giant buildups on the shallow sea floors on which they lived. They seemed able to have been able to cope with a range of substrates and survived the effects of sedimentation; but they are rarely found in sandstones, and so seem to have been really limited to environments where the sediment was dominated by calcareous deposits (hence they form limestones).

For a long time stromatoporoids were thought allied to the Cnidaria (older name is coelenterates, the group of organisms that includes corals) and the older literature include cnidarian terms, such as coenosteum – a name for the entire fossil [no longer used for stromatoporoids because they are not cnidarians]. However, in 1970 a landmark paper based on Caribbean material showed modern equivalents that are sponges; these were originally grouped together as Sclerosponges, but subsequent research showed that they are polyphyletic and thus the name of Sclerosponges is invalid and abandoned. Stromatoporoids are calcified sponges (actually formally called hypercalcified sponges because the skeleton comprises only calcium carbonate) and are the principal constructing organisms in the first major metazoan reef systems that dominated for about 100 million years in middle Palaeozoic shallow marine warm-water carbonate deposits around the world, between middle Ordovician and Late Devonian time (Wilson 1975, Chapter 4; Copper 2002). They almost totally died out, somewhat mysteriously, at the end of the Devonian Period, and thus almost completely disappeared from the rock record until the Triassic Period, when they bloomed again for some tens of millions of years. Nevertheless, their geological record is scarce in the most recent few tens of millions of years, yet there is a respectable suite of living examples that provide much insight into how the ancient ones may have lived. Stromatoporoids are the subject of detailed modern investigation in the 2015 volume of the Treatise on Invertebrate Palaeontology (Nestor 2015; Stearn 2015; Stock 2015; Webby 2015).

Stromatoporoids are important because their skeletal remains record events during their lives and permit a considerable insight into the nature and variations of the environments in which they lived. Stromatoporoids are thus a valuable archive of palaeoenvironmental processes. Recent work documents key processes in their growth and diagenesis (Kershaw et al. 2018, 2021a,b) and reveals the following major points about Palaeozoic stromatoporoids:

Their growth is characterised by:

1. Relationship with substrate, both soft and consolidated substrates; stromatoporoids may be found on substrates bearing characteristics leading to the inference that they commonly grew on partly-lithified sediment, and are

evidence of early sea-floor lithification in the times when they occur in the fossil record. *Lophiostroma schmidtii,* in almost all cases, is a thin laminar-shaped fossil that curves into large arcs, both up and down, and thus seems to have grown in relation to the substrate beneath it; but it also shows evidence of having been able to form primary cavities beneath its base as well as forming encrustations on previous organisms.

2. Growth history, including growth interruptions; stromatoporoids were commonly and repeatedly interrupted during growth, by such events as overturning and sedimentation, from which they commonly recovered; they thus record events of disturbance during their lives that give insight into the dynamic and fluctuating environments in which they lived. *Lophiostroma schmidtii* has growth characteristics that fit in very well with other stromatoporoids; thus it assisted in consolidation of the substrate for more growth and thus development of a reef body.
3. Relationship between growth form and taxonomy; certain stromatoporoid taxa are limited to certain growth forms, and allow more detailed analysis of the relationship between their biology and the environments in which they lived. *Lophiostroma schmidtii* is typified by a laminar growth form, so it could cover quite large areas of the substrate for such a thin-shaped structure; in terms of surface-area/volume ratio for substrate stabilisation it must have been an efficient and valuable component of the biota. No doubt the other stromatoporoids benefited from the presence of *Lophiostroma schmidtii* and there is evidence of this demonstrated in images in this atlas, because many case studies show other fossils grew as encrusters on the *Lophiostroma schmidtii* skeletons.
4. Relationship with associated organisms, in particular symbionts; symbionts grew along with the stromatoporoids, and the interactions and comparisons between them provide valuable information to understand the lives of both the stromatoporoids and their associated organisms. *Lophiostroma schmidtii* rarely has skeletal symbionts (e.g. intergrown corals); but it does contain evidence of non-skeletal organisms that grew within it (these are called bioclaustrations and thus demonstrate presence of organisms that would otherwise not have a record). It also formed a nice surface for other organisms to encrust upon, as mentioned above in Point 3.

Stromatoporoid diagenesis is characterised by:

1. Consistently poor preservation in comparison with adjacent corals, brachiopods and bryozoans, but better preserved than adjacent molluscs. Molluscs are almost always recrystallised to low-magnesium calcite (LMC) from an original aragonite mineralogy, whereas corals are normally well-preserved due to their original LMC composition. Stromatoporoids may contain microdolomite rhombs, commonly interpreted to indicate they had originally high-magnesium calcite (HMC) skeletons that were altered to LMC during diagenesis. However, the relationship between dolomite rhombs and stromatoporoids is not fully consistent, so the nature of their original mineralogy remains unconfirmed. *Lophiostroma schmidtii* fits with other stromatoporoids in the sense that there is an indication of its original structure preserved, but this is overprinted by diagenetic calcite; dolomite rhombs do occur in it but they are not common.

2. Ubiquitous overprinting of the original skeleton by elongate club-shaped calcite crystals mostly orientated normal to the growth layers; this is fabric-retentive recrystallisation, through which all stromatoporoids are recrystallised to a greater or less extent, and the particular form of alteration that they display seems to be unique to stromatoporoids, but the controls on this are not understood. *Lophiostroma schmidtii* has its own version of this overprinted diagenesis, consisting of a beautiful display, in vertical section, of fan-shaped crystal masses in 3D, stacked inside one another as a peculiar form of cone-in-cone fabric, but these do not look like the classic cone-in-cone structure seen in some inorganic hydrothermally-controlled carbonates. These fans emanate from the centres of the vertical apparent pillar-like elements of the skeleton of *L. schmidtii.* In the case of *L. schmidtii* the fan-shaped crystal masses seem to have been replaced in some cases by single large crystals in a process interpreted here to have been an aggrading neomorphic change. To make it even more exciting, some specimens of *L. schmidtii* illustrated in this atlas show a third alteration fabric that consists of vaguely fibrous calcite, and is here termed as “vaguely-fibrous calcite” until a better term is found. Thus *L. schmidtii* seems to be unique in stromatoporoids in having THREE diagenetic alteration fabrics that are interpreted here to have occurred in sequence: Vaguely-fibrous calcite, then 3D crystal fans, then aggrading neomorphism. You can see all of these in the images presented here, and there is a nice reconstruction diagram that brings it all together.
3. Evidence that they underwent alteration very early in diagenetic history, with clear indications that this began began just below the ancient seafloor, and possibly in the lower parts of specimens that had upper surfaces which were still alive on the seabed. *Lophiostroma schmidtii* is consistent with other stromatoporoids in this respect.

Stromatoporoids are quite variable in structure and largely fall into distinct consistent skeletal architectures that can be identified and given names. *Lophiostroma schmidtii* is a very recognisable structure that is rare amongst stromatoporoids because it can be identified in the field, it is distinctively different from other stromatoporoids. Thus stromatoporoid taxonomy uses differences of skeletal elements, as do all fossils (!!), but in stromatoporoids it is a highly problematic taxonomy at all levels. There is an uncertain relationship between what have been called stromatoporoid species and actual biological species. In my opinion the best way to deal with this uncertainty is to regard each “species” as the lowest-level of taxonomic division achievable, but these may or may not be biological species; so I call them “lowest-level taxa” and I also do not try to combine them together into higher levels of families and orders because there is no evidence that these are biologically valid. I believe this is the most appropriate scientific approach to the understanding and application of their taxonomy, that strives to minimise assumptions about how the various taxa are defined and related. Nevertheless, a lot of very useful palaeobiological and palaeoecological information can be derived from the study of stromatoporoid taxonomy in combination with growth forms and sedimentary environments. There is extended discussion of this issue in a monograph on British Silurian stromatoporoids Kershaw et al. (2021b) that adopts the same approach to their taxonomy. This approach to stromatoporoid taxonomy is applied in this atlas.

1.2. Rationale of this atlas

The recent studies cited earlier provide descriptions associated with the above summary features, but illustrated only part of the overall available image set. It is simply not possible to publish all images in peer-review literature, yet the published interpretations rely on the backdrop of a large number of specimens. Thus the purpose of this document is to present illustrations of that large number of samples, to show the full range of features, to thus provide an image toolbox to aid interpretation of data of stromatoporoid material in other deposits. Some new information is included here that has not been published elsewhere. Each image is described in a comprehensive caption. Also, I have used a method of showing repeated images of the same specimen at increasing levels of magnification, to emulate the concept of "zooming-in" on key features. Thus you will see lots of similar-looking images that demonstrate increasing levels of detail. Some people might think this is unnecessary, but if you want to get a really good understanding of the appearance of these fossils, this is a great technique, possible in the sphere of an atlas, but not in a published paper.

The images are mostly of samples from the Silurian of Gotland, Sweden, which is one of the best places in the world to study stromatoporoids. The principles applied here can be used to examine stromatoporoids of all geological ages. Please note, as mentioned above, there is quite a lot of repetition of image features in this atlas; this is deliberate because it demonstrates that not only is there is a consistency of structure in *Lophiostroma schmidtii*, but also that there is a lot of subtle variation, and so understanding this variation is a valuable feature to appreciate the range of structure in this fossil and thus the palaeoenvironmental and diagenetic processes that resulted in the present preservation.

1.3. Not peer-reviewed

This is a non-peer-reviewed contribution to stromatoporoid science. The great value of non-peer review is that the author is free from the shackles of received opinion, and has power to express own views. And indeed, we all know that the peer-review system has considerable failings (think of the number of incorrect things you read in peer-reviewed literature !!!!). However, as Spiderman (aka Peter Parker) once famously said, "with great power comes great responsibility", although in this case it refers to the responsibility to ensure the errors are limited and views are fairly expressed. I have tried my best to explain carefully and to get things right. But of course there can be other viewpoints on the material shown here; this work contains a lot of personal opinions that others may disagree with and is therefore presented as a discussion document. I aim for this atlas to be applied as a research tool for analysis of comparable material, so the information is intended to make you think about the processes rather than giving answers. Thus, I have broken away from strict scientific expression, opting instead for first person expression, to emphasise the personal approach to this study. However, please don't be misguided into thinking that this is scientifically less rigorous than peer-reviewed literature; each image in this presentation was carefully prepared. Except where indicated in captions, all the original rock samples illustrated here were collected and sectioned by me over many years, in many cases choosing specific orientations to show certain features. Some samples were repeatedly sectioned, and certain cases were prepared for thinner-than-normal sections to emphasise specific points. Each image has a caption that describes the content, and where appropriate discusses alternative interpretations; in many cases there are no clear answers, which makes this compendium all the more valuable because it encourages your inquisitive nature, thus to think carefully about the processes operating. There is a lot of information here that will hopefully have applications in other studies on stromatoporoids, and in my opinion a lot of the arguments also apply to corals, tabulates and heliolitids that occur in the same beds. Study of another hypercalcified sponge type, the chaetetids, may also benefit from the contents of this document.

You are thus encouraged to compare these images with your own material and consider the captions that in many cases offer alternative interpretations and unanswered questions; thus use this document to develop your own inspiration to interpret your material.

1.4. Updates

You can see from the front page and the filename that this is Version 01. However, fossils were living organisms and can grow, at least in numbers recorded (!); so there may be updated versions, which will be indicated in both the filename and front page. If you see any mistakes in this document, I would be most grateful if you could kindly email and tell me so I can correct them.

1.5. Big and small pictures; the format and approach of this atlas

Geologists try to see the "big picture", that is the general situation, the key trends, the large-scale overall understanding of the nature of the topic studied. The big picture is what we all strive for. However, it is an interesting and true observation that big pictures are made of lots of little pictures, which is another way to say that details matter. If the details contradict the general interpretation, then something is wrong. This atlas is about details; it encourages you to look at things carefully. It tries to go down to the deepest root of how *Lophiostroma schmidtii* lived by looking at tiny features. Importantly, a principal outcome of my decades of detailed study is how the repeatability of small-scale features informs the big picture. From this came the realisation that stromatoporoids were capable of growing on substrates that are most reasonably interpreted as having been at least partially lithified when the stromatoporoids grew, with cascading implications for the general nature of the process of lithification and thus, potentially, the state of carbonate saturation of the oceans in the middle Palaeozoic. From Middle Ordovician through to end-Devonian, this can be observed and thus brings stromatoporoids into the fold as potential tools for studying ancient controls on ocean saturation and organisms' mineralisation, because they were abundant for such a long period of geological history. However, it is also clear that stromatoporoids commonly grew on unconsolidated sediment because of the common occurrence of well-preserved basal surfaces that could not have been cemented to the substrate. Both these two cases are found in *Lophiostroma schmidtii*, and the range of images shown in this atlas demonstrate this point. These organisms therefore had a flexible response to sea-floor conditions of substrate, which may have contributed to their successful development in the middle Palaeozoic Era. Therefore, in your search for the big picture, take account of the little pictures, they all have significance in one way or another.

1.6. Material presented in this document

I have assembled all my samples of *Lophiostroma schmidtii*, collected since 1975, and most of it is illustrated here showing the range of available information. The material comes from:

A. Marl below a thick biostrome, Hemse Group, middle Ludlow of Gotland.
B. The thick biostrome above that marl, Hemse Group, middle Ludlow of Gotland.
C. Comparative specimens from other parts of the Gotland sequence and also from UK material.

1.7. Acknowledgments

Some samples in this document date back to my first PhD fieldwork on Gotland in August-September 1975, and their study is interwoven with the assistance and inspiration from others. Some of them have already passed to that great biostrome (or perhaps bioherm) in the sky; all helped the background this document in a diverse number of ways. I thank, in alphabetic order of surnames: Mike Bassett, Joan Bennett, Anne-Christine Da Silva, Al Fagerstrom, Christina Franzén, David Gowing, Li Guo, Susan Hak, Julian Harrigan, Emilia Jarochowska, Juwan Jeon, Lennart Jeppsson, Yue Li, Erik Karlkvist, Mike Keeling, Reginald Kershaw, Ruth Kershaw, Sven Laufeld, Ross McLean, Anders Martinsson, Axel Munnecke, Mari-Ann Mõtus, Björn Neumann, Arne Philip, Nicholas Palaus, Robert Riding, Olof Sandström, Carl Stock, Colin Stearn, Liza Timms, Barry Webby, David Wedden, Ron West, Graham Young. Also thanks to Kingston University, UK and the Nuffield Foundation for cathodoluminescence facility applied in a few of the images.

Although this document was inspired by the desire to spread knowledge of stromatoporoids for future studies, it is also a contribution to some UNESCO Projects:
IGCP591(2011-2016): The Early to Middle Palaeozoic Revolution;
IGCP596(2011-2015): Climate change and biodiversity patterns in the Mid-Palaeozoic (Early Devonian to Late Carboniferous);
IGCP700(2021-2026): Palaeozoic Carbonate Buildups in Southeast Asia.

1.8. Re-use of images

1.9. Some references

You don't need to read any of these sources because this atlas tries to be self-contained, but they are here if you want them. I will not burden you with extensive reading, but the information in these sources and in their reference lists contain the greater part of relevant literature.

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1.10. Abbreviations

Scattered through the captions and figures are abbreviations that are explained in the appropriate places, but are listed here in case you need them:

FRIC – Fabric-retentive irregular calcite (diagenetic alteration style of stromatoporoids that overprints the skeletal structure but does not completely destroy it)
CL – cathodoluminescence
PPL – plane-polarised light microscopy

XPL – cross-polarised light microscopy
VS* – Vertical section, that is: vertical in relation to the geometry of the stromatoporoid, and thus normal to the growth lines (in stromatoporoids another word used is *longitudinal* instead of vertical; I prefer *vertical* because it is a shorter word!)
TS* – Transverse section, that is: transverse in relation to the geometry of the stromatoporoid, and thus parallel to the growth surface (in stromatoporoids another word used is *tangential* instead of transverse; I prefer *transverse* because it is a shorter word!)

*Because stromatoporoids are complexly curved fossils, a VS of the skeletal structure may include portions that are obliquely cut or even fully TS of the skeletal sructure, depending on the geometry of any particular sample; *vice versa* for TS sections that may include portions in VS.

Stromatoporoid taxa abbreviations: if you are bemused by taxonomic names and can't remember them, then help is at hand. I developed a short-form abbreviation for each taxon in this document; thankfully in this document there are only a few, they are:
Lc – Labechia conferta
Lr – Labechia rotunda
Lsc – Labechia scabiosa
Ls – Lophiostroma schmidtii
Pc – Petridiostroma convictum
Ph – Pachystroma hesslandi
Pv – Pachystylostroma visbyense
Ps – Plectostroma scaniense
Pt – Parallelostroma typicum
Sv – "Stromatopora" venukovi
Sy – Simplexodictyon yavorskyi

<u>SECTION 2:</u>
<u>*Lophiostroma schmidtii* at home in the field</u>

This atlas focusses on a part of the middle Ludlow (upper Silurian) strata on Gotland, Sweden, where stromatoporoid biostromes are exposed, particularly along the coastline, and one of the best places is the Kuppen peninsula in eastern Gotland (Fig. 2.1).

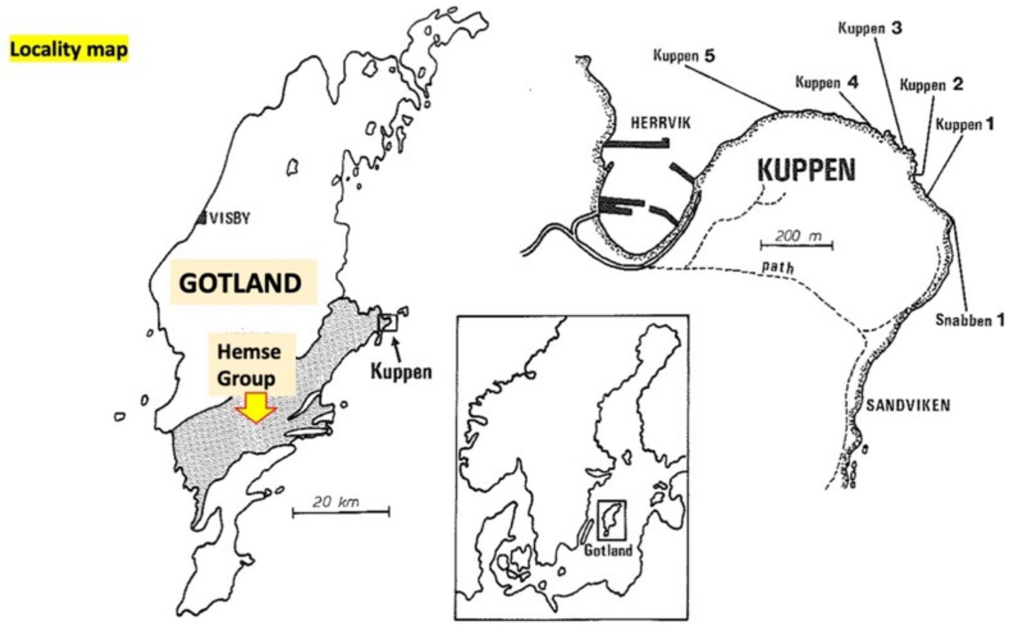


Fig. 2.1. Locality map of Kuppen peninsula, Gotland, highlighting several named locations, that appear through this atlas. There are samples from Kuppen 1-5, but none from Snabben 1, included because the stromatoporoid biostromes are exposed here also in a rather nice example of a rocky shoreline, but further south they are sparsely exposed. Note that the prominent peninsula in eastern Gotland exists only because this is where these biostromes occur, as solid limestone masses less easily eroded than softer muds that lie stratigraphically below (to the north) and above (to the south); the modern geography of Gotland thus shows the large extent of occurrence of these amazing strata. Image from Kershaw (1990, with acknowledgement to the Palaeontological Association). File: 1-01-LophiostromaSchmidti-Kuppen-FieldPhotos

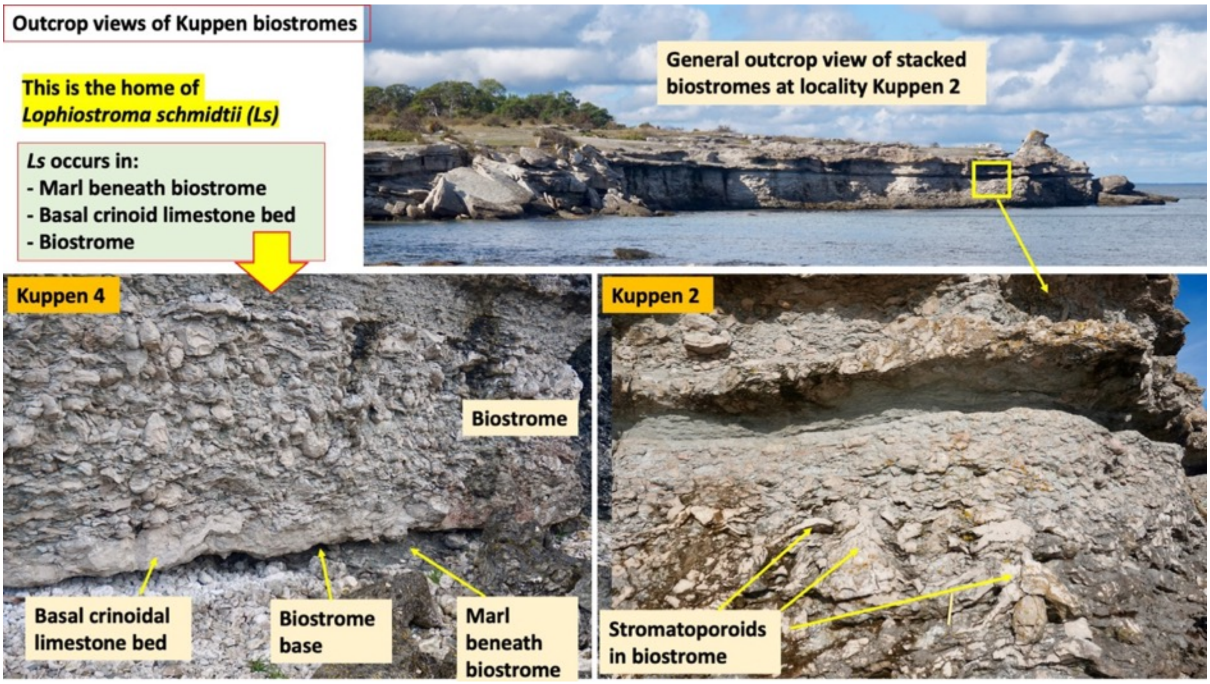


Fig. 2.2. Field photos of the Hemse Group biostromes at the key site of Kuppen, eastern Gotland. Upper photo, and detail in right photo: general view of stacked biostromes at Kuppen 2 site with details showing stromatoporoids. Left lower photo: detail of Kuppen 4 site in which some very nice samples of *Lophiostroma schmidtii* were found in: the marl beneath the biostrome, the basal crinoid bed and the main part of the biostrome, all illustrated in this atlas in detail in subsequent sections. File: 1-02-LophiostromaSchmidti-Kuppen-FieldPhotos

Fig. 2.3. Field photo of general appearance of stromatoporoids in the biostrome, at Kuppen 2. Pink crystalline areas are stromatoporoids, light grey is micrite infill. The crystalline appearance of the stromatoporoids occurs because they are recrystallised; all stromatoporoids are recrystallised to some extent, and here it is manifested in their field appearance. *Lophiostroma schmidtii* is not present here. File: 1-03-LophiostromaSchmidti-Kuppen-FieldPhotos

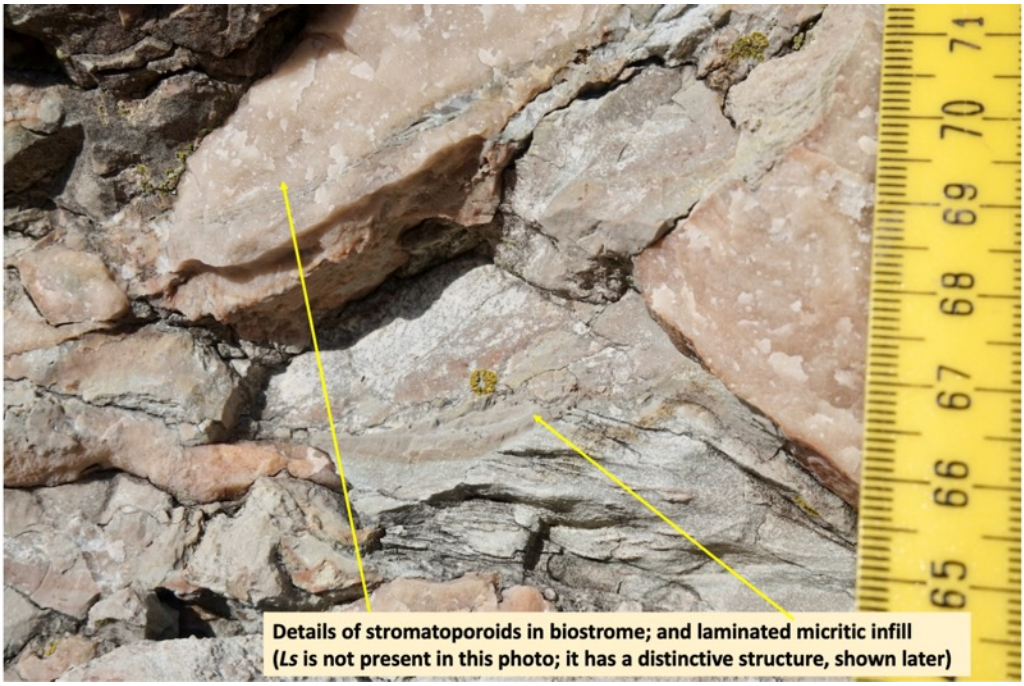


Fig. 2.4. Another field photo of general appearance of stromatoporoids in the biostrome, at Kuppen 2. Pink crystalline areas are stromatoporoids, light grey is micrite infill, that is laminated and indicates micrite deposition between stromatoporoids. *Lophiostroma schmidtii* is not present here. File: 1-04-LophiostromaSchmidti-Kuppen-FieldPhotos

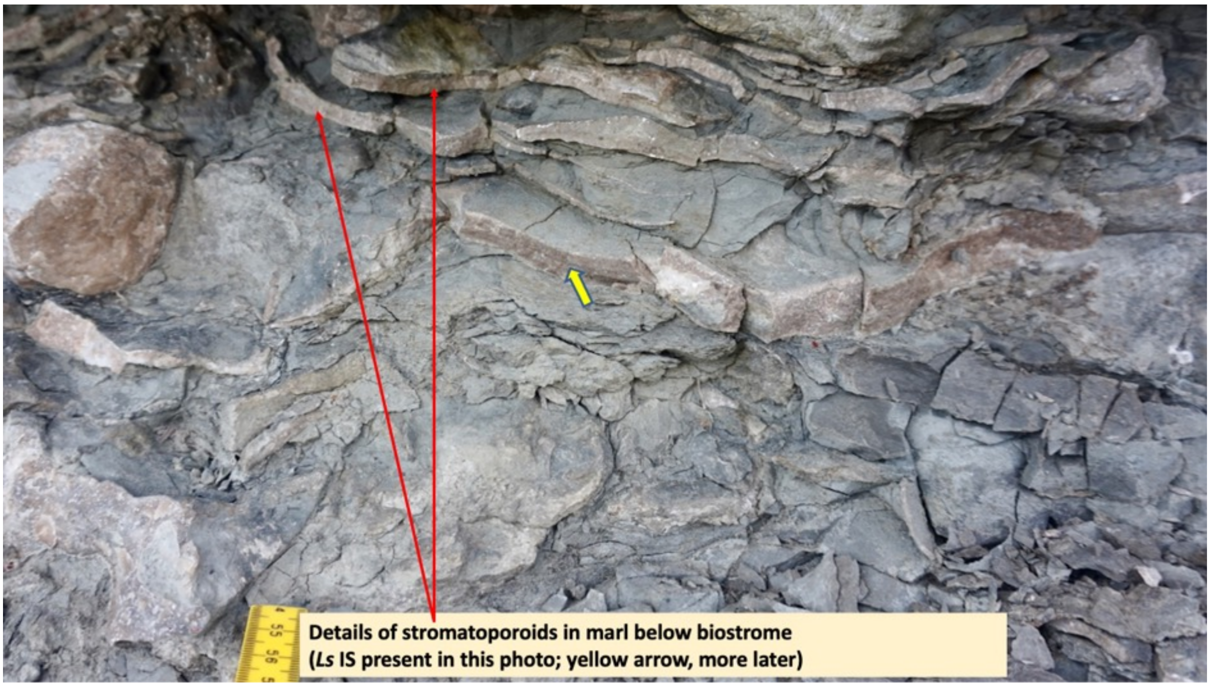


Fig. 2.5. Field photo of stromatoporoids in the marl below the biostrome at Kuppen 4. The thin laminar pink-brown layers are all *Lophiostroma schmidtii.* File: 1-05-LophiostromaSchmidti-Kuppen-FieldPhotos

Fig. 2.6. Detail of stromatoporoids in the marl below the biostrome at Kuppen 4. The thin laminar pink-brown layers are all *Lophiostroma schmidtii*, its vertical pillar-like structure is just about visible in the area arrowed. File: 1-06-LophiostromaSchmidti-Kuppen-FieldPhotos

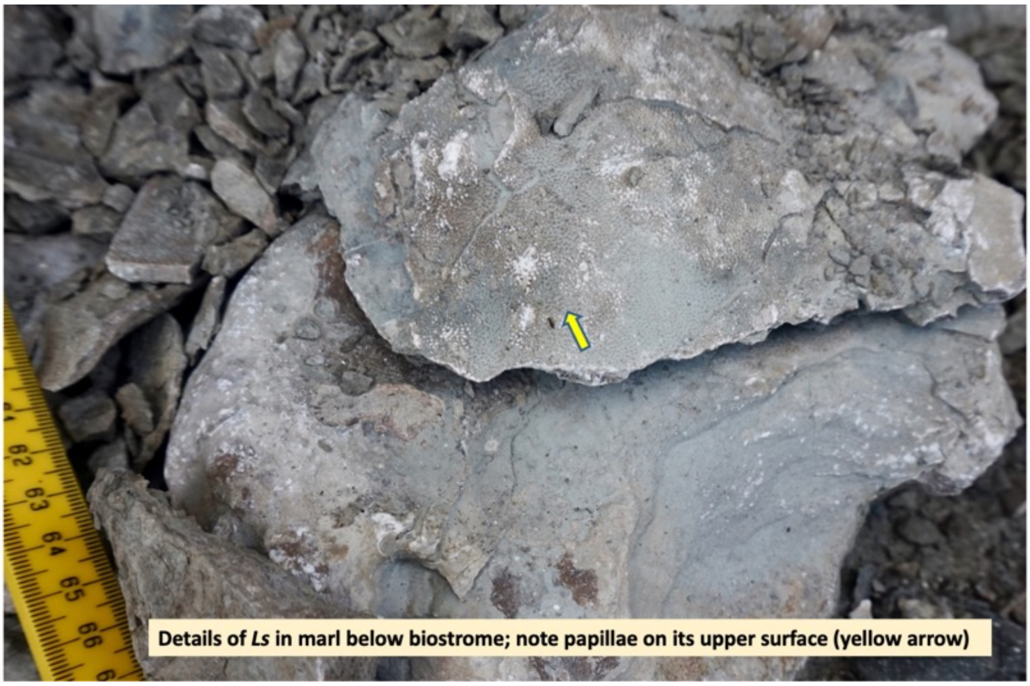


Fig. 2.7. Detail of *Lophiostroma schmidtii*, in the marl below the biostrome at Kuppen 4. The papillate upper surface is arrowed. File: 1-07-LophiostromaSchmidti-Kuppen-FieldPhotos

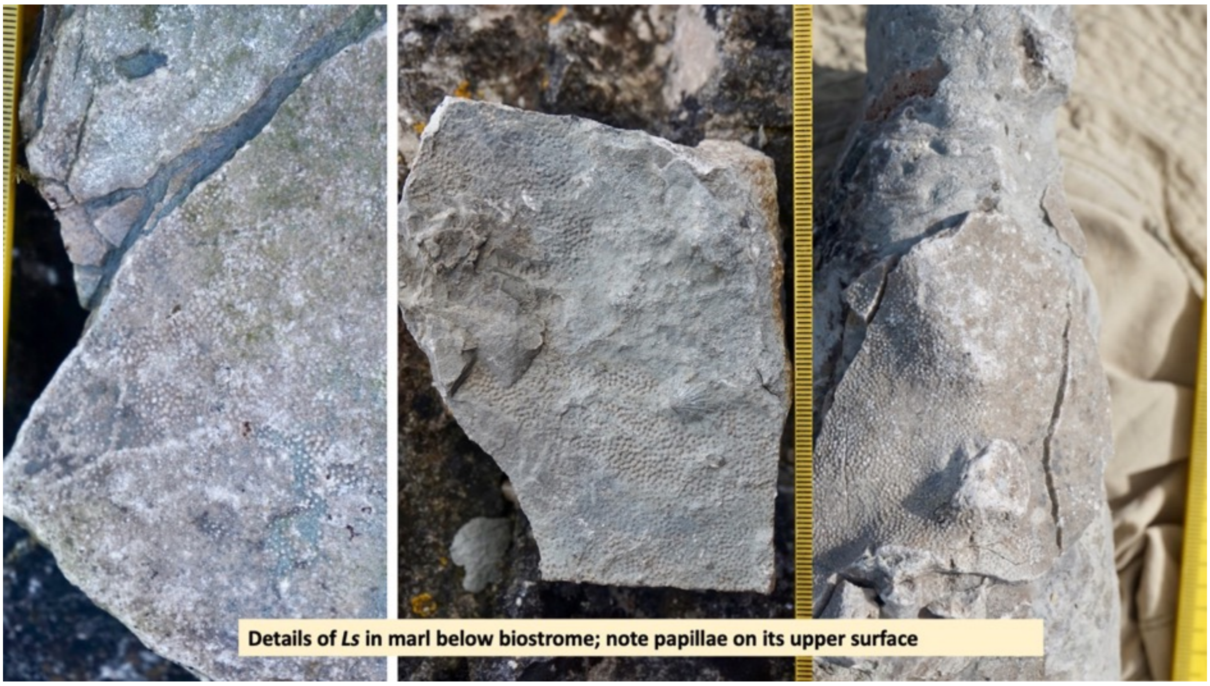


Fig. 2.8. Details of upper surface of samples of *Lophiostroma schmidtii* (*Ls*), from the marl below the biostrome at Kuppen 4. The papillate upper surface is clearly visible in each picture. The right-hand photo shows a specimen of *Ls* encrusting another stromatoporoid (a very common arrangement), viewed from the top. File: 1-08-LophiostromaSchmidti-Kuppen-FieldPhotos

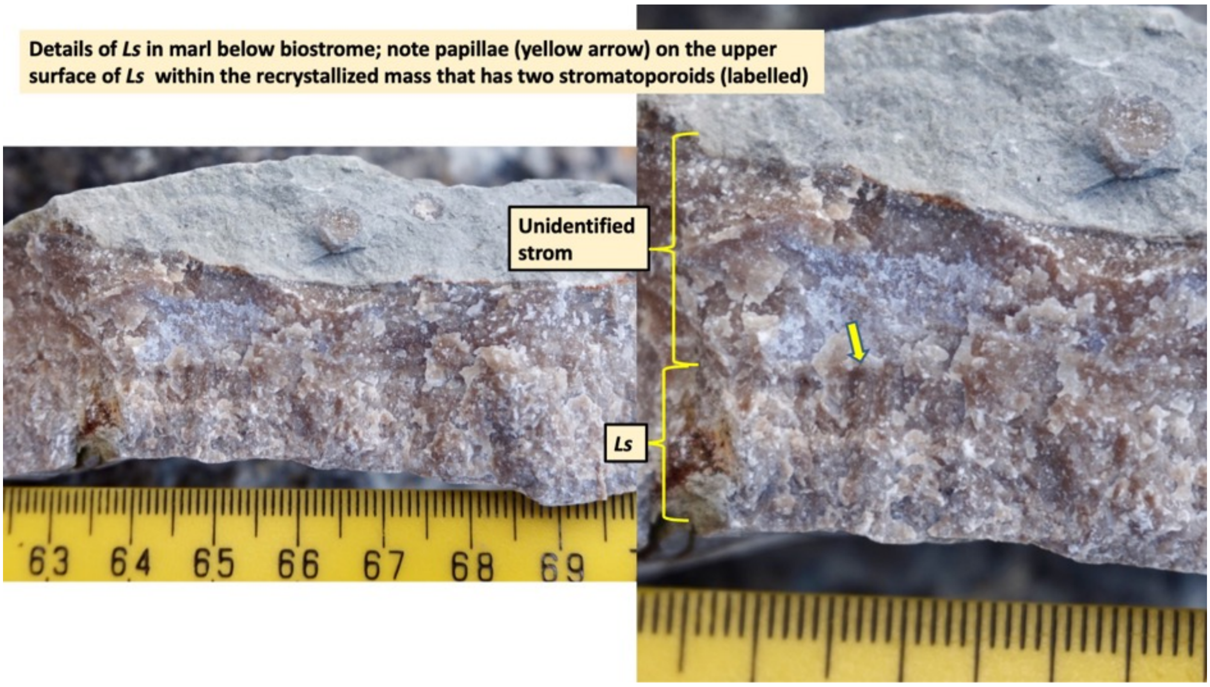


Fig. 2.9. Detail of broken vertical section of sample of *Lophiostroma schmidtii* (*Ls*), from the marl below the biostrome at Kuppen 4. The papillate upper surface is clearly visible (arrow). The lower half of the specimen is *Ls*, the upper half is another stromatoporoid (not identifiable in this photo). File: 1-09-LophiostromaSchmidti-Kuppen-FieldPhotos

Ls is found either as an encruster on other fossils;

Or it grew directly on sediment, where it forms basal growth lines, as seen here, in basal view (yellow arrows)

Note also its laminar form, which is almost always the case.

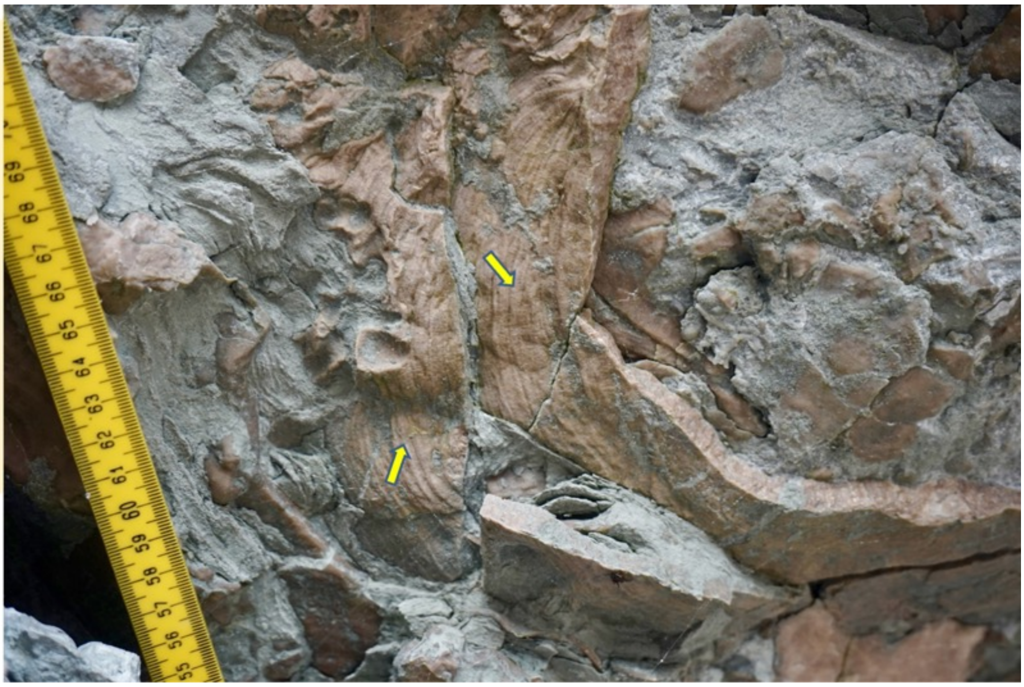


Fig. 2.10. Details of basal surface of samples of *Lophiostroma schmidtii* (*Ls*), from the biostrome at Kuppen 3. Basal lines, approximately concentrically developed are visible (arrows); grey material is micrite sediment upon which the *Ls* grew, although the presence of basal lines is evidence of primary cavities so the *Ls* grew at least partly over the substrate with a gap underneath it, that was subsequently backfilled with micrite. File: 1-10-LophiostromaSchmidti-Kuppen-FieldPhotos

In places bits of Kuppen biostrome broke away from the cliff in modern erosion and big chunks fall onto the beach, sometimes on their sides, as has happened here.

Thus this view is of a transverse section through a piece of biostrome. Thus a basal view of a laminar *Ls* is visible centre (yellow arrow), showing growth lines.

Green arrows point to huge column-shaped stromatoporoids (not *Ls*)

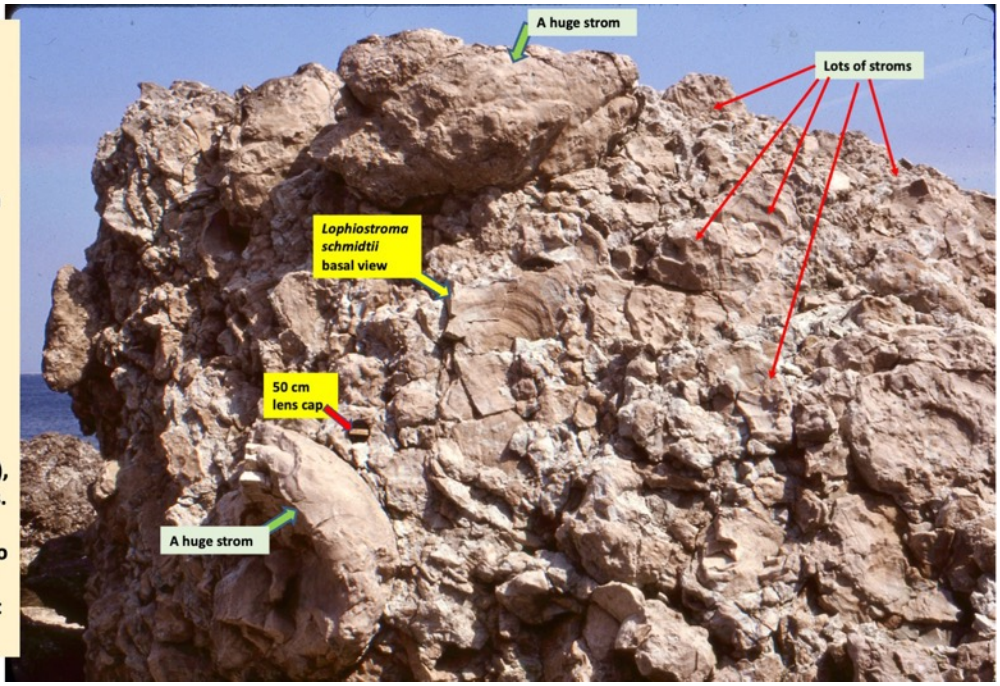


Fig. 2.11. Piece of detached biostrome as a huge boulder on the beach at Kuppen 3. Note the details in the figure, especially the basal view of *Ls.* File: 1-11-LophiostromaSchmidti-Kuppen-FieldPhotos

Fig. 2.12. Stromatoporoids show some variation of layering in field views. Here (yellow arrow) is a stromatoporoid encrusting another one, turned onto its side; however the vertical pillar-like structure of *Ls* is not visible here, so this is another stromatoporoid, not identifiable in this field view. File: 1-12-LophiostromaSchmidti-Kuppen-FieldPhotos

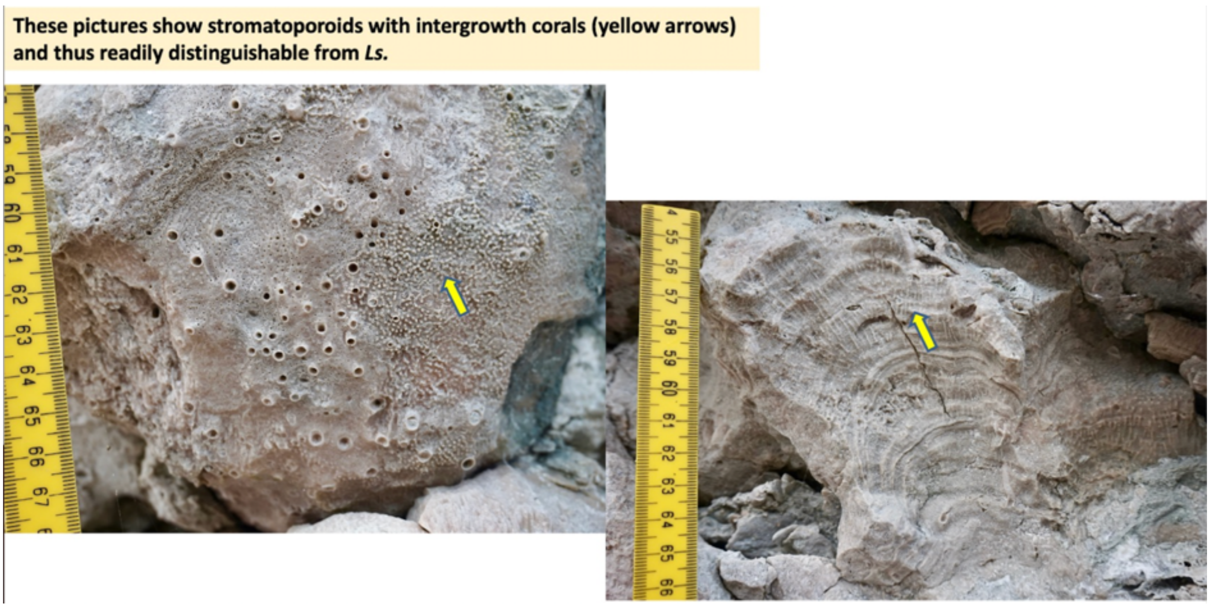


Fig. 2.13. Close views of stromatoporoids with intergrown rugosan and syringoporid corals from Kuppen 4, that do not occur in *Lophiostroma schmidtii*; so this field view can be readily distinguished from *Ls*. Interestingly in the Kuppen biostromes there are two taxa that always have syringoporid intergrown corals: *Petridiostroma convictum (Pc)* and *"Stromatopora" venukovi (Sv)*, so these pictures are of one or the other of these two taxa. However, *Sv* is rare in these rocks, while *Pc* is common; *Pc* is furthermore very abundant at Kuppen 4, making it very likely these are *Pc.* Such information shows that it is possible in some cases to identify stromatoporoids in the field, once you have prior knowledge of the fauna. File: 1-13-LophiostromaSchmidti-Kuppen-FieldPhotos

How to distinguish a stromatoporoid from a banana:
On left is a stromatoporoid that is shaped like a banana;
On right is a big stromatoporoid next to a real banana;
(stromatoporoids have growth lines, bananas don't).

Fig. 2.14. Left photo is an apparently odd-shaped stromatoporoid on a horizontal surface at Kuppen 2 (actually it is cut on the upper side by the erosion surface that has cut longitudinally through it to reveal its growth layering). This is a tall columnar form but must have fallen over during its life, then recovered growing upwards from a sideways-lying earlier part of its growth; then it rolled onto its side into its present position. Right photo shows a big dome-shaped stromatoporoid broken open along its latilaminae (=growth interruption surfaces). At the bottom of the picture is a real banana. File: 1-14-LophiostromaSchmidti-Kuppen-FieldPhotos

SECTION 3:
Recognising *Lophiostroma schmidtii* in hand specimen

Lophiostroma schmidtii (Ls) is so distinctive that it is one of only two stromatoporoids in the Gotland sequence that can be reliably recognised from hand specimens. The other one is *Labechia conferta* that looks similar to *Ls*, but is distinguishable with a hand lens. In fact, *Labechia* is not common on Gotland; this iconic form is *Labechia conferta,* which occurs only within the Halla Formation, upper Wenlock (Mori 1970, p.78), so it cannot be confused in the current samples of *Ls*, that come exclusively from the Hemse Group (middle Ludlow).

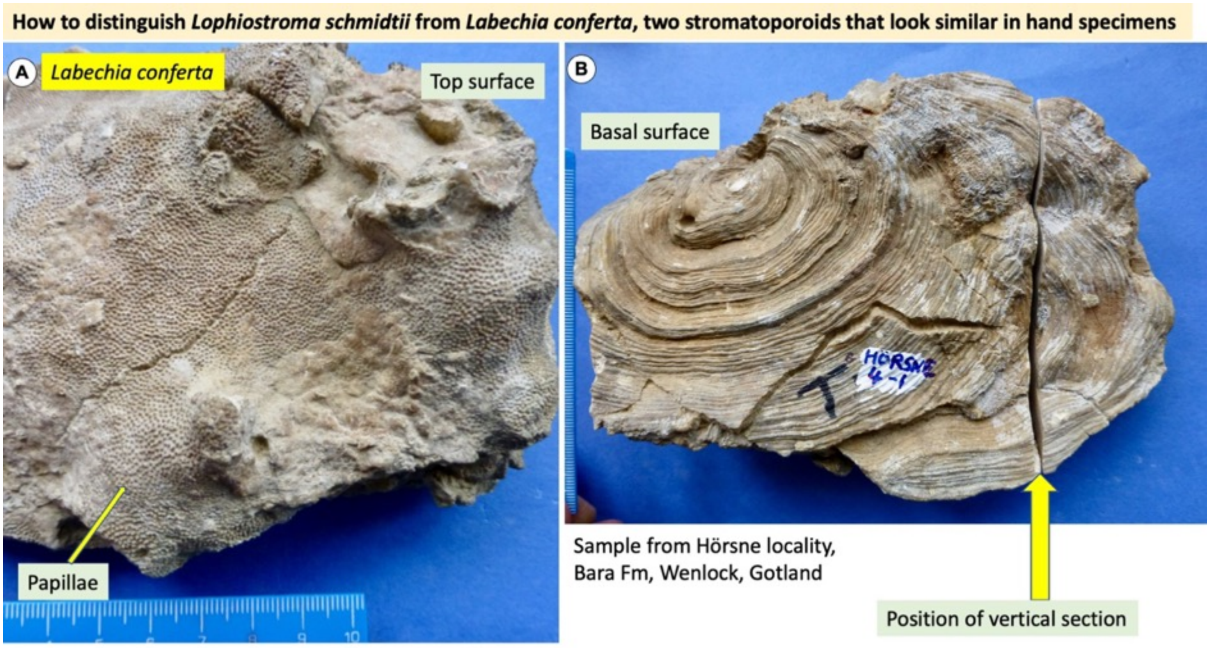


Fig. 3.1. A. Upper surface view of *Labechia conferta* showing papillae across its surface. **B.** Basal surface view of same specimen, with common concentric basal rings. The "T" written on the sample indicates this was the top of the sample when collected, indicating it had been turned upside down. Likely it grew in a low-energy environment subject to a storm event that overturned the stromatoporoid. An interesting question is about how much of the base of the stromatoporoid was in contact with the substrate while it grew; it may have grown on only the central point in the centre of the concentric circles, so the whole sample had a space beneath it while alive. However, in the right side of the basal area are 4 depressions, which could be explained by the stromatoporoid growing over objects protruding from the sea floor (earlier skeletons of corals or stromatoporoids perhaps), so it is quite possible, perhaps likely, that parts of the base were in contact with the substrate. In B, the vertical cut labelled "position of vertical section" is illustrated in Fig. 3.3. File: 2-01-Lconferta-vs-LSchmidtii

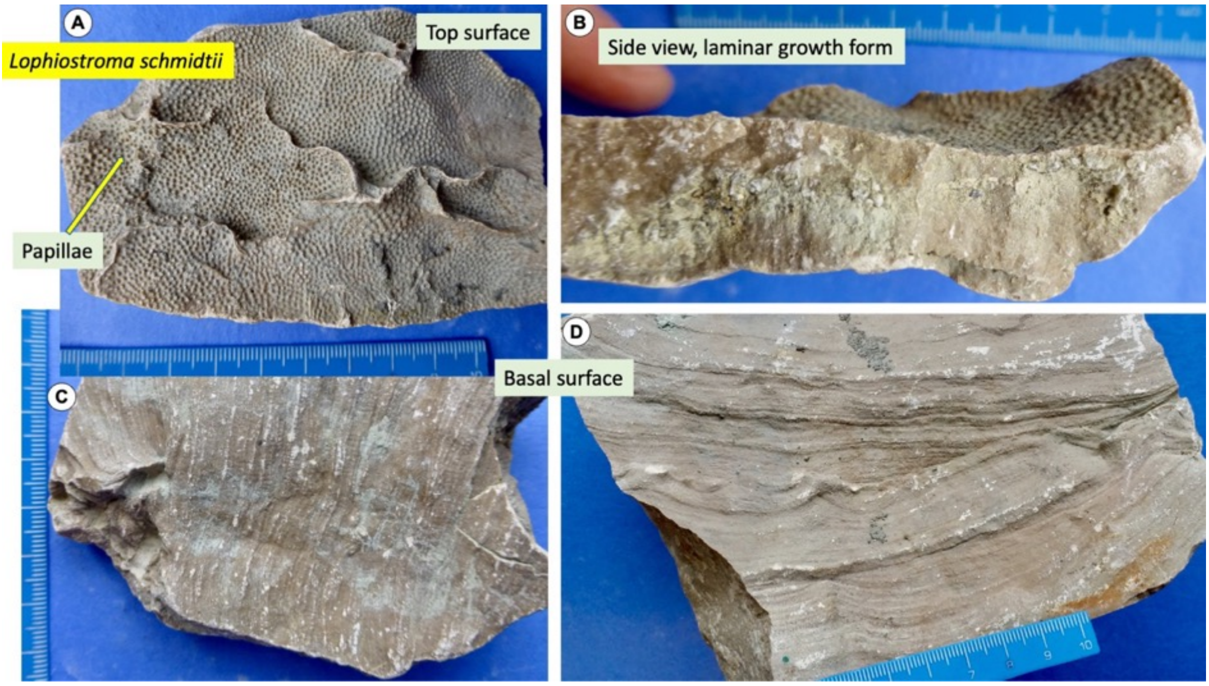


Fig. 3.2. Hand specimen views of *Lophiostroma schmidtii*, showing similarity in hand specimen with *Labechia conferta* in Fig. 3.1. To distinguish these two taxa in hand specimens, it is necessary to get a close look at the vertical section. File: 2-02-Lconferta-vs-LSchmidtii

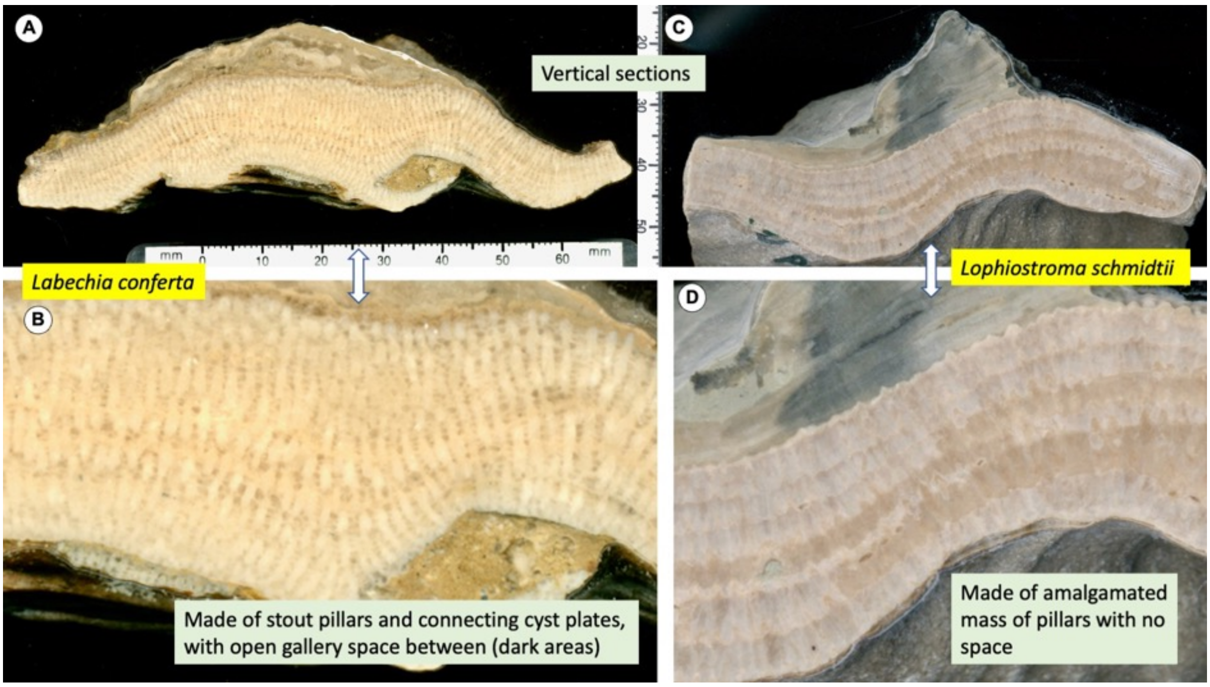


Fig. 3.3. Vertical sections of hand specimens of both *Labechia conferta* (A-B) and *Lophiostroma schmidtii* (C-D). The thick pillars and thin dissepiments of *Lc* are distinguishable from the solid mass of synchronised tightly wavy structure of *Ls*, giving impression of long pillars. File: 2-03-Lconferta-vs-LSchmidtii

Fig. 3.4. More images of contrast of construction between *Labechia conferta* (A) and *Lophiostroma schmidtii* (B). With a hand lens the two taxa are distinguishable; you should be able to see the stout pillars with spaces between, of *Labechia conferta*, contrasting the solid-looking skeleton of *Lophiostroma schmidtii.* File: 2-04-Lconferta-vs-LSchmidtii

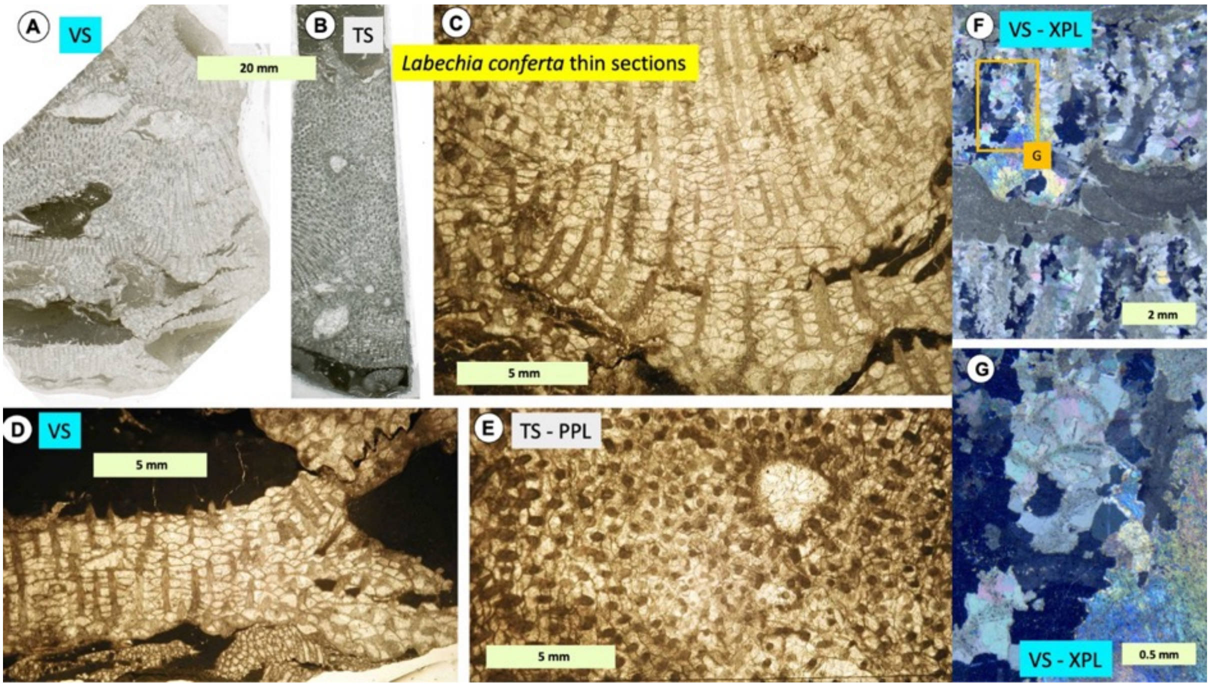


Fig. 3.5. *Labechia conferta* in thin section, VS and TS, with both PPL (A-E) and XPL (F-G). You can see the clear strong vertical pillars that are linked together by thin curved plates called cyst plates. These samples from Much Wenlock Limestone Formation, Wenlock Silurian), Wenlock Edge, Shropshire, UK. File: 2-05-Lconferta-vs-LSchmidtii

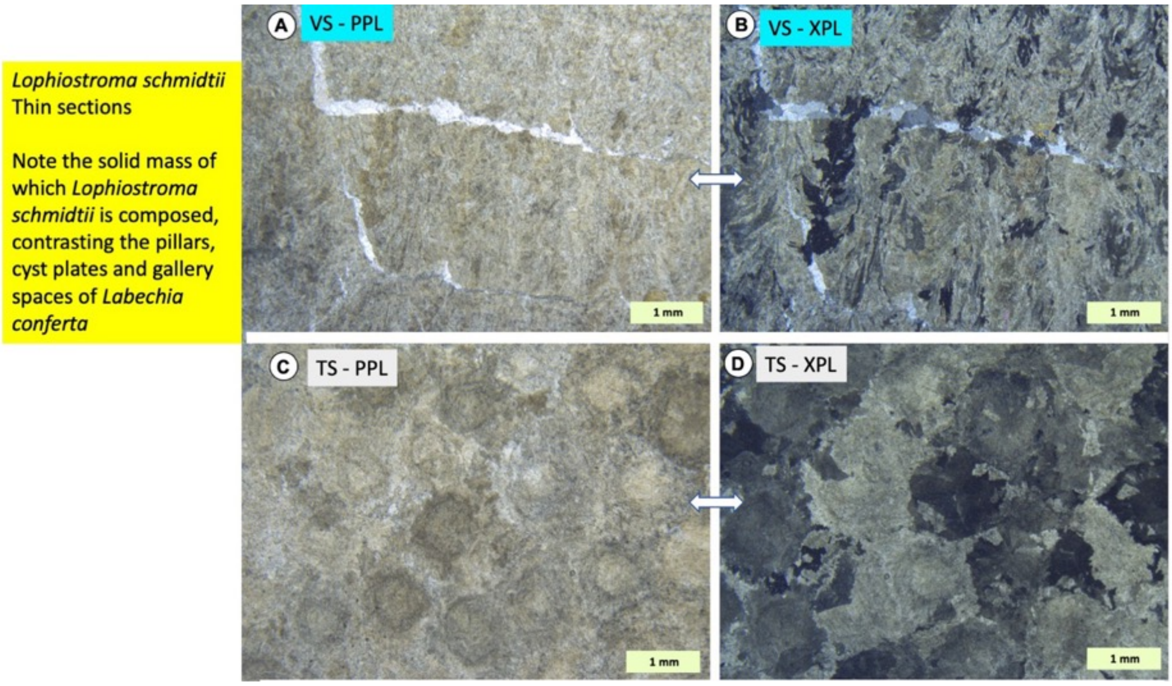


Fig. 3.6. *Lophiostroma schmidtii* (*Ls*) in thin section, VS and TS, with both PPL (A & C) and XPL (B & D). You can see this is quite different from *Labechia conferta*; here the solid structure of *Ls* is very apparent. Photos A and B also show a fracture that is filled with calcite in optical continuity with the skeletal structure; these pictures are repeated in the Case Studies section and considered in some detail; yep, you guessed it – they have some significance! These samples from Hemse Group, Ludlow (Silurian), Kuppen, Gotland, Sweden. File: 2-06-Lconferta-vs-LSchmidtii

SECTION 4:
Lophiostroma schmidtii – more general features

Fig. 4.1. Plan view of upper surface of *Lophiostroma schmidtii* (Ls) showing papillae. Yellow arrow pointing at a round object with concentric lines shows a small piece of another stromatoporoid that has fine laminae seen in top view, encrusted onto the top of the *Ls*. Kuppen, Gotland. File: 3-01-KLoose25-VS-Sv-Sb-Dp-LsEncruster

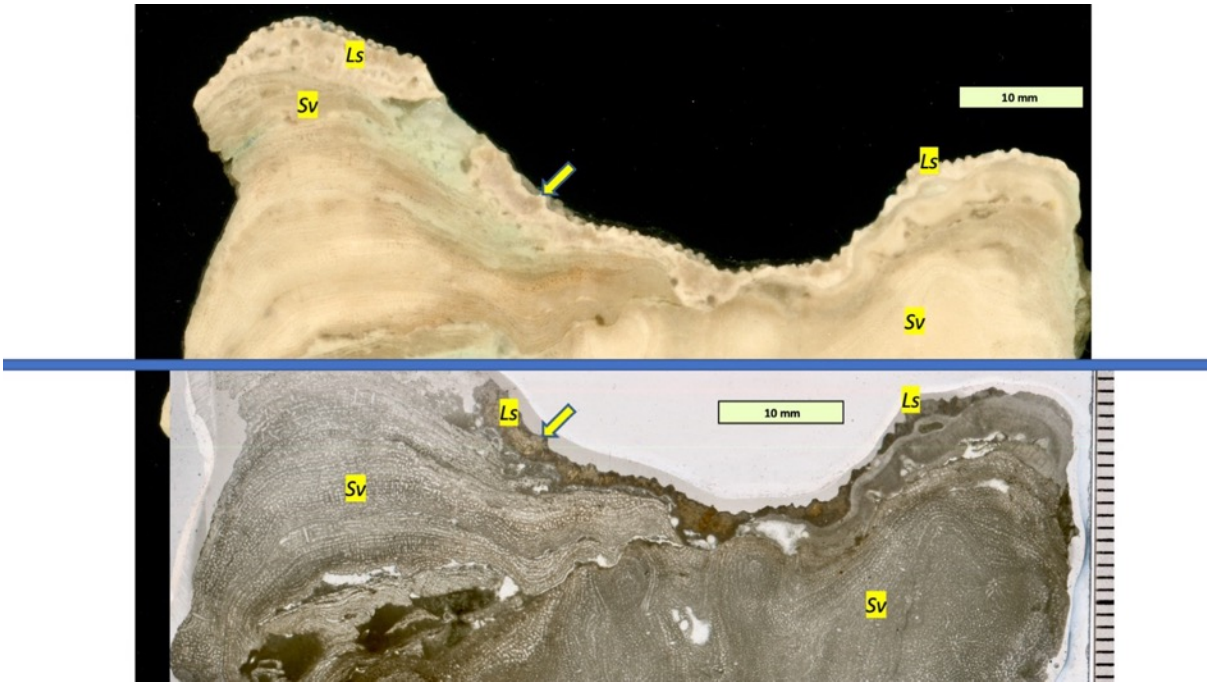


Fig. 4.2. Vertical section (upper is hand specimen, lower is thin section at same scale) showing *Lophiostroma schmidtii* (*Ls*) encrusting a specimen of *"Stromatopora" venukovi* (*Sv*). Note there is some micrite (light green colour) between part of the *Ls* and *Sv*, so the *Ls* encrusts partly on skeletal and partly on sedimentary material. Yellow arrow shows matched points between the two images and also the location of Fig. 4.3. Kuppen, Gotland. File: 3-02-KLoose25-VS-Sv-Sb-Dp-LsEncruster

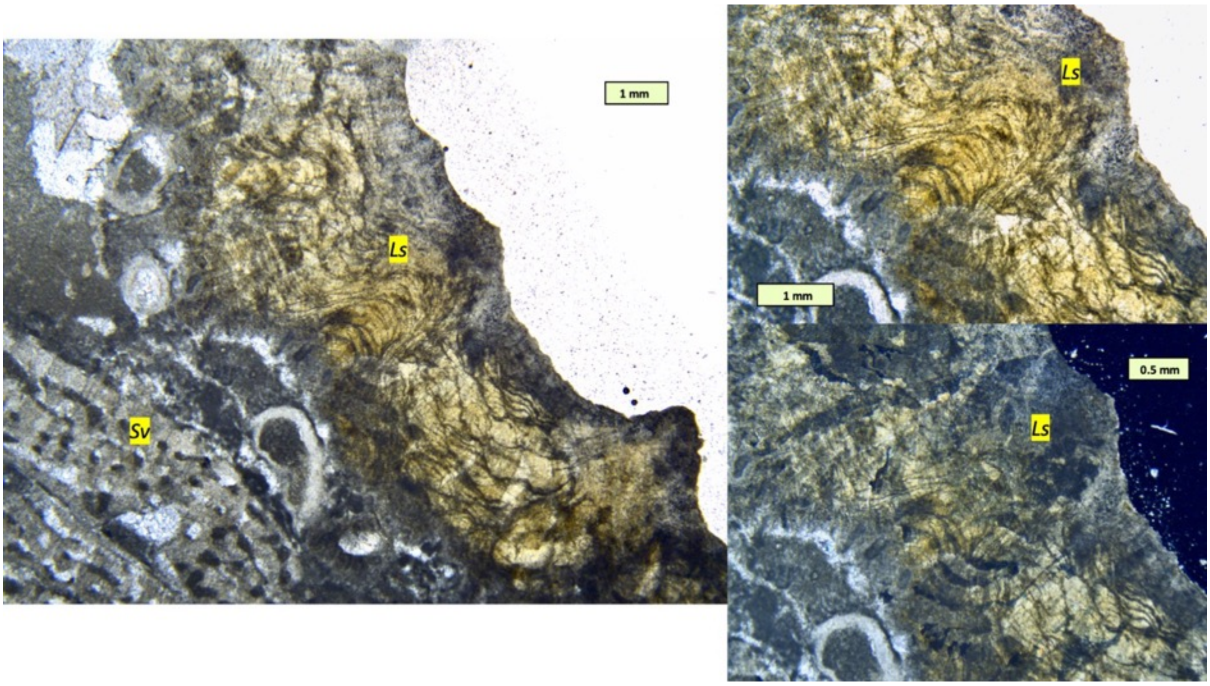


Fig. 4.3. Enlargement of area of yellow arrow in Fig. 4.2, showing *Lophiostroma schmidtii* (*Ls*) grew on bioclastic-containing micrite. Left photo and right upper photo are PPL; lower right photo is XPL, that shows overprinting of diagenetic calcite across the layering. Kuppen, Gotland. File: 3-03-KLoose25-VS-Sv-Sb-Dp-LsEncruster

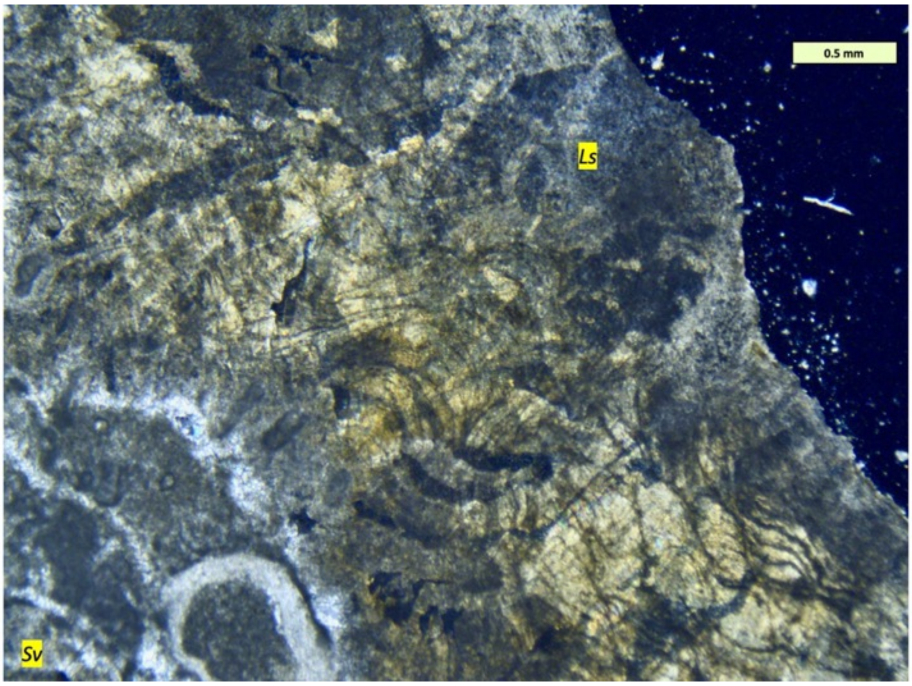


Fig. 4.4. Enlarged view of Fig. 4.3 lower right, showing *Lophiostroma schmidtii* in XPL, highlighting the layering and also the overprinted diagenetic calcite, here partly in extinction. Kuppen, Gotland. File: 3-04-KLoose25-VS-Sv-Sb-Dp-LsEncruster

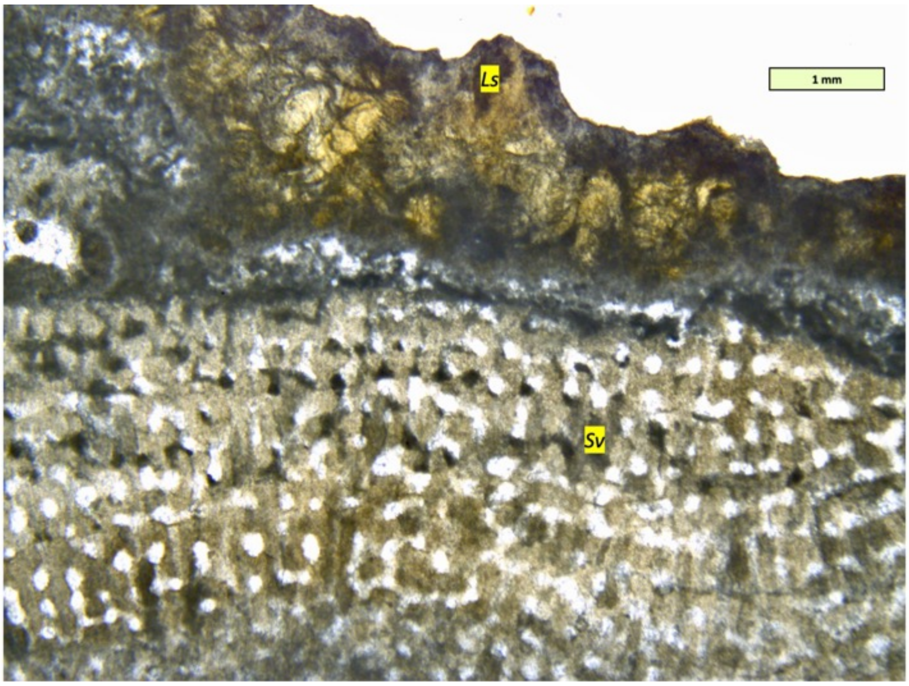


Fig. 4.5. Enlarged view of central part of Fig. 4.2, showing very thin layer of *Lophiostroma schmidtii* encrusting a thin layer of sediment on top of *"Stromatopora" venukovi.* Kuppen, Gotland File: 3-04-KLoose25-VS-Sv-Sb-Dp-LsEncruster

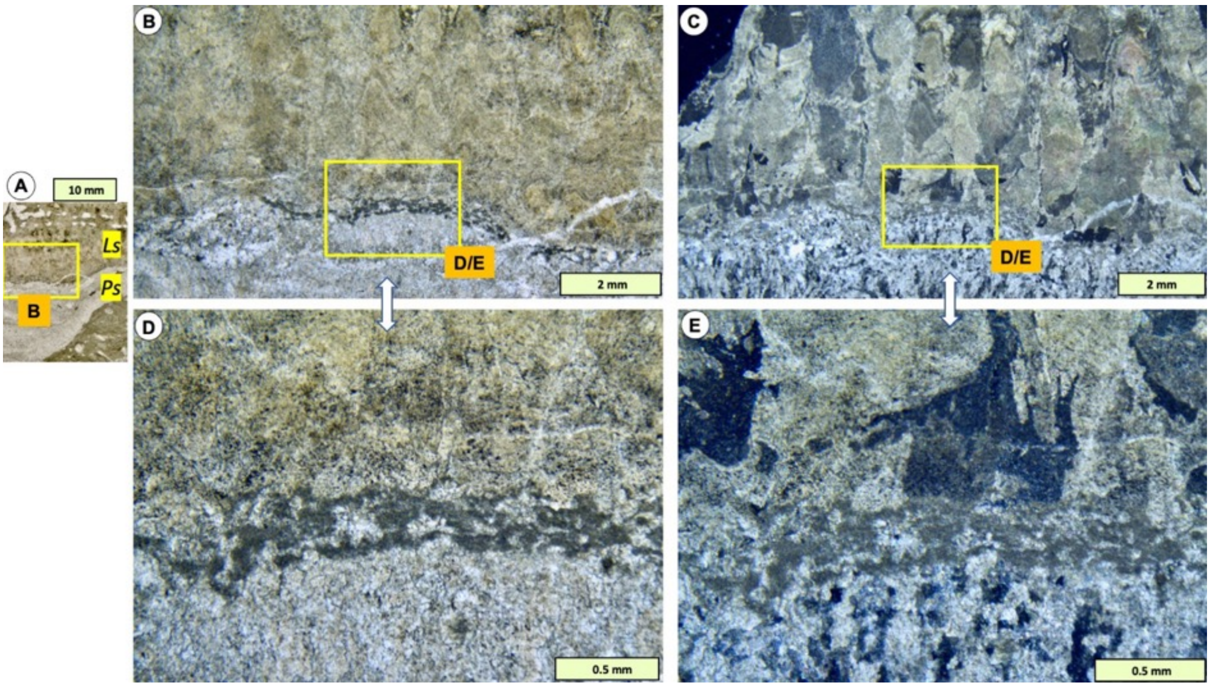


Fig. 4.6. Example of basal part of *Lophiostroma schmidtii* (*Ls*), encrusting upper surface of *Plectostroma scaniense* (*Ps*) with a thin layer of sediment between (dark layers in D & E). **B & D** are PPL, **C & E** are XPL. Note in D the base of *Ls* has large overprinting diagenetic calcite crystals that terminate at the base of the *Ls* and do not pass into the substrate material; this is a normal character of stromatoporoids, the diagenetic crystals do not pass outside the margin of the stromatoporoid, present in almost all stromatoporoids when viewed in XPL. Kuppen 3, lower part of biostrome. File: 4-1-2c7-8.76-Sed-Ps-Ls-VS-LsBase

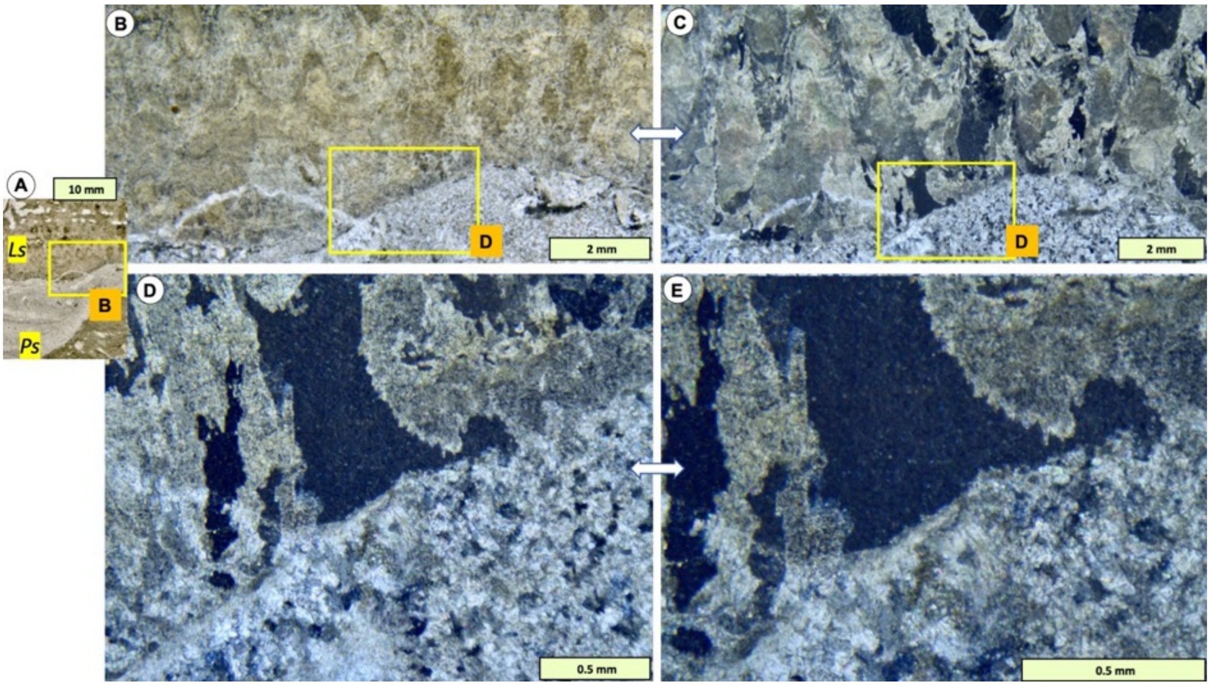


Fig. 4.7. Another part of the same thin section as in Fig. 4.6, showing detail of diagenetic calcite recrystallisation of basal part of *Lophiostroma schmidtii* (*Ls*), that does not continue into the directly underlying skeleton of *Plectostroma scaniense* (*Ps*) that the *Ls* encrusted. The same is true for the recrystallisation of *Ps* that does not pass upwards into *Ls*. Thus the recrystallisation process affecting these two stromatoporoids stops at the margins of the stromatoporoids and does not pass into material beyond. This normal in stromatoporoids and is a characteristic of fabric-retentive irregular calcite (FRIC) described and discussed by Kershaw et al. (2021 – Facies paper). Kuppen 3, lower part of biostrome, Gotland. 4-2-2c7-8.76-Sed-Ps-Ls-VS-LsBase

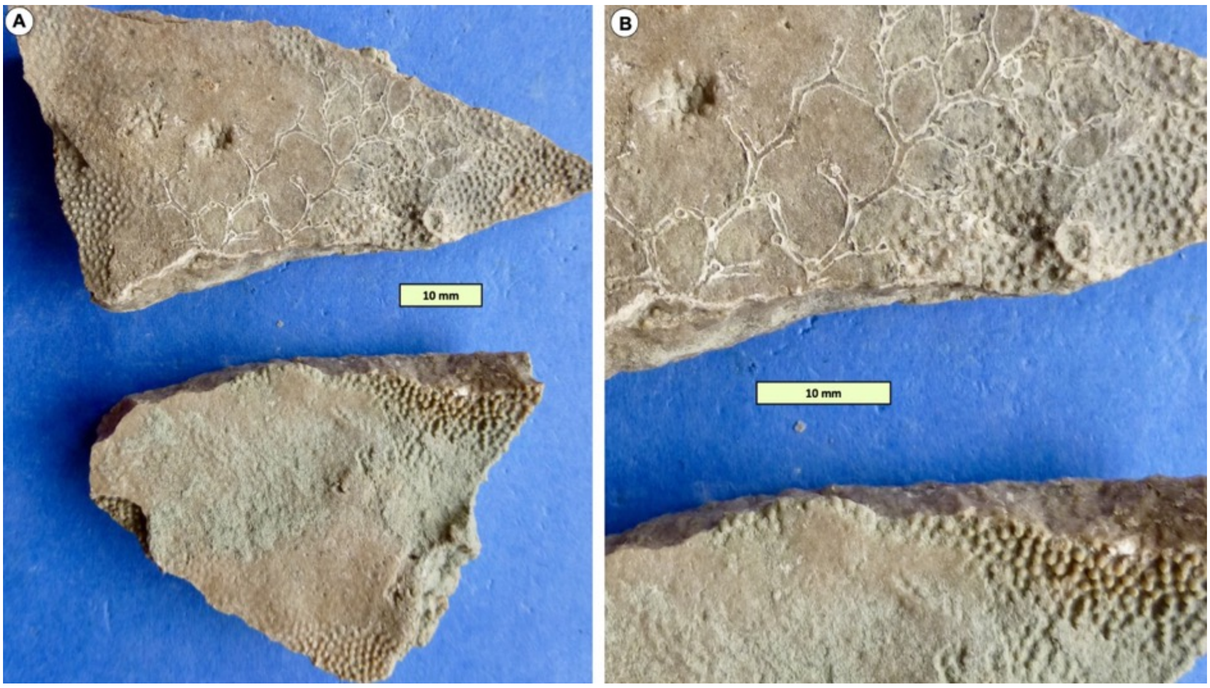


Fig. 4.8A & B. Photos of fragments of the upper surface of a laminar specimen of *Lophiostroma schmidtii* showing the papillae do not extend across the entire surface. Although at first glance, this seems to indicate that the stromatoporoid was partly eroded, there are two features which count against erosion as a cause for the smooth areas: 1) why isn't **all** of it smooth, and thus why are

papillae very well-preserved in some areas, directly next to smooth areas? Doesn't make sense; and 2) the upper fragment in the photos shows an encrusting bryozoan colony on the smooth surface of *Ls*, passing across onto the papillate surface to the right. Interestingly although the bryozoan is clearly eroded away, leaving only the attachment of its lower part on top of the *Ls*, that attachment is onto a smooth part of the *Ls* and so the smoothness of the *Ls* must have happened before the bryozoan encrusted. This peculiar situation is interpreted to indicate that the smooth area was simply an area where papillae did not form, rather than they were eroded. Further evidence to support this interpretation is provided in Fig. 4.8E-G. From Marl beneath biostrome, Kuppen 4, Gotland. File: 5-1-Lophiostroma-PapillaeTops

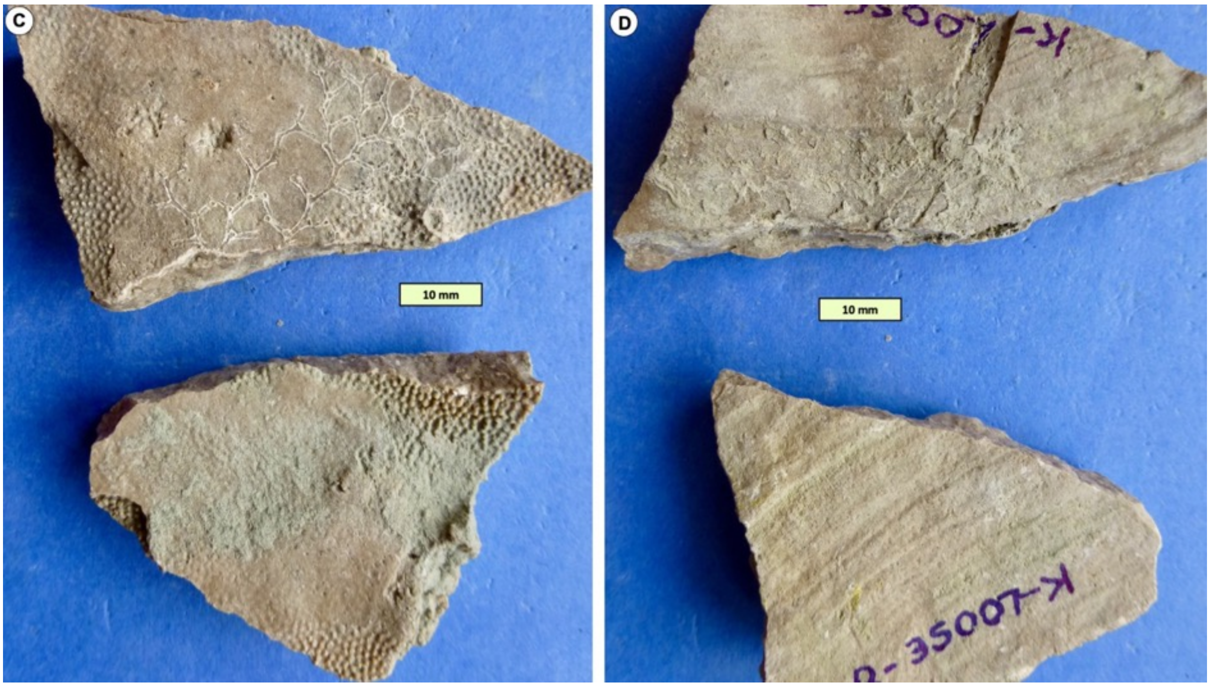


Fig. 4.8C & D. Photos of upper and lower surfaces of specimens illustrated in Fig. 4.8A & B. The lower surface shows basal lines that are part of basal rings, and may be evidence of primary cavities of a sample of *Lophiostroma schmidtii* that grew on a fine-grained sediment (micrite with clay) substrate, which comprises the marl beneath the biostrome. Kuppen 4, Gotland. File: 5-2-Lophiostroma-PapillaeTops

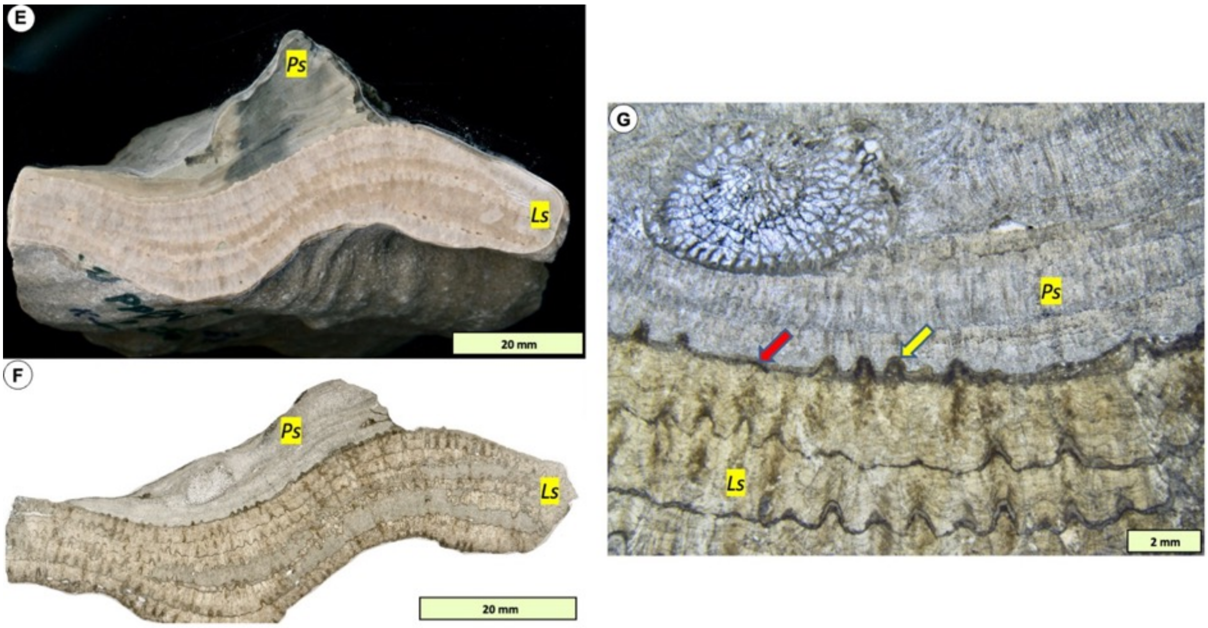


Fig. 4.8E-G. Vertical section photos of polished block (E), whole thin section (F) and enlargement of left centre of F (G), showing the papillae on upper surface of *Lophiostroma schmidtii* (*Ls*) are missing in some places, but directly next to parts of the skeleton with well-formed papillae. This is considered to be evidence that the papillae were not always fully formed, for reasons that are not clear. Note also that in G, two minor growth interruption surfaces, picked out by dark lines parallel to the growth surface; in each case the stromatoporoid has recovered with direct contact across the prior surface. There is some more detail of this specimen in Fig. 4.13. Kuppen 4 marl, Gotland. File: 5-3-Lophiostroma-PapillaeTops

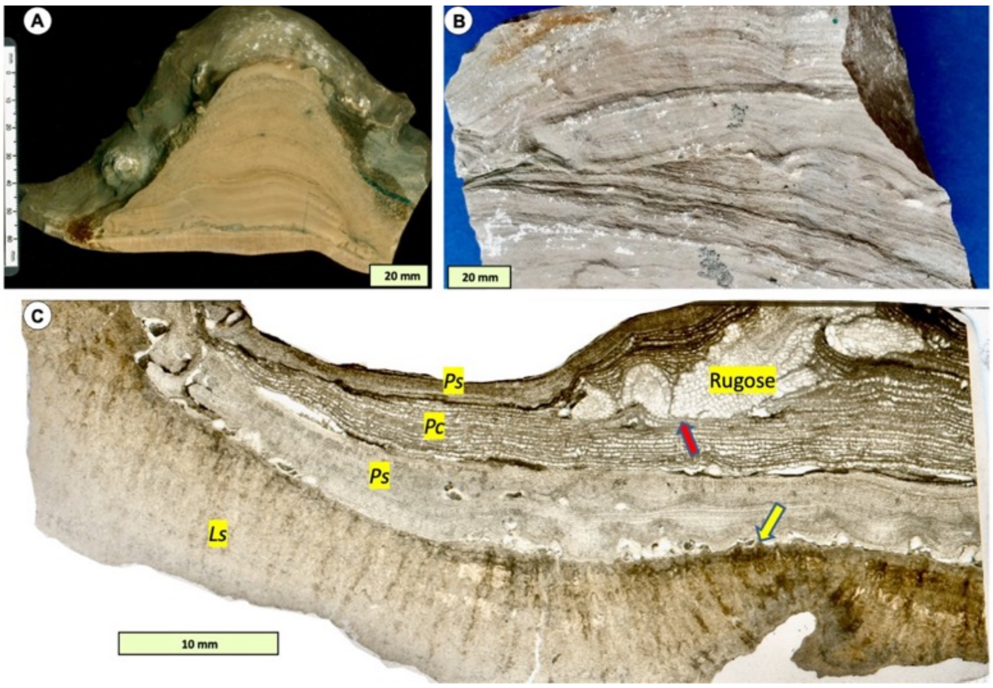


Fig. 4.9. A. Vertical section of polished block showing laminar *Lophiostroma schmidtii* (*Ls*) at the base, encrusted by domical forms. **B.** View of part of basal surface of *Ls*, showing basal ridges, considered to be evidence of primary cavity formation. The fact that the ridges are clearly visible indicates the stromatoporoid grew on unconsolidated sediment removed by modern weathering. **C.** Whole thin section view showing *Ls* at the base, encrusted by *Plectostroma scaniense* (*Ps*), subsequently encrusted by *Petridiostroma convictum* (*Pc*). The surface of *Pc* was encrusted by

rugose corals, and then further *Ps.* This type of multiple encrustation based on *Ls* is common in the Hemse Group biostromes on Gotland. Yellow arrow shows prominent papillae, but further left along the same upper surface, just below the "Ps" label the upper surface of the *Ls* is smooth. In the lower right corner of C is a cleft in the base of *Ls*, that is wrapped over by curving laminations, indicating that the cleft represents an object present in the base of the *Ls*, over which it grew, but then was not preserved; this is a possible soft bodied organism (bioclaustration) that the *Ls* grew over. Kuppen 4 marl, Gotland. File: 6-1-Ls-AssdOrgs

D

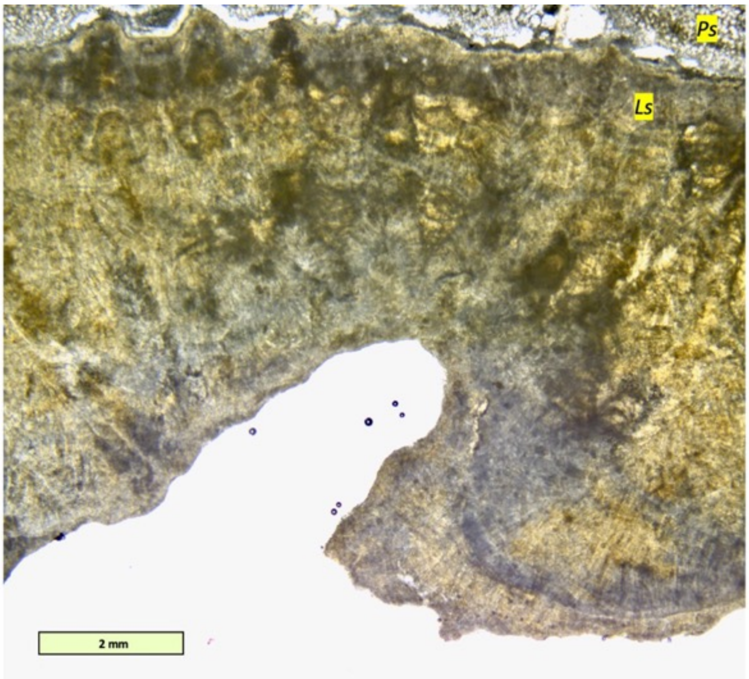


Fig. 4.9D. Enlargement of lower right corner of Fig. 4.9C, showing detail of curved growth of *Ls* around unknown object that it grew over, that may have been a soft-bodied organism (bioclaustration) so did not leave a fossil. Kuppen 4 marl, Gotland. File: 6-2-Ls-AssdOrgs

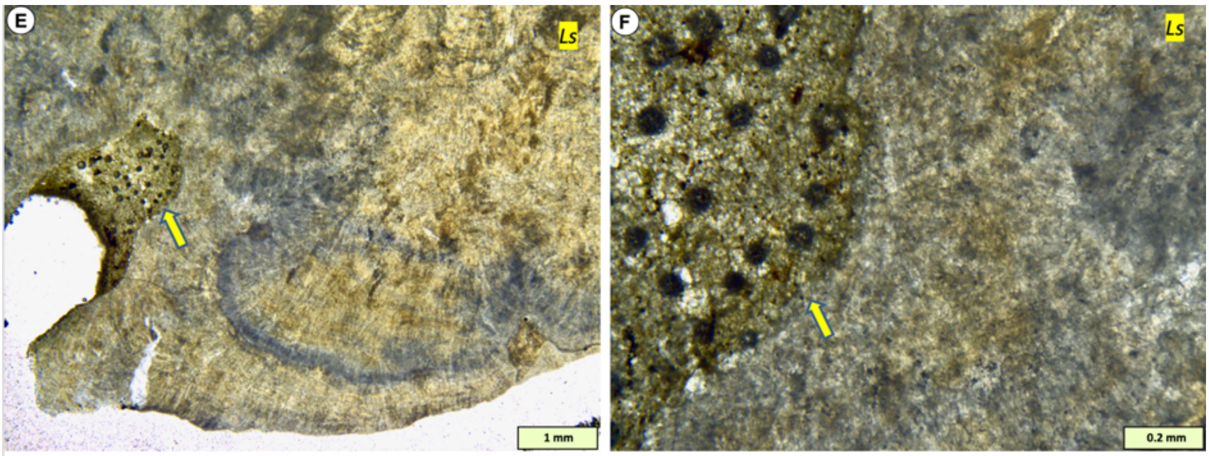


Fig. 4.9E,F. Enlargement of a parallel thin section to Fig. 4.9D, showing sediment infill in the base of *Ls* (together with some air bubbles [dark circles]). Whether there was a soft-bodied organism in the cavity now occupied by sediment is open to speculation. Yellow arrow shows matched points. Kuppen 4 marl, Gotland. File: 6-3-Ls-AssdOrgs

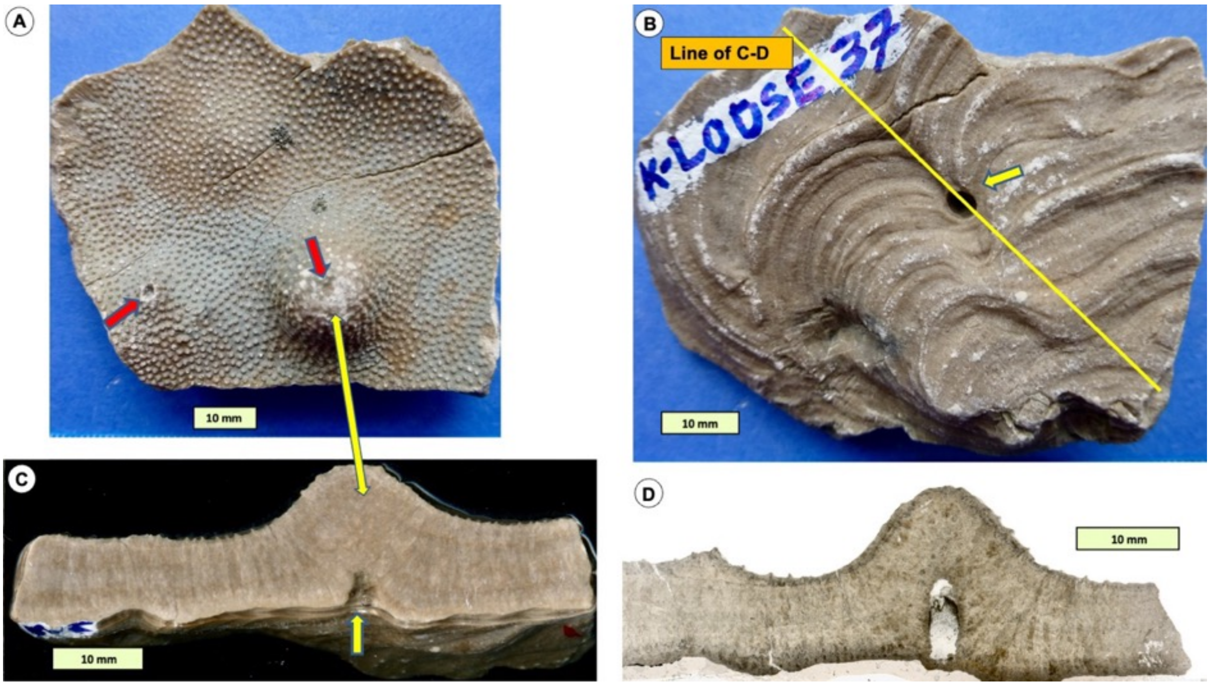


Fig. 4.10A-D. *Lophiostroma schmidtii* (*Ls*) sample with peculiar basal cavity (yellow arrow). **A.** Upper surface view showing nice papillate surface that undulates. There is a prominent hill in the lower part, shown in C & D in section, but the sections in C & D do not pass through the tiny hole in its apex (right-hand red arrow). Another small hill is on left with a tiny hole in the top of the hill (left-hand red arrow). **B.** Basal view showing line of section in C & D and the basal hole (yellow arrow). **C.** Polished sample along line of cut in B, with basal hole (yellow arrow). **D.** Vertical thin section parallel to C, showing more of the basal hole, noting that this cut is slightly off-centre of the hole which is presumed to continue to the apex of the hill in A (that has a tiny hole in the apex, right-hand red arrow). The next two slide show details of the thin section, focussing on the basal hole. Kuppen 4 marl, Gotland. File: 6-4-Ls-AssdOrgs

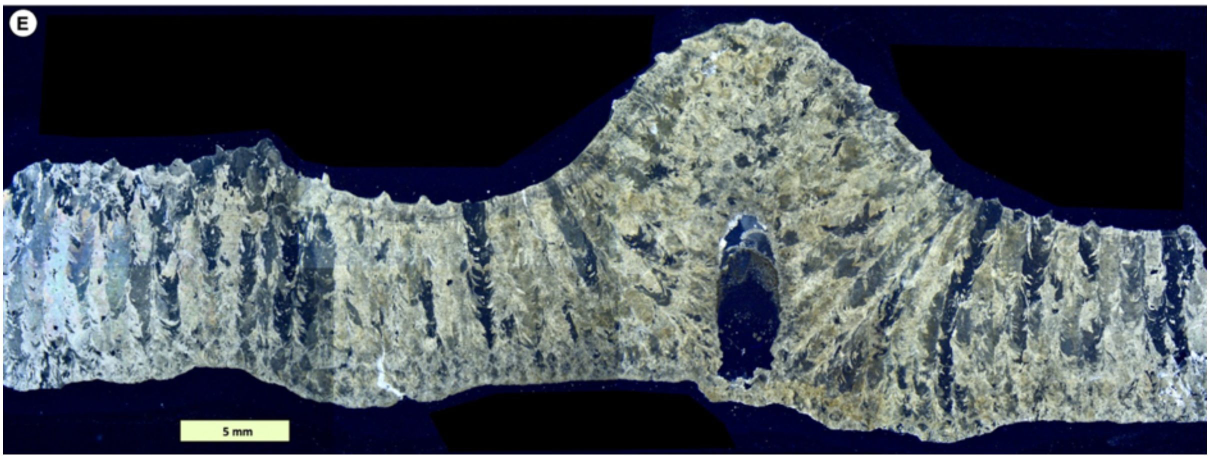


Fig. 4.10E. Vertical thin section from Fig. 4.10D, shown as a montage of images in XPL. Note the vertically-orientated diagenetic fabric with singe crystals of FRIC passing from base to top of the cross section. The skeleton above the basal hole passes into oblique TS orientation of the skeleton wrapped around the object that occupied the hole (possibly a bioclaustration organism). Kuppen 4 marl, Gotland. File: 6-5-Ls-AssdOrgs

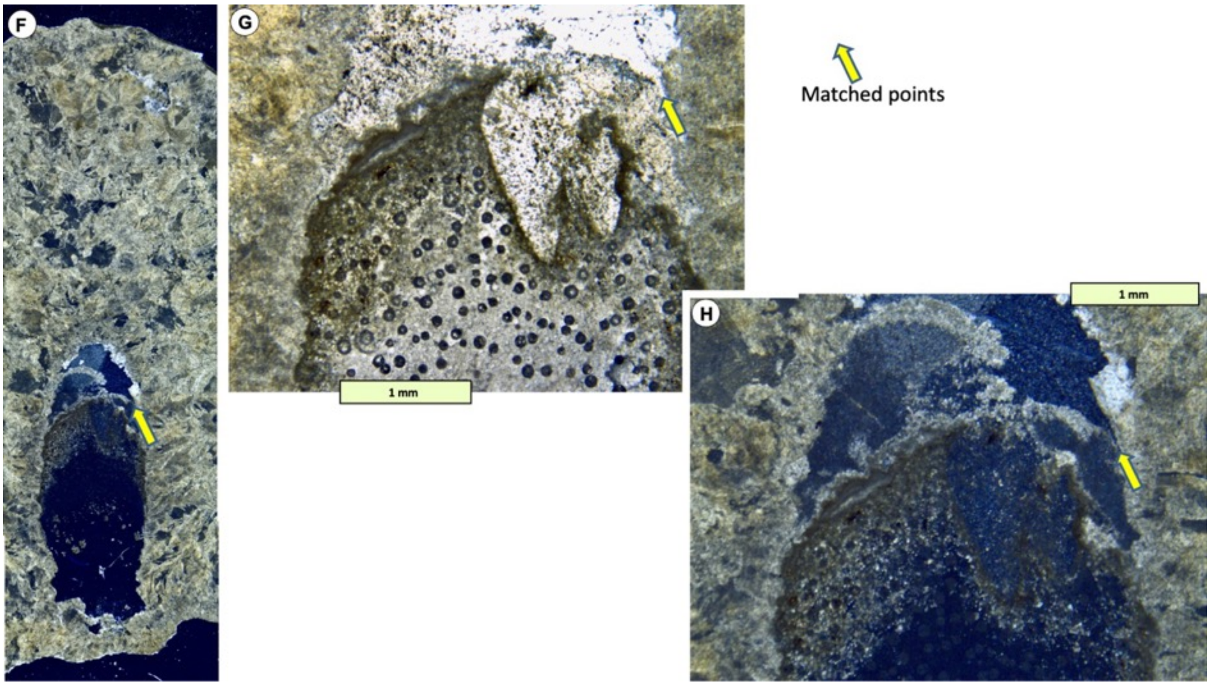


Fig. 4.10F-H. Details of the basal hole. **F.** XPL view. The hole must be obliquely orientated within the stromatoporoid because in F, at the very bottom of the picture the stromatoporoid skeleton continues across below the hole; thus the line of section has clipped the edge of the stromatoporoid at the base. **G-H.** PPL (G) and XPL (H) views of the upper part of the cavity in this plane of section (noting that the hole is oblique). Yellow arrows show matched points. There is micrite in the cavity (plus lots of air bubbles) and some of the sediment was lost in thin section preparation, so there are holes in the slide, shown as dark areas in H. There is obscure curving structure across the hole, at the position of the yellow arrow, that might be shell material; otherwise the edges of the basal hole are not lined with shell structure and are thus evidence of a non-calcified structure around which the stromatoporoid grew. These pieces of evidence point to a bioclaustration as the cause of the hole and thus an associated organism that the stromatoporoid grew around. The tiny holes at the peaks of the hills in A might indicate an access point of an organism to the seawater, thus keeping it alive and possibly preventing the stromatoporoid from killing the proposed associated organism. Kuppen 4 marl, Gotland. File: 6-6-Ls-AssdOrgs

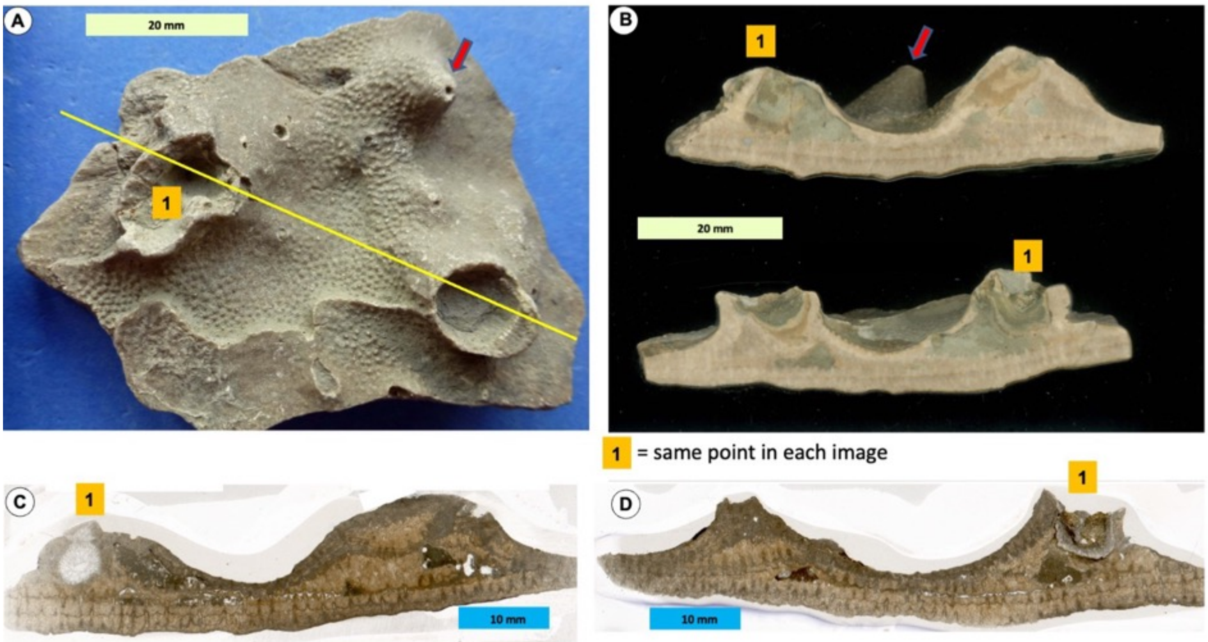


Fig. 4.11A-D. Another sample of *Lophiostroma schmidtii* (Ls), with intergrown corals and a small chimney structure (red arrow) that looks like the structure in Fig. 4.10. Kuppen 4 marl, Gotland. File: 6-7-Ls-AssdOrgs

Fig. 4.11E. Enlargements of Fig. 4.11C&D, showing this thin stromatoporoid has a prominent growth interruption surface in the middle, with growth recovery, some of which has resulted in minor primary cavity development (thin irregular light horizontal lines in the middle of the stromatoporoid indicate the cement-filled cavity). The upper growth has rugose coral that is presumed to have settled on the living stromatoporoid surface that reacted and grew up around the coral. Kuppen 4 marl, Gotland. File: 6-8-Ls-AssdOrgs

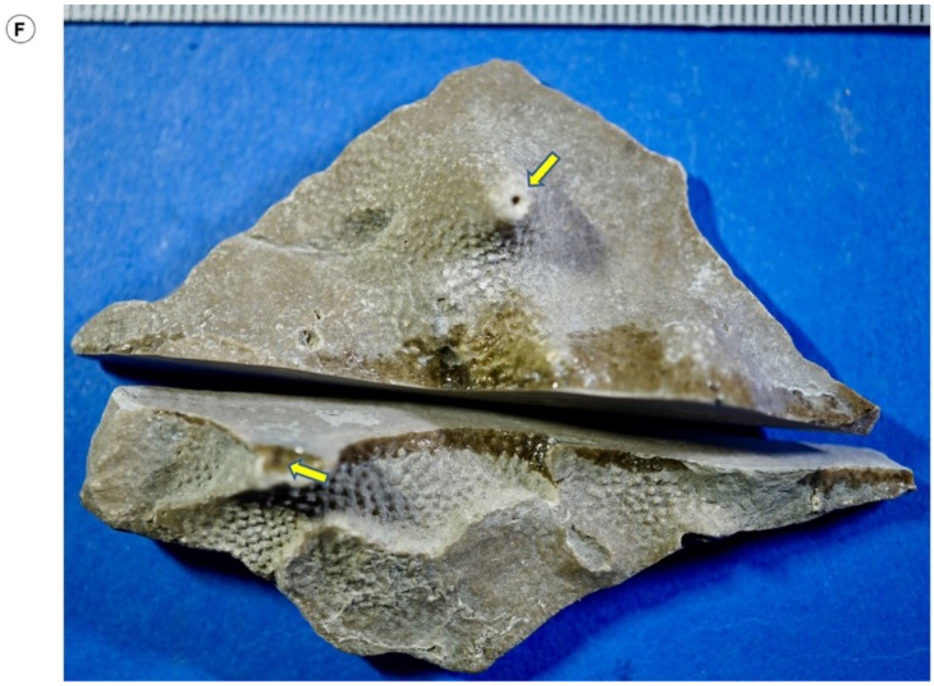


Fig. 4.11F. Another specimen of *Lophiostroma schmidtii* (*Ls*), upper surface view, showing tiny chimneys (yellow arrows), as in Figs. 4.10 and 4.11A-E, further evidence of bioclaustrations associated with the *Ls.* Kuppen 4 Marl, Gotland. File: 6-9-Ls-AssdOrgs

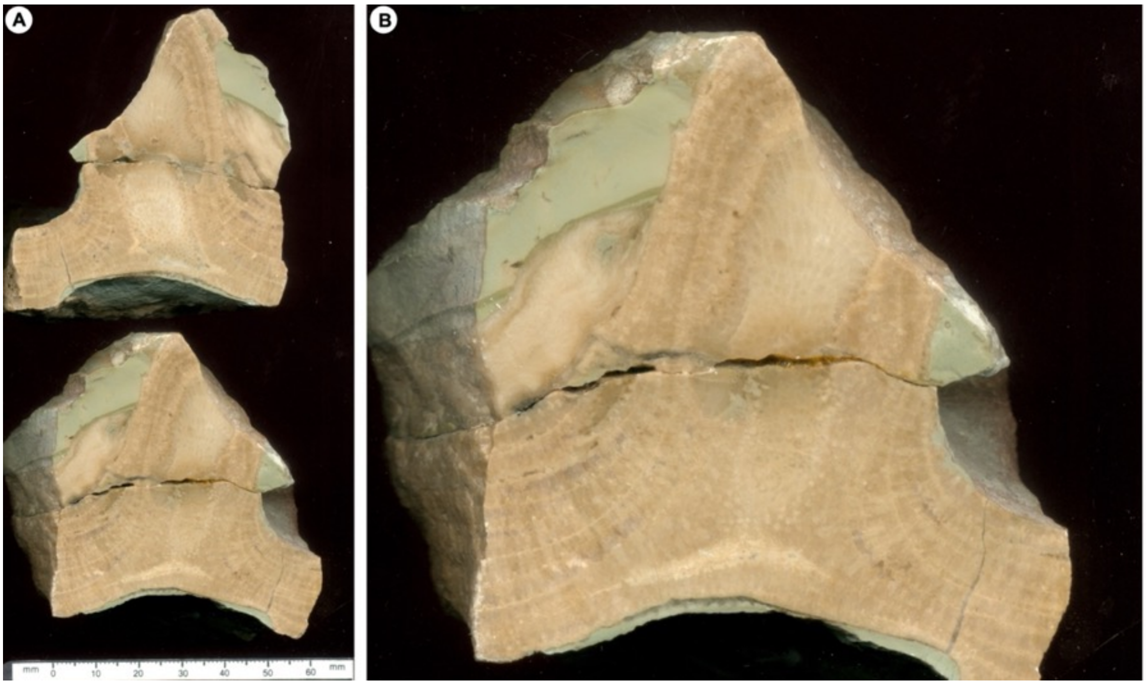


Fig. 4.12A-B. *Lophiostroma schmidti* (*Ls*) and associated columnar tabulate (*Laceripora*). These pictures show the Ls began as a flat plate, which is its growth form, it does not occur in any form other than laminar growth if it grew alone. Micrite beneath the base of the stromatoporoid shows this did not encrust another organism but grew on sediment substrate. The origin of the coral is not known in this sample because it is outside the plane of section. The coral may have grown on a dead part of the *Ls*, or may have settled on the living stromatoporoid live surface as happened in many other stromatoporoids (I know this because the stromatoporoid was not affected either side of the encrusters and then the stromatoporoid grew over and entombed the encrusters – stromatoporoids were quite capable of dealing with intruders if they could not grow fast to keep up). In the case of the *Laceripora* illustrated here, *Ls* responded to the coral's presence and encased it forming a column;

this arrangement is unusual for *Ls*. It seems likely the coral and *Ls* grew along together, but this can't be verified as a mutualisti biological association, the coral seems to have used the stromatoporoid as a solid base to live on. A second stromatoporoid encrusted the (probably dead) *Ls* surface on the left side in [B]. Biostrome, Kuppen 2, Gotland. File: 6-10-Ls-AssdOrgs=4.9-Kuppen2-LS-02 copy

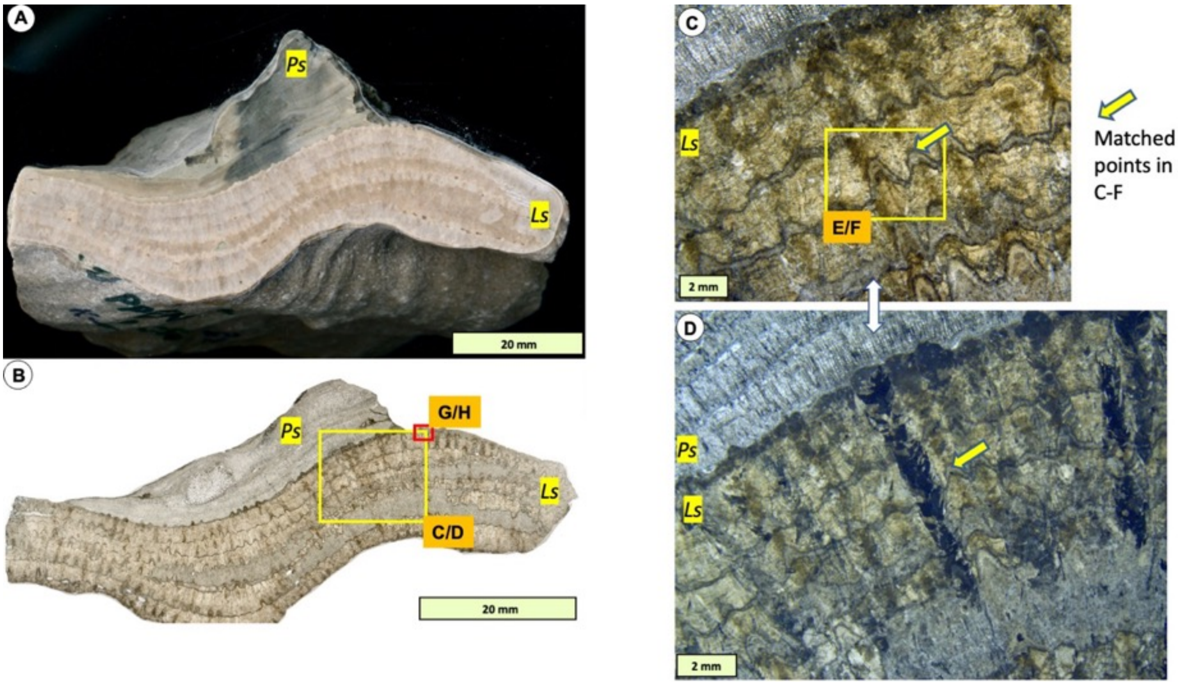


Fig. 4.13A-D. More details of this specimen from Fig. 4.8 above. **A.** polished block vertical section of *Ls* encrusted by *Ps*, a common occurrence. **B.** Whole thin section view. **C-D.** PPL (C) and XPL (D) views of yellow box in B, showing undulating structure of laminations, that are synchronised vertically into apparent pillars, but D demonstrates diagenetic alteration so that large elongate calcite crystals develop along these vertical lines; these are shown in more detail in E & F, and are part of the FRIC diagenesis. However, there are also narrow grey bands in C, and a thick grey band in the lower part of D, of another form of alteration that pre-dates the FRIC, and is an area of currently poor understanding of structural change; there are more images of this in subsequent figures. Kuppen 4 marl, Gotland. File: 7-1-KLoose23-i-Ls-Ps

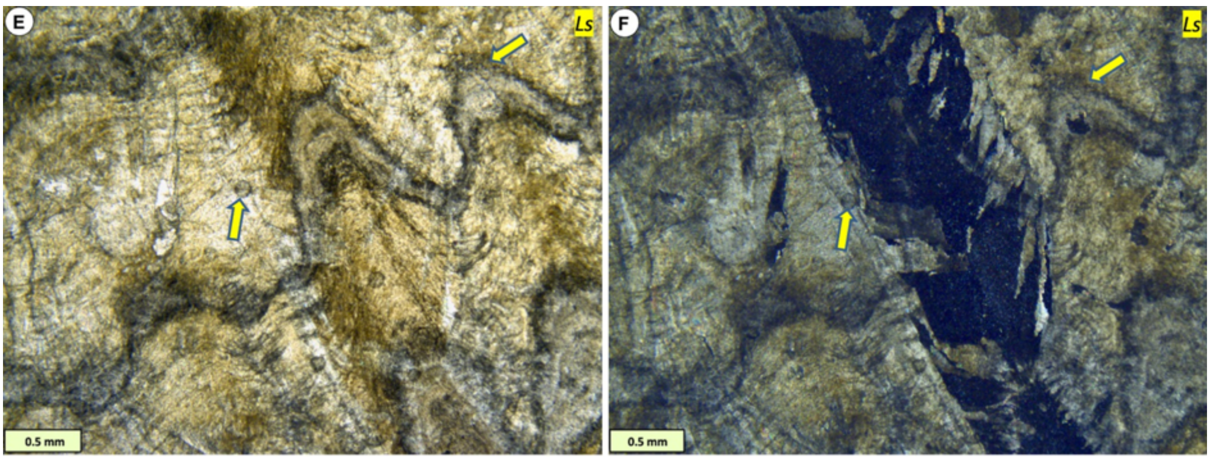


Fig. 4.13E-F. Enlargement of yellow box in C above, showing PPL (E) and XPL (F) views of the same area, yellow arrows show matched points. Note the overprinting diagenetic FRIC crystal in extinction in centre of F, that has a chevron-like appearance, described by Webby (2015) as "a kind of cone-in-cone" structure; there is detailed examination of this in Section 5 of this atlas. In E, there is a grey band following the growth layering (right-hand yellow arrow points at the grey band); also visible in

lower right corner of the photo. F shows the grey band is overprinted by the FRIC crystals and represents some earlier change. More on this character is provided later in the Atlas, in the Case Studies of Section 6. Kuppen 4 marl, Gotland. File: 7-2-KLoose23-i-Ls-Ps

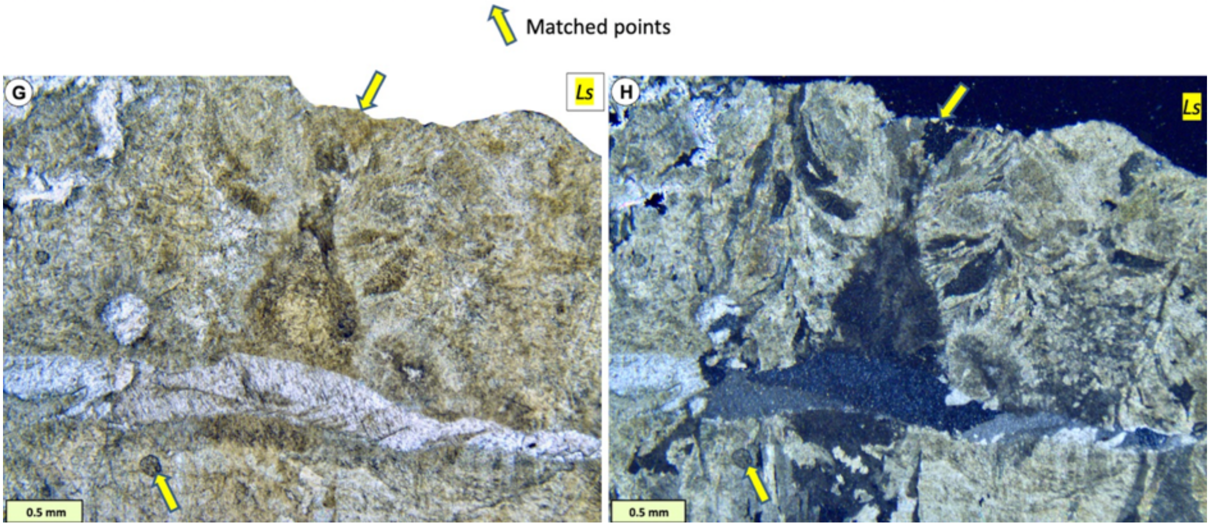


Fig. 4.13G-H. Detail of red box in B, yellow arrows mark matched points; **G.** PPL and **H.** XPL vertical section views of top layer of *Ls* , showing the overprinting FRIC and "cone-in-cone" structure, especially in H, but also the FRIC is in optical continuity with the sparite calcite that occupies the tangential cavity in lower part of images. It seems this cavity was open at the time that FRIC recrystallisation occurred so that the cavity was filled with cement along with the recrystallisation of the stromatoporoid skeleton. There is a detailed explanation of FRIC in Kershaw et al. 2021, Facies paper. Kuppen 4 marl, Gotland. File: 7-3-KLoose23-i-Ls-Ps

<u>SECTION 5:</u>
<u>Taxonomic description of *Lophiostroma schmidtii*</u>

5.1. Introduction

This section deals with the taxonomic position and description of *Lophiostroma schmidtii* (*Ls*). Taxonomy is commonly perceived to be the most uninteresting aspect of palaeontology, but is critical to appreciate the detailed form of a fossil and comparisons with other fossils. Thus taxonomic description is needed here to demonstrate the construction of *Ls* and the differences from other stromatoporoids, that underpin appreciation of the images in this atlas. I have tried to make this taxonomic description interesting to read, and as relevant as possible to understanding the growth and diagenesis of *Ls*. Therefore please don't skip over this section; its details are important to appreciating images in the rest of the atlas.

Below is the full list of traditional stromatoporoid orders and families, and in red colour are named the taxa that are illustrated in this atlas, noting that one (*"Stromatopora" venukovi"*) is incorrectly named as a *Stromatopora* taxon due to earlier redefinition of *Stromatopora* by Colin Stearn in 1993, which makes *"S." venukovi* no longer compatible with *Stromatopora*; this awaits a new genus name to place it in the traditional taxonomic scheme.

Please note that I consider this scheme to be so completely artificial that it is unusable as a reliable biological taxonomic classification because: 1) of the unknown degree of convergence between biological taxa that may (or may not) manifest themselves as the same skeletal structure; and 2) there is no way to test whether similar skeletal structures are related to each other biologically. There is a full discussion of this issue in Kershaw et al. (2021, monograph on British Silurian stromatoporoids). Thus the list below is presented to allow compatibility with other published descriptions of taxa, in particular the 2015 Treatise on Invertebrate Paleontology, Part E (Revised), Porifera, vols 4–5 (see reference list). The list here is considered here more as a type of form-grouping of skeletal structure, but there is no implication of biological taxonomic meaning.

Phylum Porifera Grant, 1836
Class Stromatoporoidea Nicholson & Murie, 1878
- Order Labechiida Kühn, 1927
  - Family Rosenellidae
  - Family Labechiidae: *Labechia conferta*
  - Family Stromatoceriidae:
  - Family Platiferostromatidae
  - Family Stylostromatidae
  - Family Aulaceratidae
  - Family Lophiostromatidae: *Lophiostroma schmidti, Labechia rotunda, ?Labechia scabiosa*
- Order Clathrodictyida Bogoyavlenskaya, 1969
  - Family Clathrodictyidae
  - Family Actinodictyidae
  - Family Gerronostromatidae: *Petridiostroma convictum*
  - Family Tienodictyidae
  - Family Anostylostromatidae
  - Family Atelodictyidae
- Order Actinostromatida Bogoyavlenskaya, 1969

Family Actinostromatidae: *Plectostroma scaniense*
Family Pseudolabechiidae
Family Actinostromellidae
Family Densastromatidae
Order Stromatoporellida Stearn, 1980
Family Stromatoporellidae: *Simplexodictyon yavorski*
Family Trupetostromatidae
Family Idiostromatidae
Order Stromatoporida Stearn, 1980
Family Stromatoporidae
Family Ferestromatoporidae
Family Syringostromellidae
Order Syringostromatida Bogoyavlenskaya, 1969
Family Coenostromatidae
Family Parallelostromatidae: *Parallelostroma typicum*
Family Stachyoditidae
Order Amphiporida Rukhin, 1938
Family Amphiporidae
Order and Family Uncertain
Class Uncertain
Order Pulchrilaminida Webby, 2012
Family Pulchrilaminidae

Taxon illustrated in this atlas but waiting to be placed in the taxonomic scheme:
"Stromatopora" venukovi

5.2. Taxonomic description of Lophiostroma schmidtii

The description below is adapted (actually substantially re-written) from Webby (2015, p.749-752), and modified because of diagenetic features recognised in this atlas that obfuscate appreciation of the taxonomy. Also, throughout this description I have inserted short explanations of meaning of terminology, in order to assist your understanding of the structure. So this is written as a narrative instead of the normally condensed form of taxonomic descriptions (which are, to be honest, quite boring to read). Therefore please note that the text of this taxonomic description is a hybrid of sentences and phrases from Webby (2015) and my writing.

Traditional family LOPHIOSTROMATIDAE Nestor, 1966 [Lophiostromatidae Nestor, 1966a, p. 58]
These fossils are described as encrusting laminar, latilaminate, calcareous structures. Latilaminate means that there are prominent tangential lines (latilaminae) that follow the growth undulations in the skeleton and divide it into successive growth stages; they occur because of growth interruption. Mori (1970) also described the taxonomy of *Ls*, and stated that it is predominantly encrusting, and also mostly laminar; in my experience *Ls* is entirely laminar in growth form, consistent with Webby's (2015) description. However, many samples of *Ls* I have seen in field, and in the preparation of this atlas, clearly grew directly on sediment substrates and many have prominent basal growth rings that are easily imagined as evidence for primary cavity formation (avoiding touching the substrate in substantial areas of the

base). So I don't agree that this taxon is predominantly encrusting, it clearly was able to deal with sediment substrates, as were pretty-much all other stromatoporoids.

Unless otherwise indicated, reference citations in the following paragraphs are listed in Webby (2015), but not repeated in full in this atlas.

Lophiostromatids are composed of tangential skeletal layers which are almost completely solid, so there is little to no obvious space within the skeleton. But this may be misleading because the skeleton is also heavily overprinted by diagenetic calcite making it difficult to see what the skeleton was originally made from. This feature is considered further below.

Growth interruption events commonly lead to minor primary cavities in *Ls* as the succeeding growth layer does not in all cases lie directly upon the upper surface of the underlying growth layer (there are photos of such primary cavities in this atlas). The skeleton possesses tightly undulated skeletal layers forming pillarlike upgrowths appearing as papillae on the upper surface. According to Webby's account, discrete longitudinal and tangential elements are rare; in my experience for *Ls*, they are absent, but that might be due to preservation of the material I studied. Only two genera, *Lophiostroma* and *Dermatostroma,* are regarded as valid, and one other, the genus *Tarphystroma,* is tentatively included in this family. *Solidostroma* Khromykh, 1974a, from the Lower Devonian of northeastern Siberia, was originally described as a member of the Lophiostromatidae but currently has uncertain status, doubtfully included as a junior synonym of *Euryamphipora* Klovan, 1966 (p. 826). *Priscastroma* Khromykh, 1999a, from the Middle Ordovician of the Siberian Platform, was considered to be an early representative of the group (Khromykh, 1999b, p. 223), but it is not a typical member of the family given its very thin, long-low to irregularly undulating to zigzag-shaped elements, resembling cyst plates, with these mainly separated by an abundance of unfilled interskeletal spaces; consequently this genus is transferred to family Rosenellidae (see p. 715 of Treatise). *Taymyrostroma* Khromykh, 2001, from the Upper Ordovician, Taimyr Peninsula, has also been assigned to the lophiostromatids (Khromykh, 2001, p. 347), but this genus remains inadequately described and illustrated; it is regarded by Webby (2015) as convergent toward younger (Siluro-Devonian) clathrodictyid genera, such as *Intexodictyides* and *Atelodictyon* and is best grouped elsewhere (see p. 829–836 of Treatise). Lophiostromatid-form stromatoporoids occur from Middle Ordovician (Darriwilian) to Upper Devonian (Frasnian), but also some uncertain ones are known in the Triassic.

Lophiostroma Nicholson, 1891a, p. 160 [*Labechia? schmidtii* Nicholson, 1886c, p. 16, pl. 2,*6–8*] [=*Chalazodes* Parks, 1908, p. 33 (type, *C. granulatum* Parks, 1908, p. 36)]. Skeleton commonly latilaminate and laminar, consists of, dominantly, much thickened, superposed, sheet- like layers, sharply and regularly undulating into columnar, pillarlike upgrowths, see Fig. 5.1.

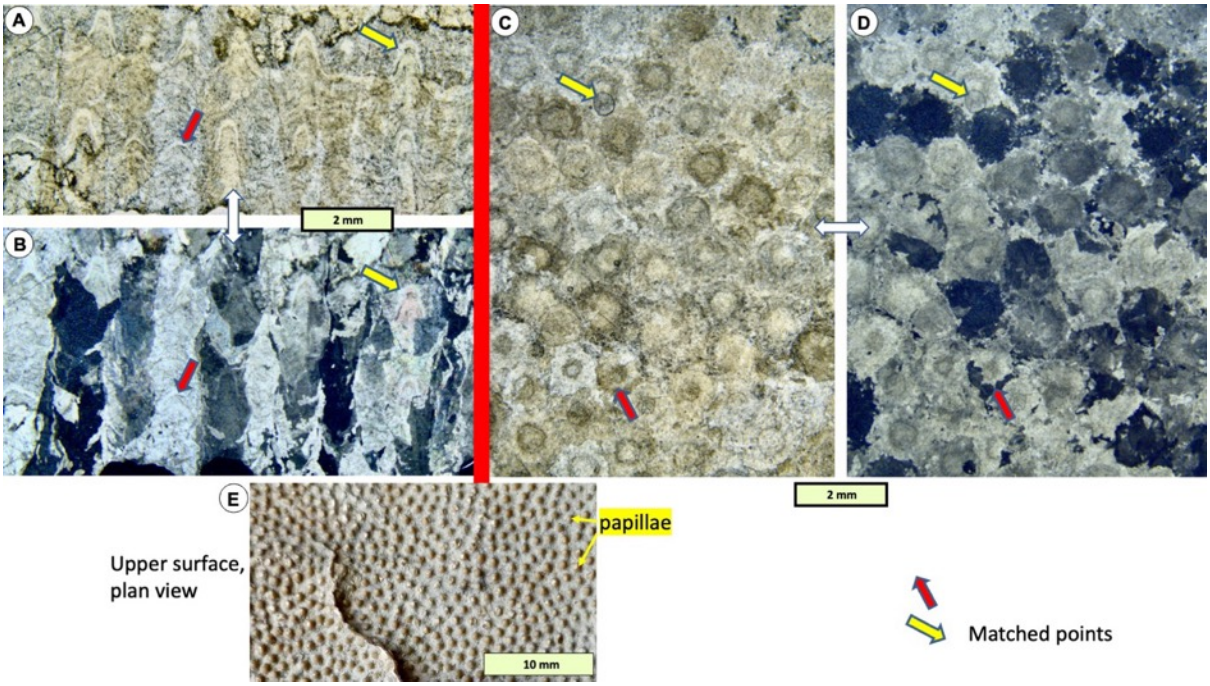


Fig. 5.1. A-B. VS in PPL (A) and XPL (B) of *Lophiostroma schmidtii* (*Ls*), the type species of *Lophiostroma*, showing the solid undulating structure giving impression of pillars, but actually do not form discrete pillar structures, unlike *Labechia conferta* (which is composed of thick pillars and interconnected cyst plates). However, the XPL view (B) does show discrete vertical features, but these are diagenetic, as is demonstrated in detail in successive photos in this Section and subsequent Sections of this atlas. One key point of taxonomic descriptions is that they don't use XPL, and therefore separation of primary and diagenetic structures are less easy to appreciate. **C-D**. TS views in PPL (C) and XPL (D), showing even distribution of the upcurving portions, that on the surface of skeleton (**E**) terminate as papillae. Note that in some specimens, papillae do not occur over the entire surface area (see Fig. 4.8) for reasons that are not clear. In B & D XPL views show the diagenetic crystalline structure is tightly pressed together and gives the impression of competitive but compromise growth of calcite crystals, the variations of which are explored through much of this atlas. File: 7B-1-Lophiostroma-TaxonomyPhotos-Sorted

Webby (2015) stated that the overlapping of the upcurved laminations results in "a kind of cone-in-cone structure; these upgrowths expressed as papillae on upper surfaces.". Figs 5.2 – 5.6 explore this "cone-in-cone" structure and compare it with classic cone-in-cone structure in inorganic diagenetic calcite from the Lower Jurassic of England.

Although the *Lophiostroma* skeleton appears solid, there is some indication in some specimens that it was not completely so. Webby (2015) noted that the skeleton ". . . consists of sheetlike layers almost entirely occupy interiors and do not represent true laminae, only rarely discernible cysts preserved; compact microstructure has a transverse fibrosity within sheetlike layers.". Such sheetlike layers are best seen in Fig. 5.4, but very hard to recognise because of the diagenetic overprint. However, in later sections of this atlas are some images in cathodoluminescence (CL), that demonstrate these sheetlike layers very well. However, stromatoporoid taxonomy is always achieved using normal light (not even XPL, and even PPL isn't necessary); BUT CL opens up possibilities for stromatoporoid taxonomy as will be clear from viewing the CL pictures of *Ls*. Thus it is an interesting observation that future developments in stromatoporoid taxonomy might benefit from standard use of CL as a means of describing structural elements in stromatoporoids.

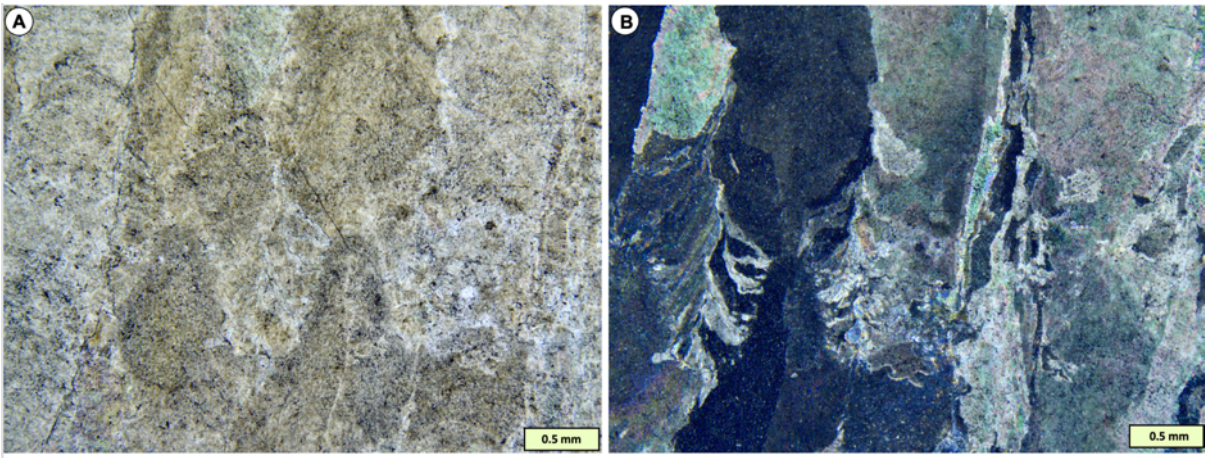


Fig. 5.2. A-B. PPL (A) and XPL (B) VS views of interior of a sample of *Ls*. In A, the tightly upcurving features are clearly visible but in the paired XPL image in B, the diagenetic overprint shows much of the structure comprises large areas of calcite in optical continuity and therefore are single crystals. Centre-left is a more complex area of multiple calcite crystals arranged in fan-shape emanating symmetrically from the vertical centre line of the upcurved feature; this is the character referred to by Webby (2015) as “a kind of cone-in-cone structure”. Actually it is not, and this can be appreciated in Figs 5.3 – 5.6. File: 7B-2-Lophiostroma-TaxonomyPhotos-Sorted

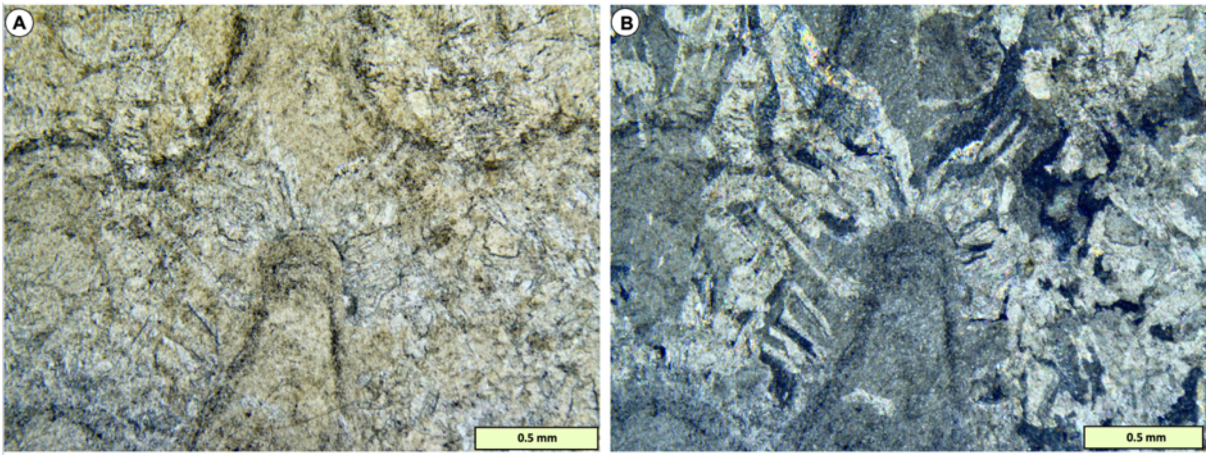


Fig. 5.3A-B. PPL (A) and XPL (B) VS views of *Ls*. The fine-layered structure of the skeleton is vaguely visible in the central column-shaped portion of A, and the splay of upward-expanding crystals of calcite are visible in the centre of A, very clearly seen in XPL in the matching photo in B. File: 7B-3-Lophiostroma-TaxonomyPhotos-Sorted

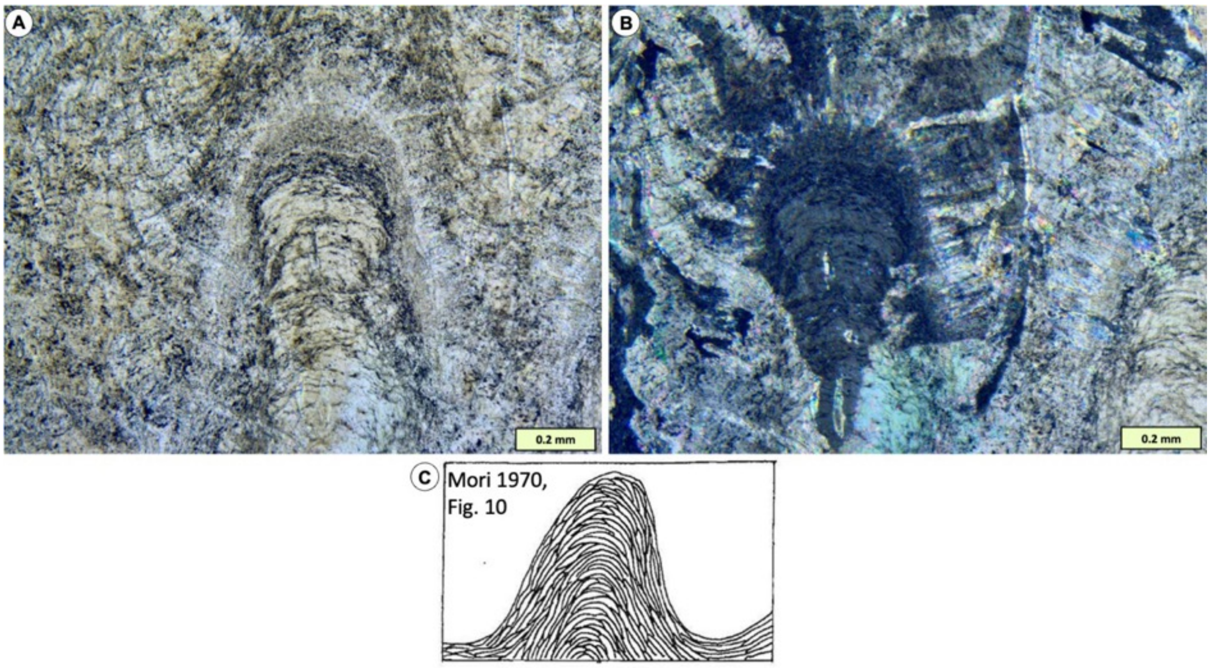


Fig. 5.4. VS thin sections. **A.** PPL and **B.** XPL. Photos show more details of *Ls* structure showing the finely laminated architecture in the central part of A, also in right-hand edge of B that is not in extinction. B also beautifully demonstrates the overprinting FRIC crystal display that seems to emanate from the central column that itself consists of a mass of finely laminated structure. Also the central pillar in A shows a greater clarity of detail of structure, and may be an early alteration feature that was overprinted by later diagenesis noting that the same area in B is a single crystal in extinction, of overprinted calcite. **C.** A drawing by Mori (1970) of the structure of *Lophiostroma* in VS, showing an interpretation that it is made of overlapping very fine curved plates, that organise into layers wrapping into columnar form, that seem to be the constructing elements of the fossil. The difficulty is that in most specimens, these fine laminations are not visible. File: 7B-4-Lophiostroma-TaxonomyPhotos-Sorted

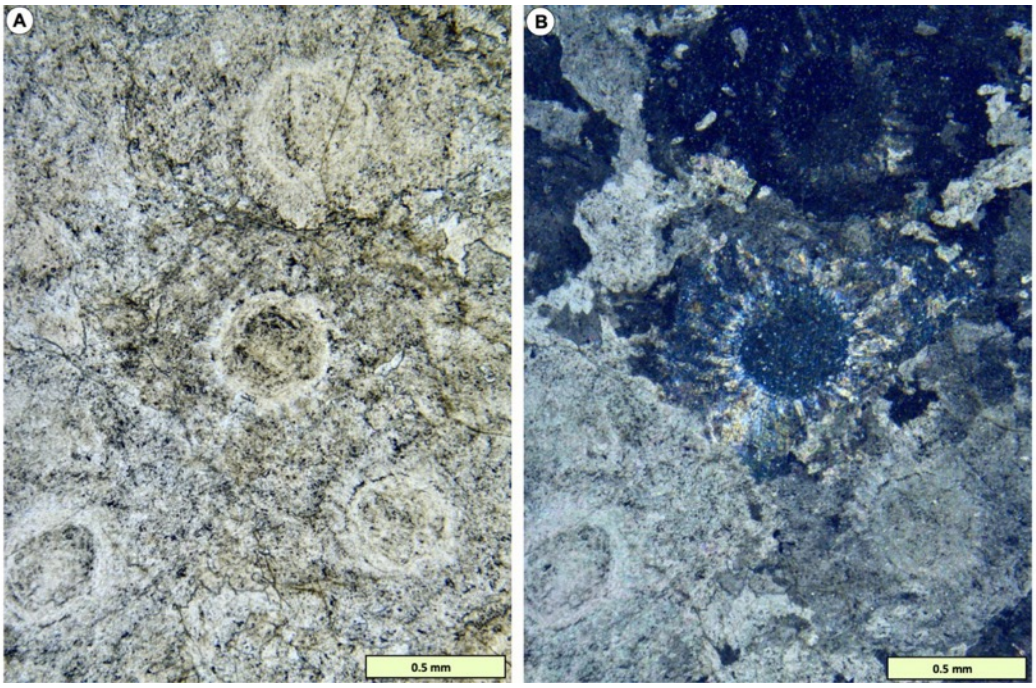


Fig. 5.5. TS thin section views of *Ls*, showing the circular expression of the centres of the columns seen in earlier VS views. **A.** PPL and **B.** XPL, in matching photos. In B the central column shows radiating calcite crystals within a single crystal that is mostly in extinction; at the top edge of B is

another one, that is fully in extinction but the radiating calcite crystals can be seen. The lower two column centres do not show the radiating calcite crystals, but do give a vague indication of circular layering, that is the TS view of the layered structure of *Ls.* File: 7B-5-Lophiostroma-TaxonomyPhotos-Sorted

Vertical sections illustrated in Figs 5.1 – 5.4 show very well the expanded fans of calcite crystals, especially seen in XPL, considered by Webby (2015) as cone-in-cone structure. However, Figs 5.5 and 5.6 show that these are **not** nested cones, and for comparison, some real cone-in-cone calcite from the Lower Jurassic of England are shown in Fig. 5-7. The TS views of *Ls* in Figs 5.5 and 5.6 show the fans of calcite crystals are narrow elongate crystals, forming a circle centred on the mid-point of the upcurved laminations of *Ls*; if these were cone-in-cone structures then in TS they would be solid circular rings. Instead it is like a basket, or perhaps a spray of petals from a flower. They are therefore termed here as "three-dimensionally upward-expanding crystal fans", shortened to "3D crystal fans" hereafter rather than cone-in-cone. The key point is that these are diagenetic, but they represent a form of diagenetic alteration of the original skeleton so that the skeleton influenced the form of the diagenesis. They overprint the finely layered overlapping plates illustrated in a diagram by Mori (1970), illustrated in Fig. 5.4. The reason why the crystals form fans is because the diagenetic crystals are at a high angle in relation to the laminated structure of the stromatoporoid skeleton, and therefore fan out upwards due to the tight curvature of the *Ls* laminations across the upcurved portions of the skeleton. This is a form of "fabric-retentive recrystallisation" introduced by Kershaw et al. (2021 – Facies paper) termed "fabric-retentive irregular calcite" (FRIC); FRIC forms crystals orientated normal (= 90 degrees) to the growth layering in stromatoporoids, there are numerous pictures of other taxa in this atlas that show this. However, FRIC in *Ls* appears more organised and less irregular than in other stromatoporoids; it is possible this difference is due to the unique skeletal form of *Ls*, comprised of very tight wavy skeletal lamination. So, ultimately there may not be that much difference between FRIC of *Ls* and FRIC of other stromatoporoids. FRIC is rarely seen in other fossils, and does not occur in the corals and bryozoans that co-existed with stromatoporoids; FRIC is thus likely a characteristic of stromatoporoids and is a good reason to continue to class *Lophiostroma schmidtii* as a stromatoporoid.

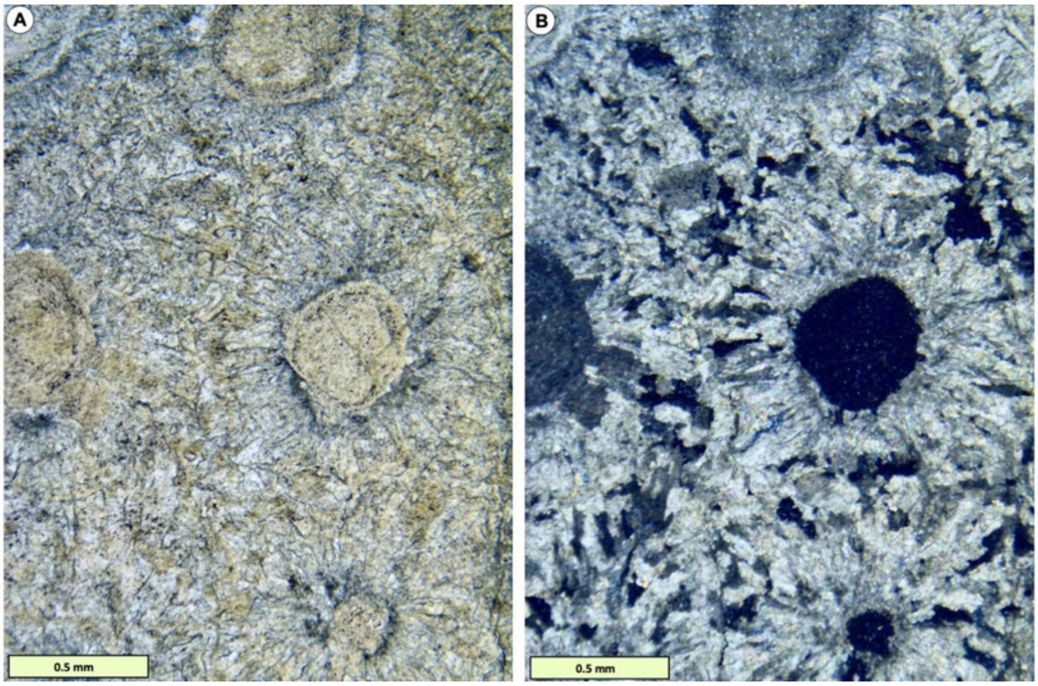


Fig. 5.6. TS thin section views of *Ls*, showing the circular expression of the centres of the columns seen in earlier VS views. **A.** PPL and **B.** XPL, in matching photos. In B, the dark-centred column shows the central part is in extinction, contrasting the radiating crystals surrounding it; the other column centres in these images show the same feature and also that the boundaries between radiating crystal masses of the adjacent columns meet along compromise boundaries. The radiating calcite crystals are an expression of the FRIC, so are diagenetic and not part of the original growth structure; more information on this aspect is given in the Case Studies section, where there are some cathodoluminescence (CL) images. File: 7B-6-Lophiostroma-TaxonomyPhotos-Sorted

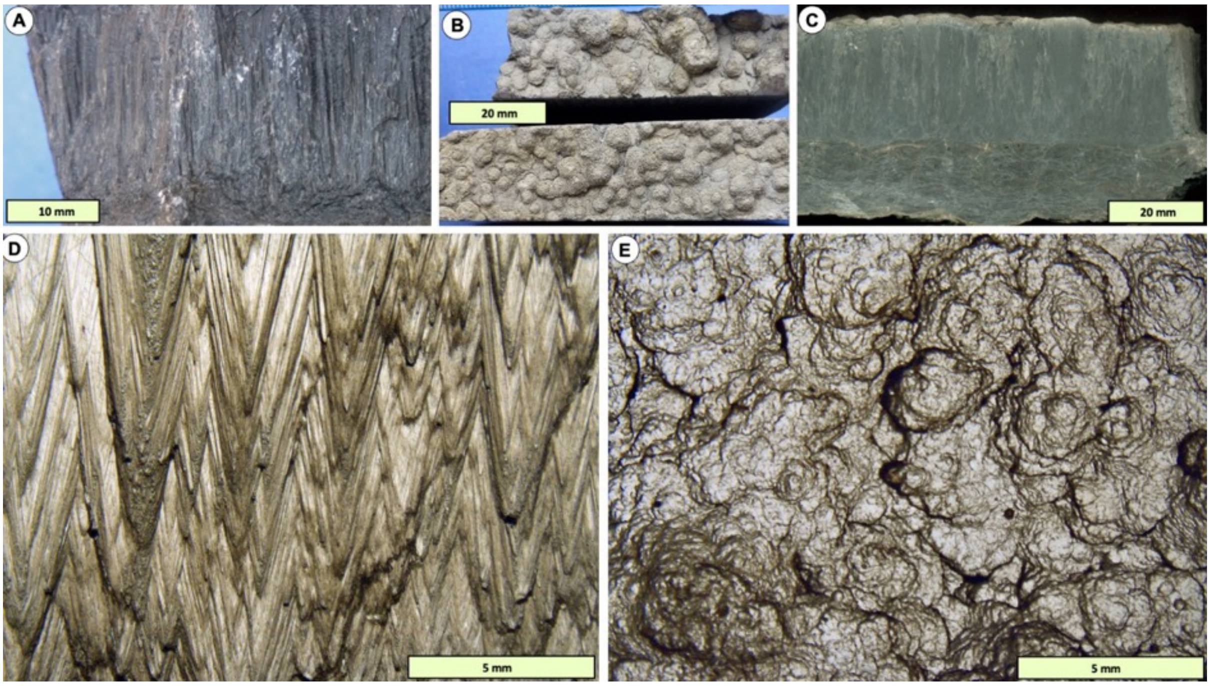


Fig. 5.7. Classic cone-in-cone structure from inorganic hydrothermally-related calcite veins in calcareous mudstone, Lower Jurassic, Lyme Regis, southern England. **A & C.** Broken vertical section (A) and polished cut surface (B) of hand specimen showing apparent vertical fibrous structure; at very bottom of each photo is some of the interbedded bioclastic wackestone in which the cone-in-cone

calcite sheets formed. **B**. Upper surface view of a hand specimen of a cone-in-cone calcite sheet, showing a lumpy character of approximately circular projections on the surface of the sheet; these are the centres of cone-in-cone calcite fibres, that are made of approximately circular sheets in TS, but taper downwards to form the cones. **D-E.** VS (D) and TS (E) PPL thin section views of cone-in-cone calcite. In D the zigzag appearance in VS occurs because of compromise growth of adjacent calcite cones abutting each other. In E, the mass in TS shows approximately circular areas that are the tangential cross sections of cones, containing concentric sheets of calcite cones nested inside one another and abutting each other horizontally into a compromise arrangement of cones. The geometry of classic cone-in-cone calcite is very different from the 3D calcite fans present in *Lophiostroma schmidtii* (*Ls*) illustrated in Figs. 5.2 – 5.6; these images show that *Ls* does not have a cone-in-cone structure. File: 7B-ConeInCone-Jurassic-England

Webby (2015) also addressed the spelling of *Lophiostroma schmidtii.* He noted that “Nicholson’s original spelling of the species name with its double “ii” termination is retained, in accordance with ICZN Art. 33.4 (1999) rather than *schmidti* (see Galloway, 1957, p. 439; Nestor, 1966a, p. 60; Flügel & Flügel-Kahler, 1968, p. 381; Mori, 1970, p. 141), which is deemed to be an incorrect subsequent spelling.”. Somewhat to my chagrin, I discovered this after the British Silurian stromatoporoids monograph was published (Kershaw et al. 2021) which thus contains the *schmidti* spelling rather than the correct *schmidtii*. At least in this atlas it is corrected, and I am glad that I said it rather than somebody else pointing it out!! In terms of taxonomic meaning of *Ls* there is no impact of this spelling difference.

The rest of this section is quoted from Webby (2015) as background information:

“A number of Upper Paleozoic–Triassic stromatoporoid-like forms have been described as species of *Lophiostroma,* but their affinities remain in doubt. Stearn and Stock (see p. 310) recognized two of them as ‘calcareous crusts’ coming from the Carboniferous and Permian of Japan (Yabe & Sugiyama, 1931b; Sugiyama, 1939) but excluded them completely from a close association with the genus, even suggesting one was a brachiopod, based on a restudy by Mori (1980). A third species from the Triassic of the southeastern Pamirs was described by Boiko (1970a) as *Lophiostroma boletiformis*. It was based on a single specimen with clearly discernable zigzagged upper and lower boundaries of the sheetlike latilaminae and longitudinally oriented, dark, columnar to cone-shaped upgrowths that align and may be superposed across the upwardly bent parts of the latilaminar boundaries, but other parts of the skeleton are composed of spar-filled calcite that is nondiagnostic, making it difficult to confirm this early Mesozoic species unquestionably as a member of the genus.] *Middle Ordovician (Darriwilian)–Upper Devonian (Frasnian), ?Triassic:* China (Shandong), *Darriwilian;* Mongolia, Russia (Siberian platform), *Upper Ordovician;* Canada (Ontario, Quebec), England, Sweden (Gotland), Estonia, Turkey, USA (Michigan, Kentucky), Ukraine (Podolia), *middle Silurian–upper Silurian;* Russia (Kuznetsk basin), *Frasnian;* Tadjikistan (southeastern Pamirs), *?Triassic.*——fig. 413*a–f. L. schmidtii* (Nicholson), Paadla stage, Ludlow, Pilguse (=Hoheneichen) locality, 33 km west of Kuressaare, Saaremaa, Estonia; *a–b,* holotype, NHM, P.5606, longitudinal and tangential sections, ×7.5 (Webby, 2012c; Nicholson’s slides 279a, 279, rephotographed by Webby in 1989); *c,* topotype, IGTUT 114-49 (Co3178), showing papillae representing tops of pillarlike upgrowths, ×2 (Nestor, 1966a, p. 60, pl. 23,*3*); *d,* specimen SMNH, B10-X (GIK-195), Ludlow Hamra Formation of loc. 150 (south of Burgsvik) Gotland, showing papillose upper surface, with addition of an encrusting auloporoid coral, ×2 (Mori, 1970, p. 28, pl. 19,*2*); *e–f,* specimen IGTUT 114-48 (Co3177), from another Paadla age locality at Riiumägi, Saaremaa, longitudinal and tangential sections showing better preserved details of internal features of skeleton than in designated holotype, ×10 (Webby 2012c, photos courtesy of Heldur Nestor; see also Nestor, 1966a, p. 60, pl. 23,*1–2*).”

Webby’s (2015) account above highlights the point about how many species of *Lophiostroma* exist. Webby (2015, p. 709) notes that the accounts of *Lophiostroma* are centred on *Ls* as the main taxon and is the type species of *Lophiostroma*. Mori (1970) drew attention to two publications, Ozaki (1938) and Bolshakova & Utilina (1985) that illustrate a taxon referred to as *Lophiostroma shantungense*, also mentioned by Webby (2015, p. 715). For Ozaki (1938) the pictures are quite bad, making it difficult to decide what they are. For Bolshakova & Utilina (1985), the pictures are better and it is clearly not the same as that shown in Ozaki (1938), and it is also quite different from *Lophiostroma schmidtii*. It seems that *Ls* stands on its own as a taxon, certainly on Gotland there are no variants; *Ls* is easily recognisable and so consistent in structure as to convey confidence of a single fossil taxon. HOWEVER, that does not prove there was only one biological species present, yet its consistency of growth form and internal structure are powerful indicators that it may be true.

MORI’S DESCRIPTION OF *LOPHIOSTROMA SCHMIDTII*

The taxonomic description above is drawn from the 2015 Treatise, but it is also instructive to take note of Mori’s (1970) description, because it is based on Gotland material, same as the *Ls* samples in this atlas. Thus below I have quoted Mori’s (1970) taxonomic account, in full. Note the very important descriptive sentences that talk about the growth form and the details of the interior structure of which the fossil is made. Please note Mori’s use of “coenosteum” to describe the entire fossil. Coenosteum is a term derived from hydrozoan cnidarians that stromatoporoids were previously considered to belong to, by many authors, prior to the confirmation of their sponge nature.

Mori (1970) also addressed two taxa set up by Nicholson (*Labechia scabiosa)*, and Johnston (*Labechia rotunda*) that are considered synonyms of *Lophiostroma schmidtii*. There is more about these fossils in Section 9 of this atlas, including photos of the original material.

In Mori’s (1970) description there is also a lot of palaeobiological and palaeoecological content. It is my continuing experience that Mori’s (1969, 1970) monograph on stromatoporoids from Gotland contains a huge amount of valuable information, that remains as relevant today as it was 52 years ago when it was published!!!!

MORI 1970, p.141>>

Lophiostroma schmidti (NICHOLSON)

Pl. XIX, figs. 1-7; Pl. XX, figs. 1-4; Pl. XXIV, fig. 4

1886b. *Labechia* ? *Schmidtii,* NICH.- NICHOLSON, p. 16, pl. 2, *figs.* 6-8.

Lophiostroma (Labechia ?) *Schmidtii* - NICHOLSON, p. 160. *Labechia scabiosa,* n.sp. - NICHOLSON, p. 160, pl. 20, figs. 4-6.

Labechia conferta LONSDALE- BOEHNKE, p. 177, text-figs. 28, 29.

Labechia rotunda - JOHNSTON, p. 433, pl. 15, fig. 8.

Lophiostroma sp. - RIABININ, p. 39, pl. 34, *figs.* 1, 2.

Lophiostroma smotritschiense, n. sp. - RIABININ, p. 36, pl. 11, figs . 5, *6;* pl. 12, figs. 1, 2.

Lophiostroma schmidti (NICHOLSON)- GALLOWAY, *pl.* 34, *fig. 5. Lophiostroma schmidti* (NICHOLSON) - NESTOR, p. 60, pl. 22, figs. 3, 4; *pl.* 23, figs. 1-5.

Lophiostroma dnestriense BOLSHAKOVA, sp. nov. - BOLSHAKOVA, p. 26.

Lophiostroma dnestriense dnestriense BOLSHAKOVA, subsp.nov. BOLSHAKOVA, p. 27, pl. 3, fig. 1.

Lophiostroma dnestriense ttndulatum BOLSHAKOVA, subsp. nov. BOLSHAKOVA, p. 28, pl. 3, fig. 2.

Hemse Beds, Eke Beds, Hamra Beds and Sundre Beds.

MATERIAL. - From a total of 41 specimens, 16 are from the Hemse Beds, one from the Eke Beds, 10 from the Hamra Beds and 14 from the Sundre Beds (GIK- 191, GIK-192, GIK-193, GIK-194, GIK-195, GIK-196, GIK-197, GIK-198 and GIK-199).

DESCRIPTION. - The coenosteum is predominantly laminar and exceptionally conical. The largest specimen is 40 mm high and 500 mm wide and the smallest 1 mm high and 9 mm wide. The surface is distinctly papillate. In tangential section there are 68--120 papillae in 100 mm^2. The height of the papillae is variable, 1.0 mm on average (1.6 mm maximum). *The* skeleton is composed of very thin densely spaced, delicate horizontal elements, numbering 10-16 in 0.1 mm (Fig. 10h). These delicate elements are bent upwards into vertical columns, the number of which is 4-6 in 5 mm. Neither galleries nor vertical pillars are developed. The dark growth lines are frequently observed in vertical sections. The number of these strongly undulated lines are variable. Astrorhizae are absent. The microstructure is multilayered.

REMARKS AND COMPARISON. -The present species is characterized by papillae, very fine horizontal elements and a lack of galleries. Many Gotland specimens show crystalline fibres oriented perpendicularly to the horizontal skeletons. They seem to have been formed by recrystallization of the calcareous skeleton, because well preserved specimens show that the skeleton is composed of very delicate horizontal structures which can be easily distinguished from real laminae by their extremely fine, densely spaced elements.

Labechia scabiosa NICHOLSON (NICHOLSON, 1891, p. 180, pl. 20, *figs.* 4-6) from the Wenlockian limestone of Dudley, England and *Labechia rotunda* JOHNSTON (JOHNSTON, 1915, p. 433, pl. 15, *fig.* 8) from the Wenlockian limestone of Shropshire, England are here considered as probable synonyms of *Lophiostroma schmidti.* NICHOLSON described only the outer features and did not examine the inner structures of *L. scabiosa.* He mentioned (1891, p. 161) that "I have felt much hesitation in giving a name to this form, as I have only a single small specimen of it, and therefore been unable to examine its internal structure by means of thin sections. It is clear, however, that we have to deal here with a species *of Labechia* which is distinct from *L. conferta".* Also *Labechia rotunda* was described without examination of the inner structures. According to JOHNSTON (op.cit.), *L. rotunda* can be distinguished from *L. conferta* by differences in the sizes and shapes of the coenostea and by their representation at different stratigraphic levels (op.cit., p. 433). The present author had the opportunity of examining the holotype specimens of *L. scabiosa* and *L. rotunda* which are stored in the British Museum, london. The author had the permission to make thin sections of these specimens. By the studies of the thin sections it became evident that none of the species belong to the genus *Labechia* but to *Lophiostroma.* The "holotype" specimens are poorly preserved but show similarities with *Lophiostroma schmidti.*

Lophiostroma dnestriense BOLSHAKOVA (BOLSHAKOVA, 1968, p. 26), *Lophiostroma dnestriense dnestriense* BoLSHAKOVA (op. cit., p. 27, *pl.* 3, fig. 1) and *Lophiostroma dnestriense undulatum* BOLSHAKOVA (op. cit., p. 28, *pl.* 3, fig. 2) are here considered to be synonymous with *L. schmidti* (see discussion on p. 140).

OCCURRENCE AND ECOLOGY. - Twenty specimens out of 41 were found in the massive limestones: 20 in the stratified limestones and one in marl. The present species is frequently found in its growth position, especially in the massive limestones. It is characteristic that *Lophiostroma schmidti* has a laminar shape in most cases, even though other stromatoporoid species associated with *L. schmidti.* are massive. This species is frequently encrusting other stromatoporoids and tabulate corals, and is itself encrusted by these organisms. *L. schmidti* seems to have preferred to grow in shallow and turbulent water in luxuriant association with other reef builders (especially in the ludlovian) and seems to have avoided marly bottoms where it was found only exceptionally.

GEOLOGICAL AGE. - Wenlockian and Ludlovian.

GEOGRAPHICAL DISTRIBUTION. - Gotland, Estonia, Podolia and England.

COMMENT: regarding *Labechia rotunda* and *Labechia scabiosa* mentioned above in Mori's text, I also looked at these thin sections and photographed them; there is more to say, and it is given in both Kershaw et al. (2021 monograph) and at the end of this atlas.

SECTION 6:
Case studies

Introduction

There are 14 examples presented in this section as case studies; these provide the deep details of the structure and variations of *Lophiostroma schmidtii* (*Ls*), and include PPL, XPL and CL images. As far as I am aware this is the most detailed treatment of *Ls* available; probably you don't want to read all of this, but it contains more-or-less all the information I have on *Ls*. So it is worth to keep this for comparison with any samples you may find, therefore use it as a look-up reference. Anyway, it was fun putting it all together.

6.1. Case Study 1: 4c1-4.83

Sample of basal crinoidal limestone bed at bottom of Lower Biostrome at Kuppen 4 (See Fig. 2.1). This bed directly overlies the Kuppen marl (that itself contains lots of *Lophiostroma schmidtii*), thus samples of *Ls* in the crinoidal bed may have been recycled from the underlying marl. This particular sample has revealed an enormous amount of information regarding *Ls* in relation to the crinoidal limestone grainstone attached to the *Ls*. Numerous CL images are included, matched to PPL and XPL views. It is in this sample that CL images show the likely nature of the original growth laminae of *Ls*.

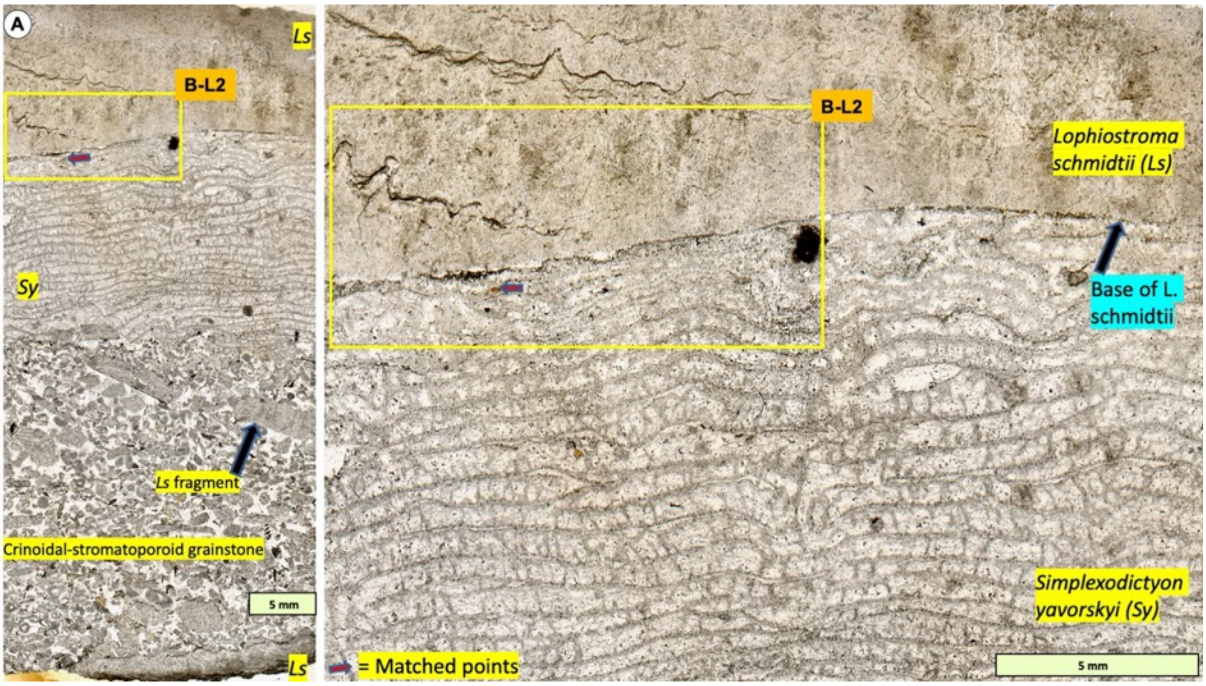


Fig. 6.1A. VS PPL thin section showing grainstone made of largely crinoidal debris and stromatoporoid fragments, with some other bioclasts, overlain by *Simplexodictyon yavorskyi* (*Sy*), that is encrusted by *Lophiostroma schmidtii* (*Ls*) containing small growth interruptions. Matched points in small red arrows. File: 8-01-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

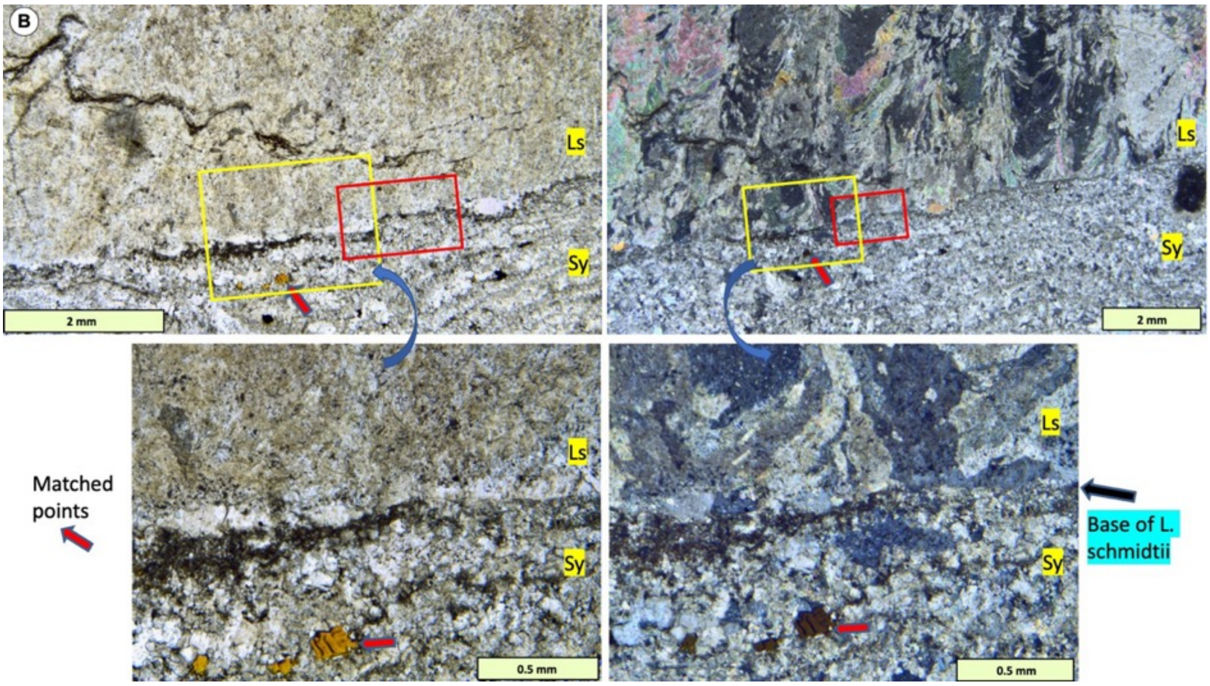


Fig. 6.1B. Upper 2 photos show enlargement of yellow box in A; **Upper left** PPL, **Upper right** XPL. Lower 2 photos show enlargement of yellow box in upper photos. **Lower Left** PPL, **Lower right** XPL, shows details of contact between *Sy* and *Ls.* Brown patches in PPL are holes with burned resin due to the CL electron beam are useful to match to holes in the thin section shown as black areas in XPL (red arrows). File: 8-02-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

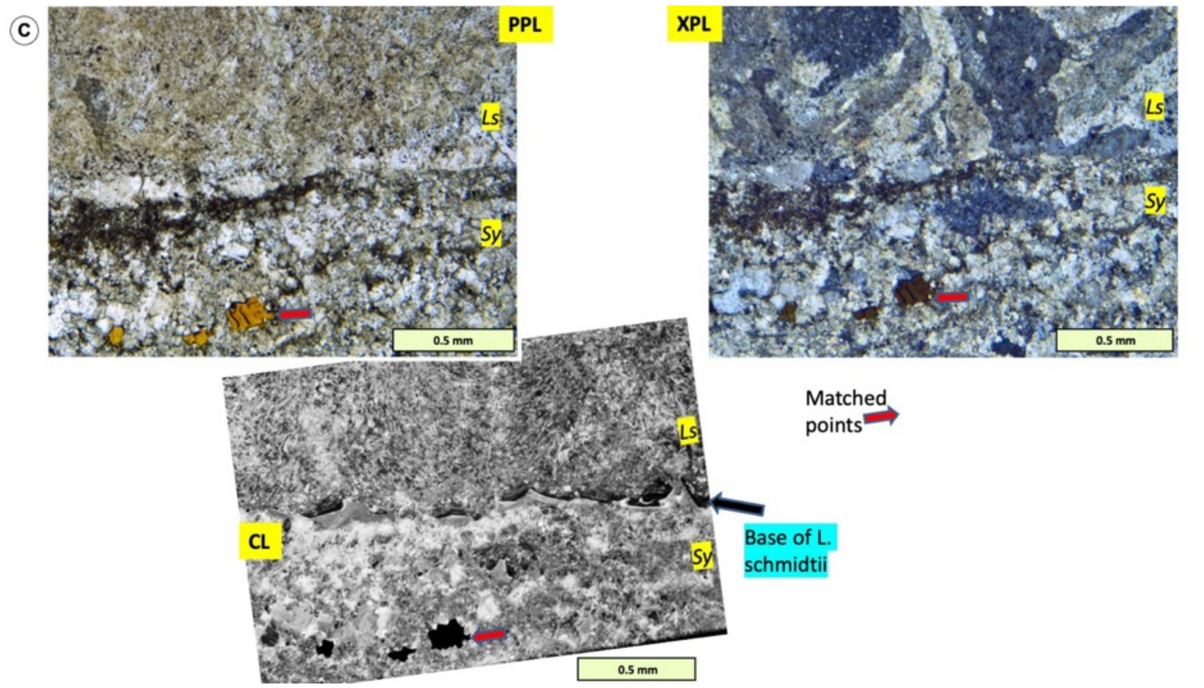


Fig. 6.1C. Upper images are repeats of Fig. 6.1C, but lower photo is a low-magnification monochrome CL photo that partly reveals the laminate structure of *Ls.* More detailed photos in succeeding images. File: 8-03-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

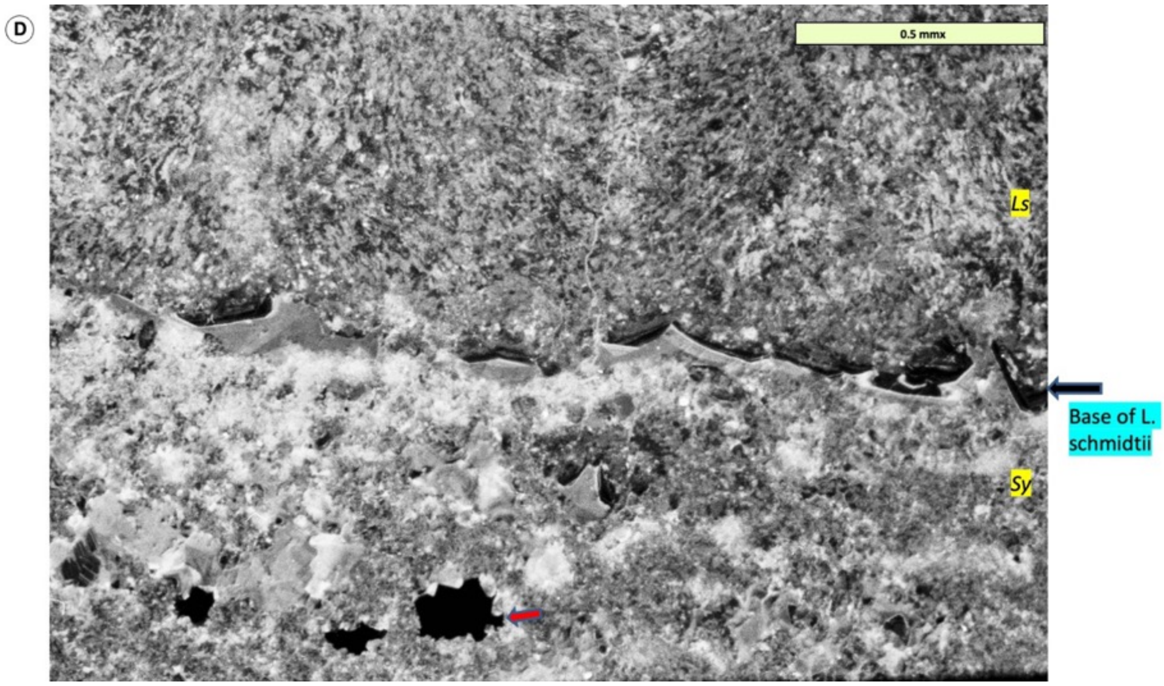


Fig. 6.1D. Enlarged version of CL image in Fig. 6.1C, showing base of *Ls* has small primary cavities between it and the underlying *Sy.* The CL view here shows the *Ls* is composed of small crystals in approximate alignment; more images in subsequent figures. File: 8-04-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

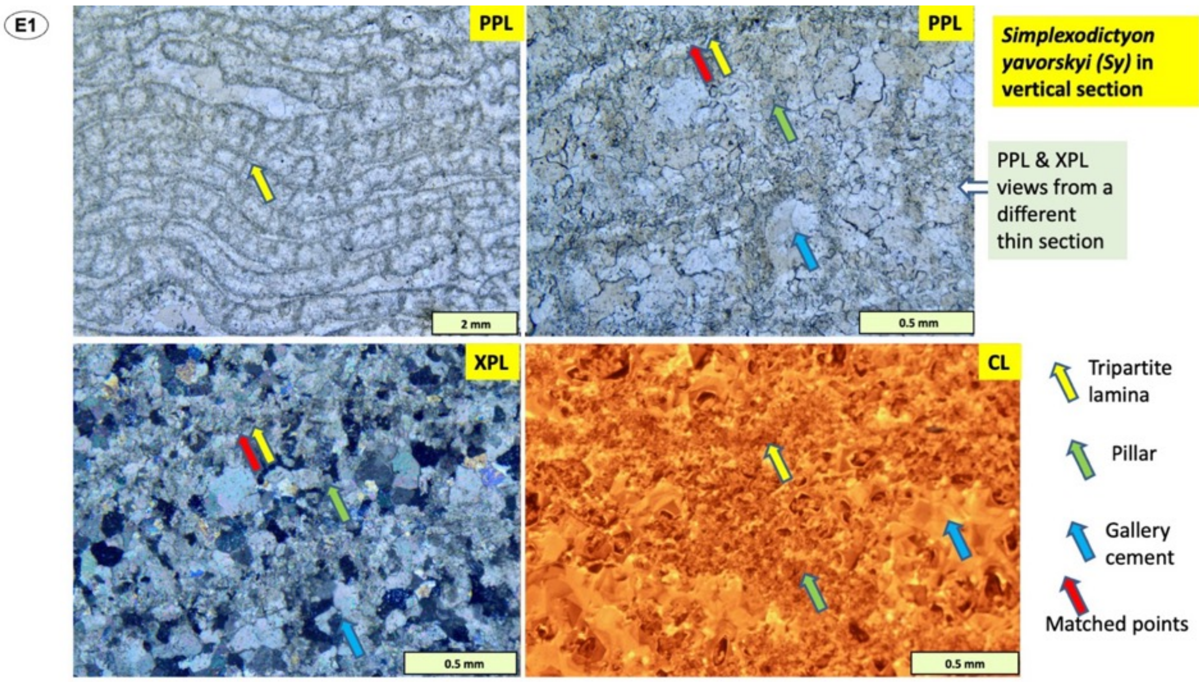


Fig. 6.1E1. Comparative images of VS of *Simplexodictyon yavorskyi* (*Sy*) in PPL, XPL and CL; the CL image is from sample 4c1-4.83, but the PPL and XPL images are from another sample which show the architecture of *Sy* more clearly; thus the CL image is not matched to the PPL & XPL images in this figure. In the CL image, the tripartite lamina structure that defines *Sy* is visible, compare with the PPL pictures (yellow arrows). The laminae of *Sy* show the typical speckled mixture of dull and bright CL that is normal in stromatoporoids, and the gallery cement fills of larger sparite cement, that is syntaxial with recrystallisation cement (FRIC) which typifies stromatoporoids and is seen in lower left photo. In contrast, the CL view shows the gallery cement sharply abuts the stromatoporoid skeletal structure, interpreted as the original arrangement, that is overprinted in XPL view by FRIC reorganisation of the stromatoporoid's mineralogy. File: 8-05-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

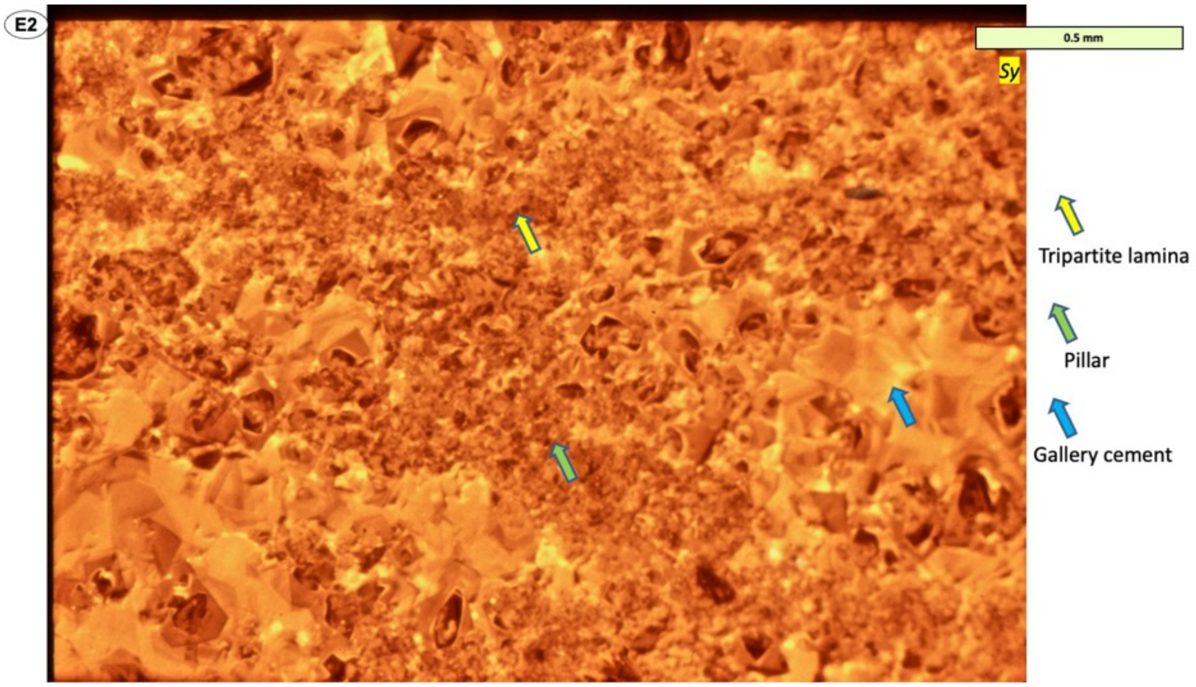


Fig. 6.1E2. Enlargement of CL picture in Fig. 6.1E1, showing the same features more clearly at larger magnification. File: 8-06-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

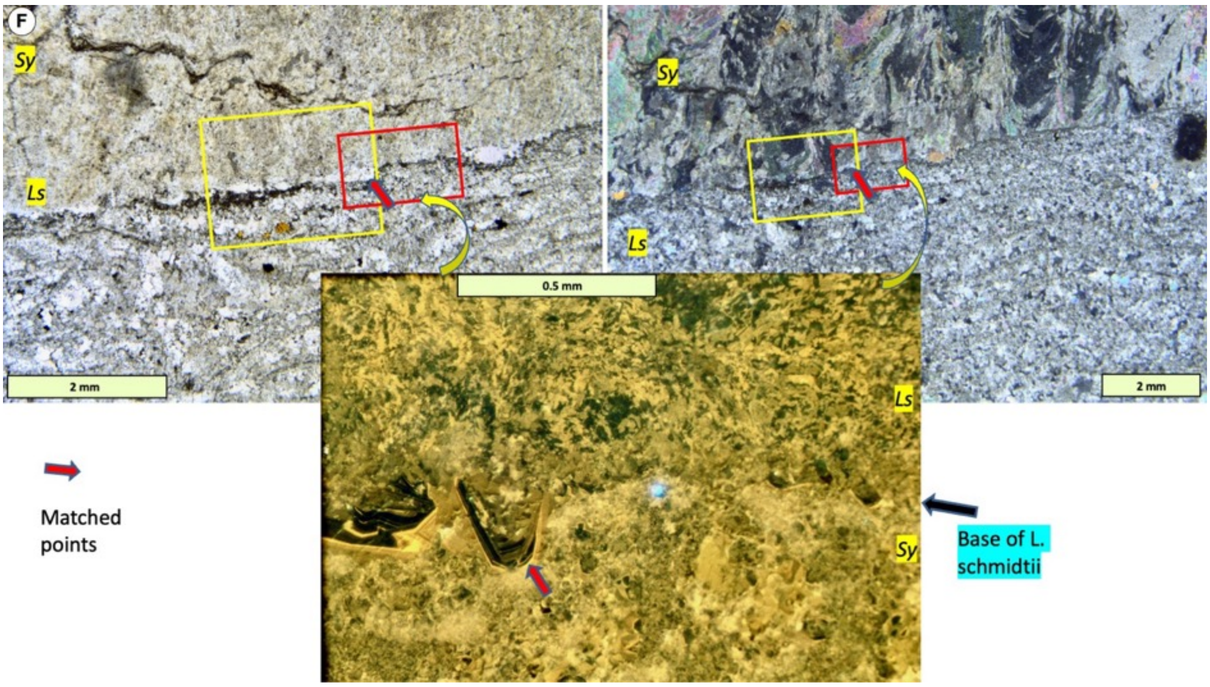


Fig. 6.1F. Upper photos are repeat of Fig. 6.1B to highlight red box, in which lower photo is a CL image of the red box, showing detail of contact between *Sy* and *Ls.* Note the partial primary cavity (left one third of photo) compared to the tight contact in right two thirds, and no overlap of CL textures between the two taxa, that reflects the sharp contact seen in XPL where the recrystallised fabric does not pass from one taxon to the other, normal in stromatoporoids. The CL image also shows the texture of lower part of *Ls*, composed of layers of crystals in some alignment. File: 8-07-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

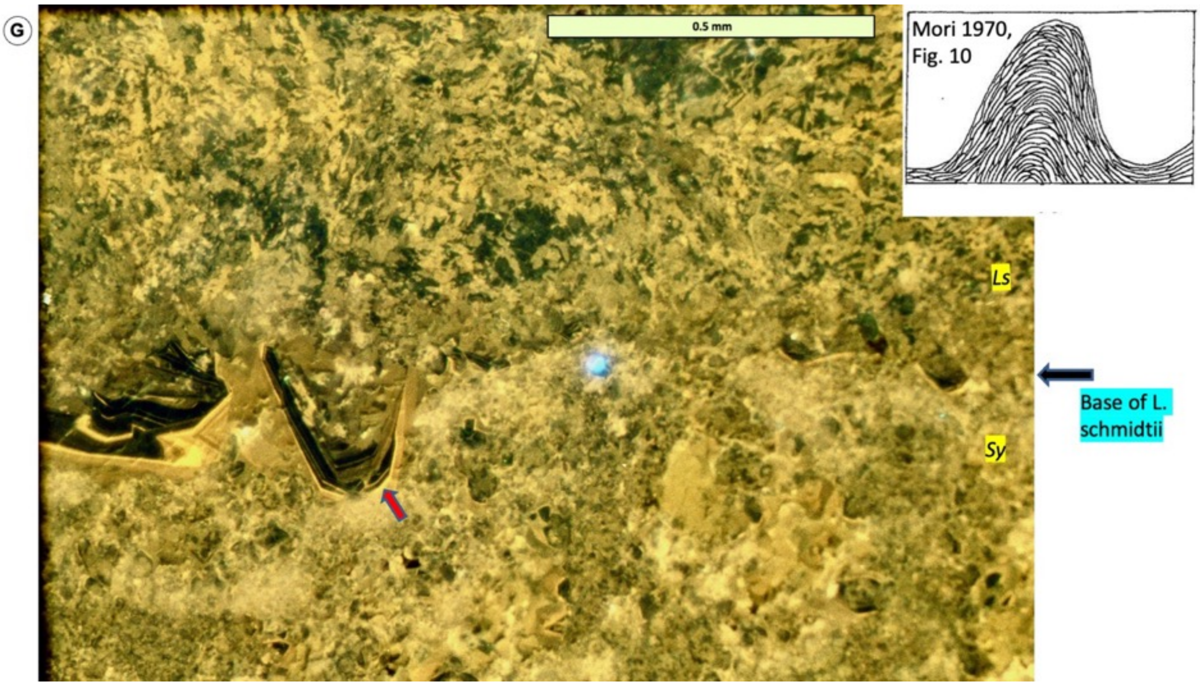


Fig. 6.1G. Enlargement of Fig. 6.1F CL photo showing same features with more clarity. The structure of the *Ls* seems to be made of a mass of partly-aligned irregular crystals, that contrast the upper right corner drawing from Mori (1970) of interpreted nature of *Ls* construction as fine overlapping layers. File: 8-08-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

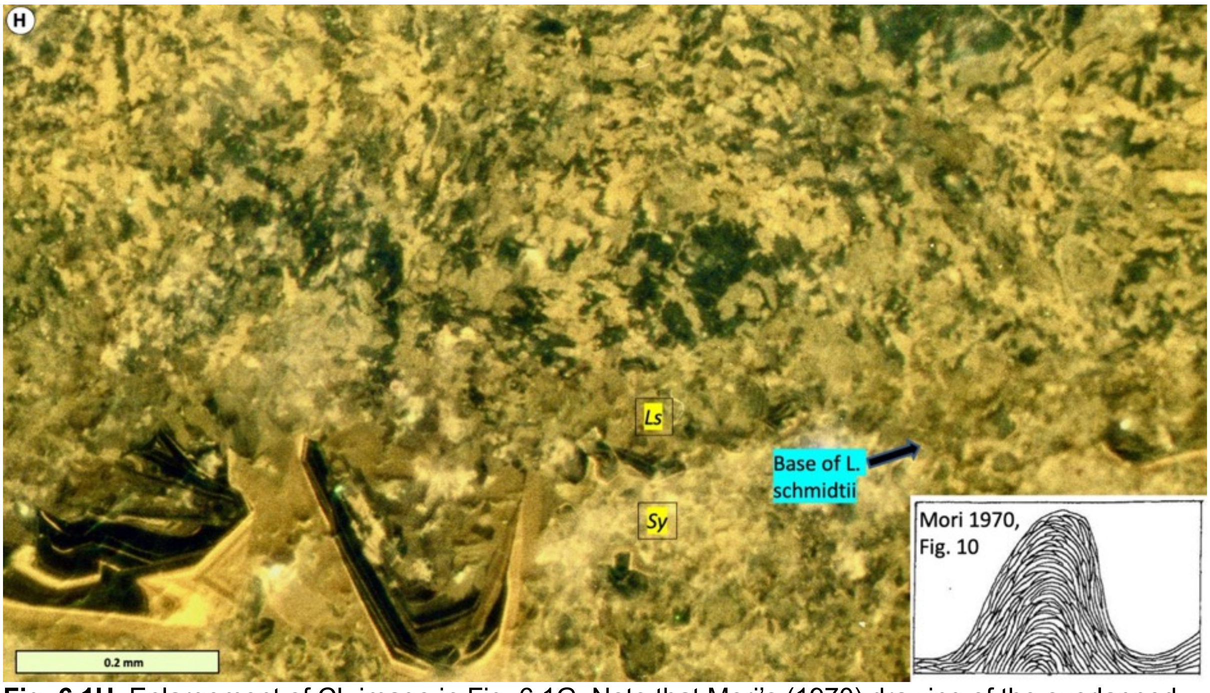


Fig. 6.1H. Enlargement of CL image in Fig. 6.1G. Note that Mori's (1970) drawing of the overlapped layer structure of *Ls* is not consistent with the irregular partly layered crystal structure seen in this CL photo. Other CL photos indicate that this more disorganised skeletal structure occurs at the bottom of the *Ls* growth, but higher up in the specimen, the structure is more similar to that portrayed by Mori (1970). File: 8-09-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

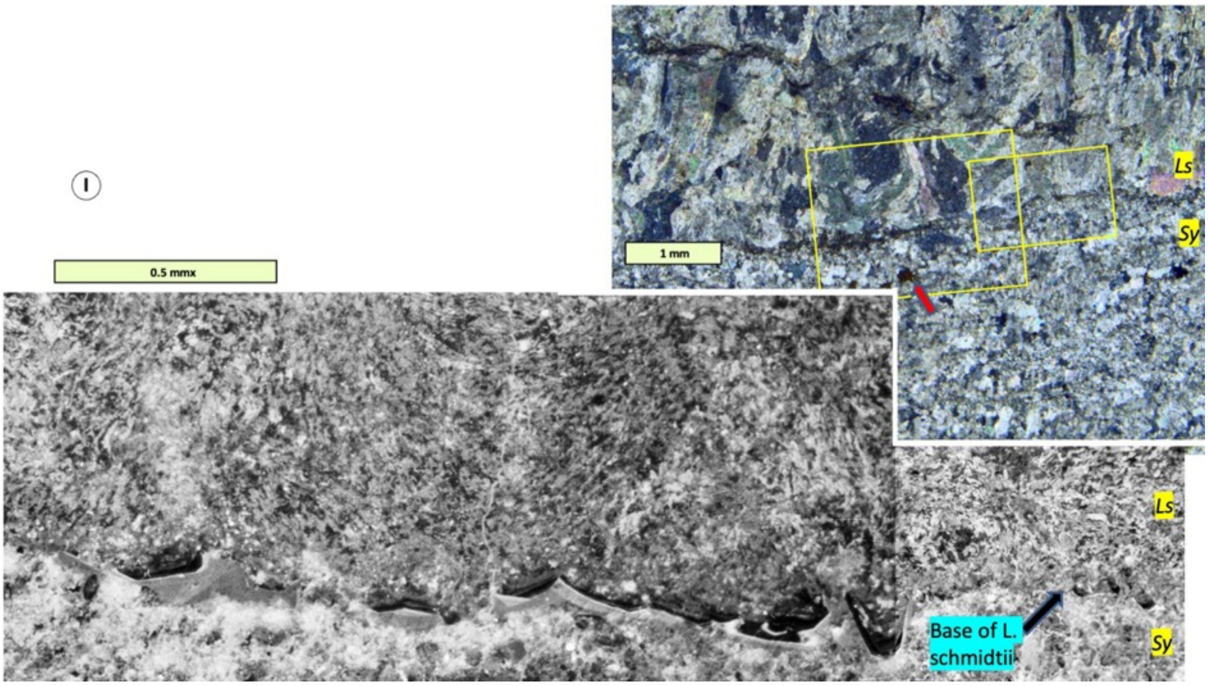


Fig. 6.1I. Composite image showing monochrome CL view of the combined boxes in upper image. There is a vague indication of development of the wavy laminations of *Ls* in the CL image. File: 8-10-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

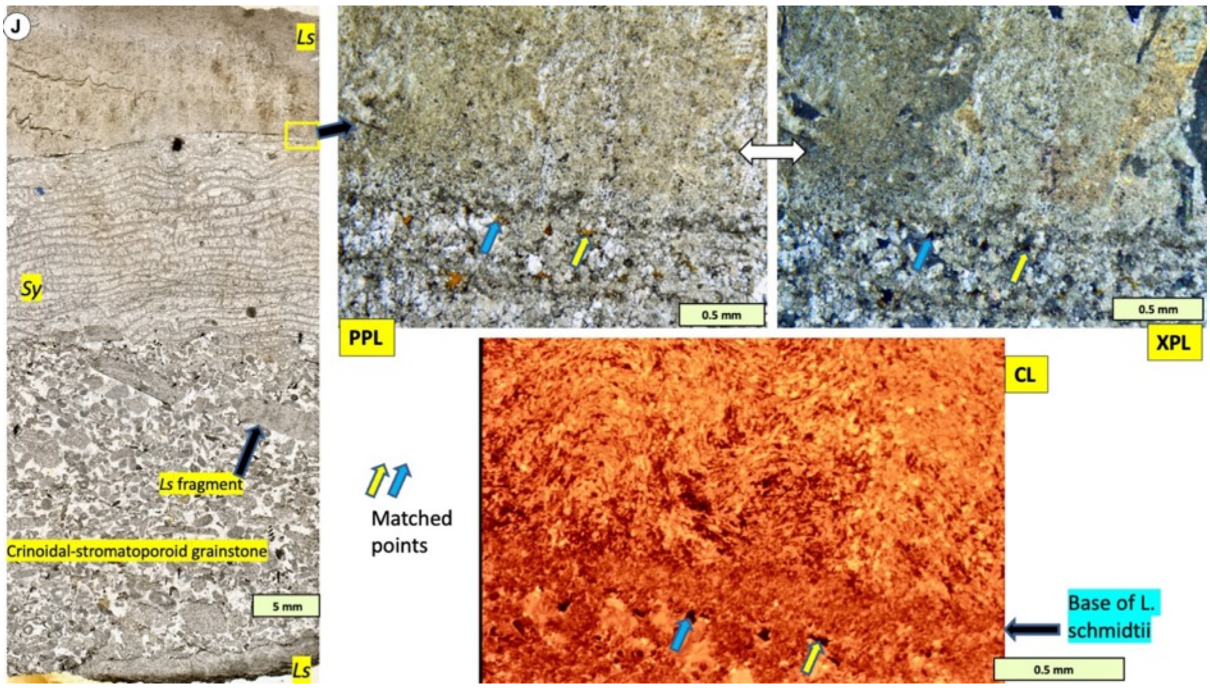


Fig. 6.1J. Another matched set of PPL, XPL and CL images. Note the diagenetic calcite in XPL view overprints the CL image that shows vague wavy laminations made of elongate irregular small crystals. File: 8-11-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

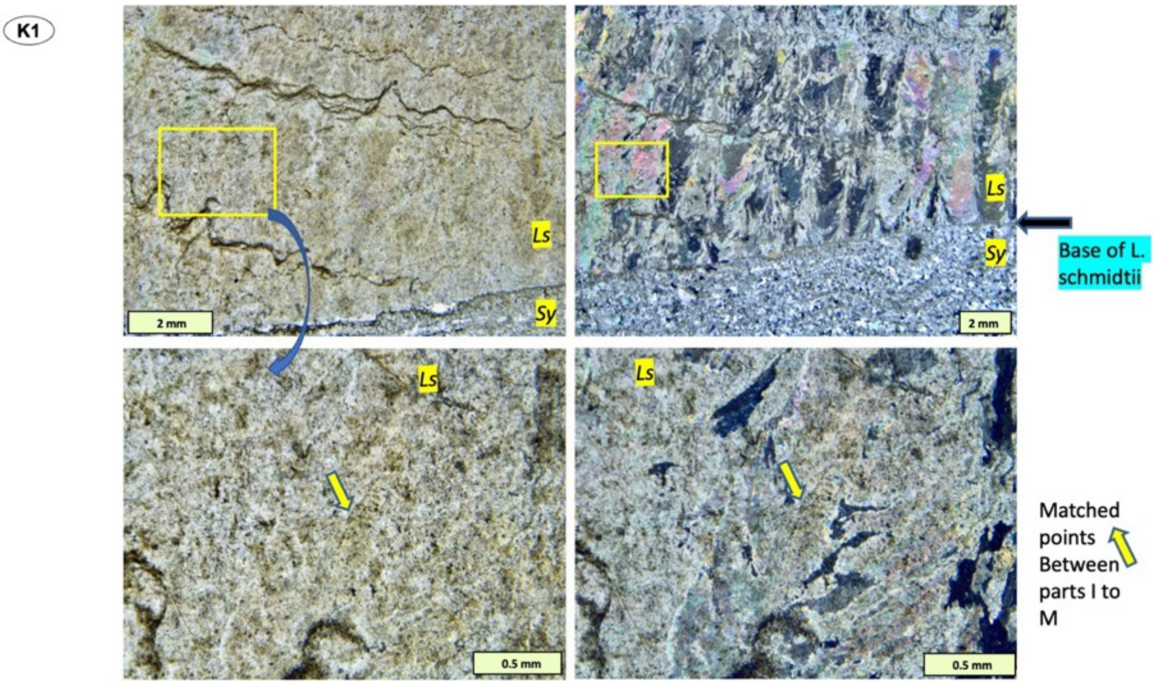


Fig. 6.1K1. PPL and XPL images of upper left-side of thin section. The overprinted FRIC in XPL image contrasts the PPL. File: 8-12-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

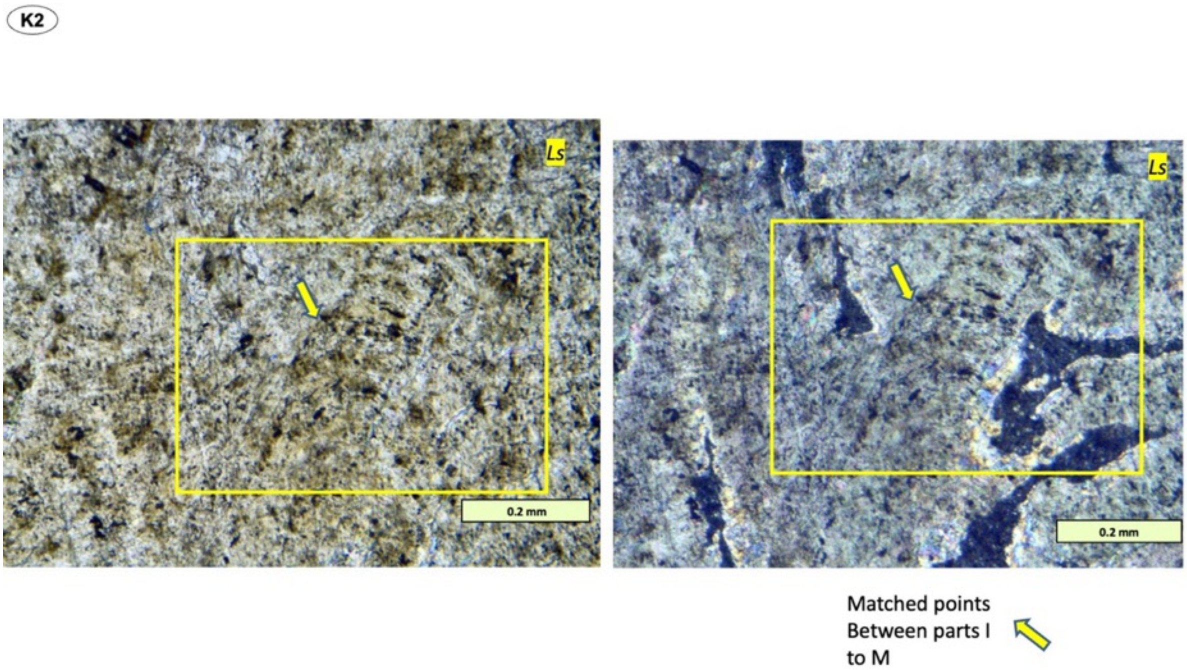


Fig. 6.1K2. Enlargements of Fig. 6.1K1, highlighting a yellow box area that matches a CL image in next few figures. In these two photos you can see the curving laminated structure in the centre of the yellow box, that is picked out better in CL in the next figure. File: 8-13-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

K3

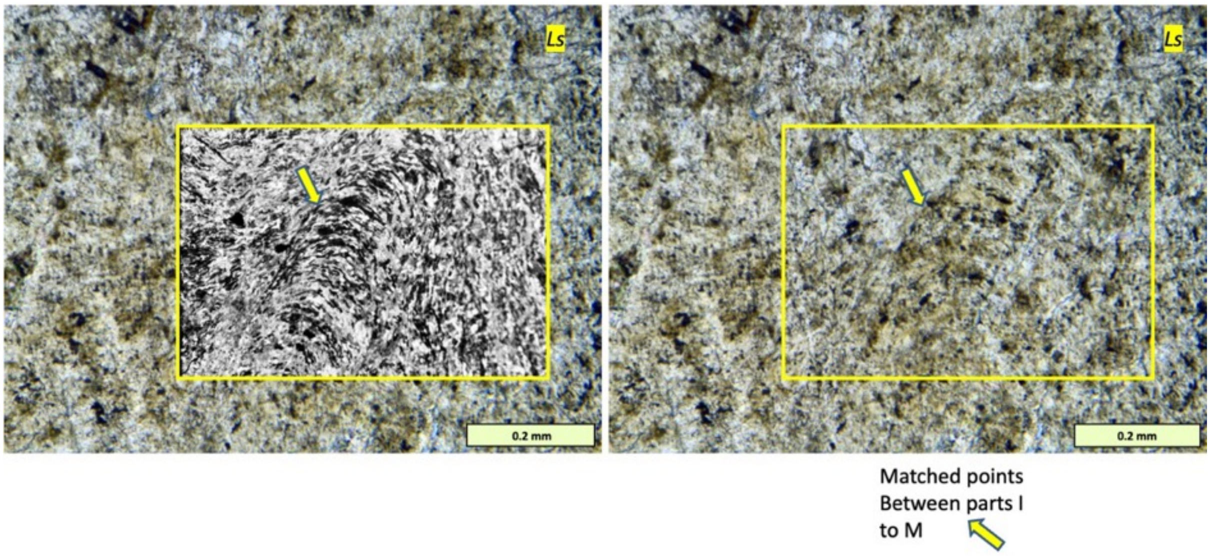


Fig. 6.1K3. PPL images; left photo has monochrome CL image superimposed as a matched image. The vague layering visible in the PPL image (right) is much more clearly seen in CL image (left). File: 8-14-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

K4

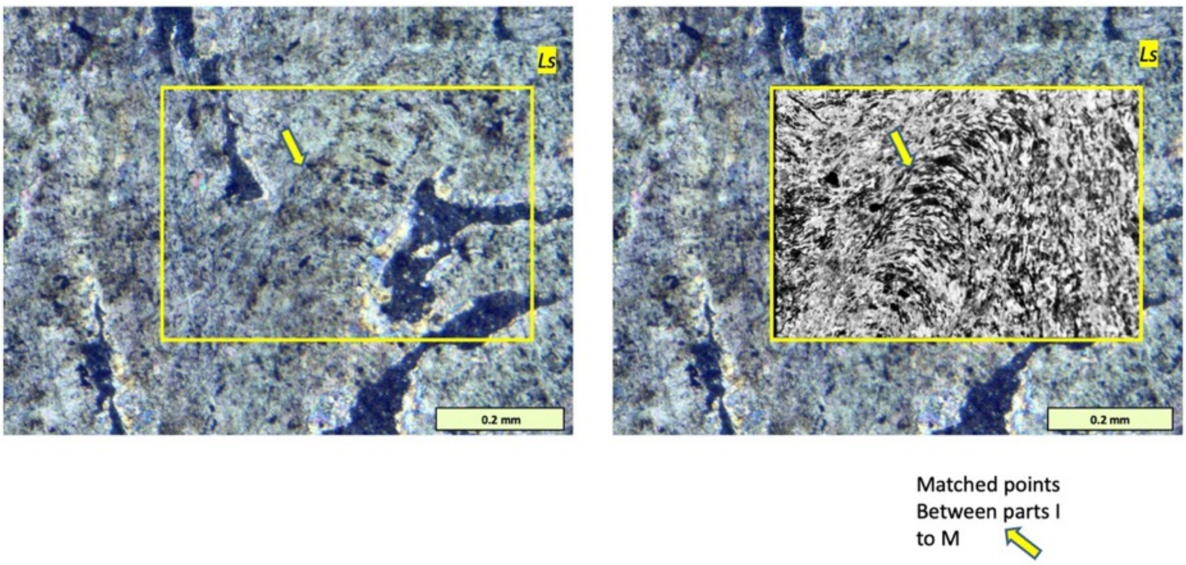


Fig. 6.1K4. Matching the previous figure, in CL (right) the laminated structure is visible despite the overprinted FRIC alteration seen in XPL. File: 8-15-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

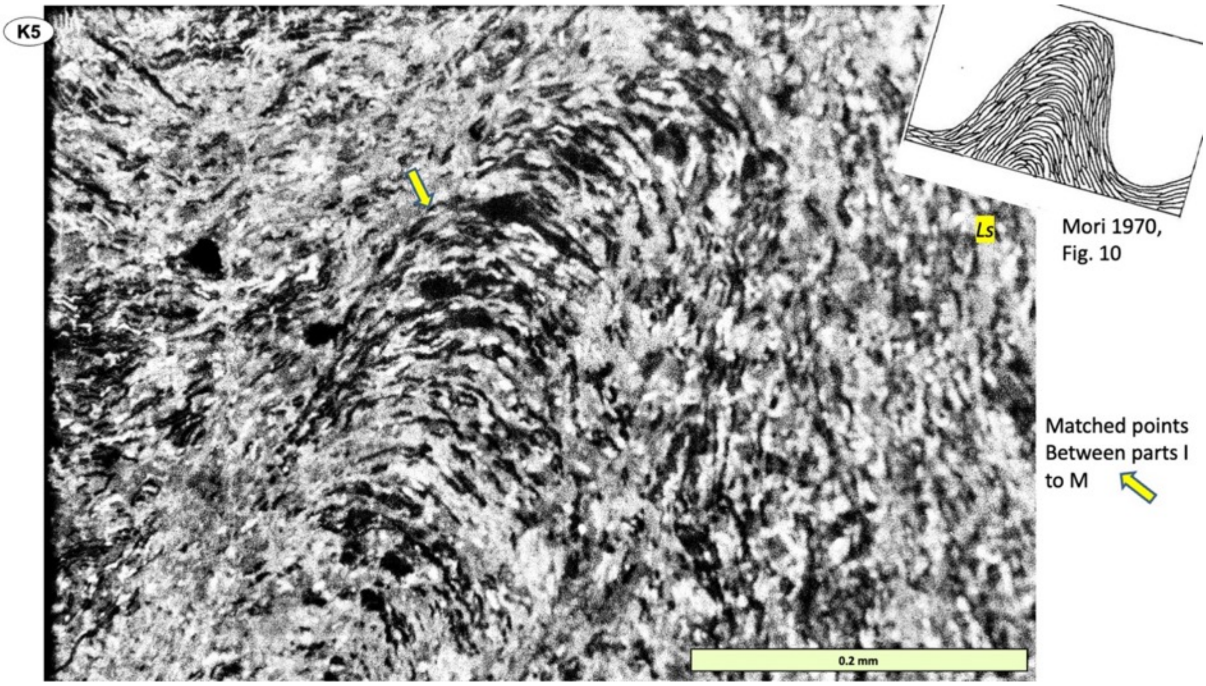


Fig. 6.1K5. Enlargement of monochrome CL image of *Ls* from previous figures showing the clear laminated structure. Comparison with stylised drawing by Mori (1970); the CL image looks like the structure is made of layered elongate irregular crystals, rather than simple curved plates illustrated by Mori. File: 8-16-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

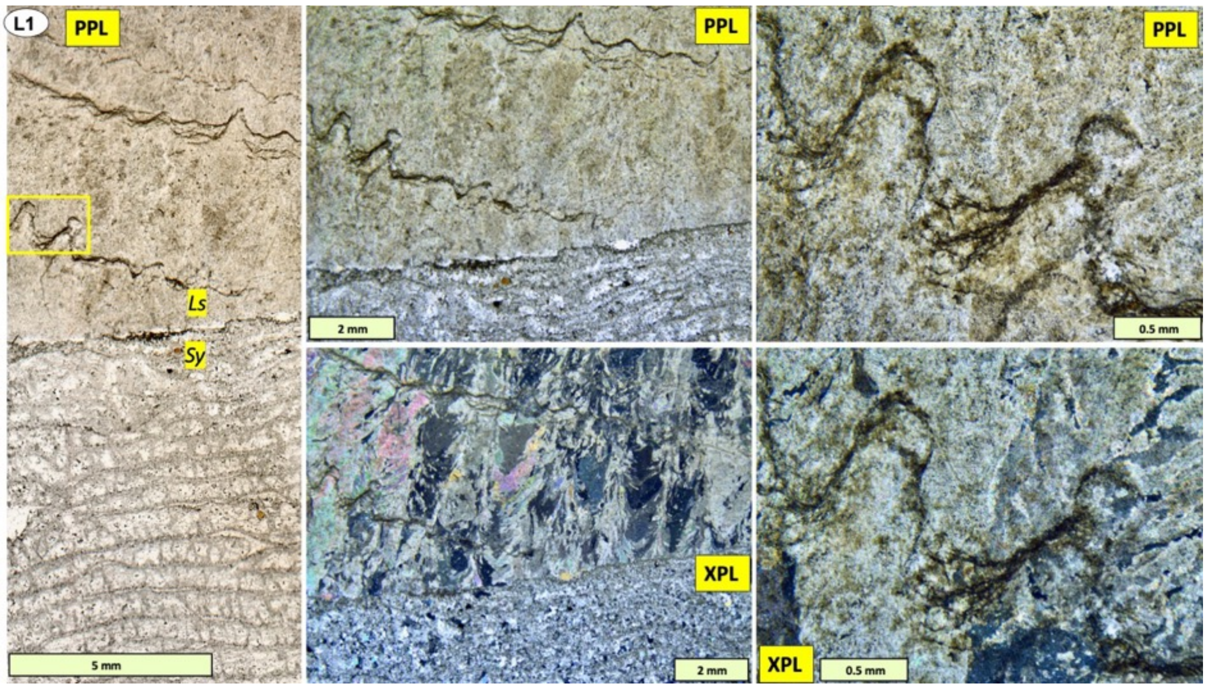


Fig. 6.1L1. Part of *Ls* showing contrasts between poorly visible structure in PPL and the overprinting effect of FRIC in XPL. These images show detail across a growth interruption event (dark lines in the *Ls*). File: 8-17-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

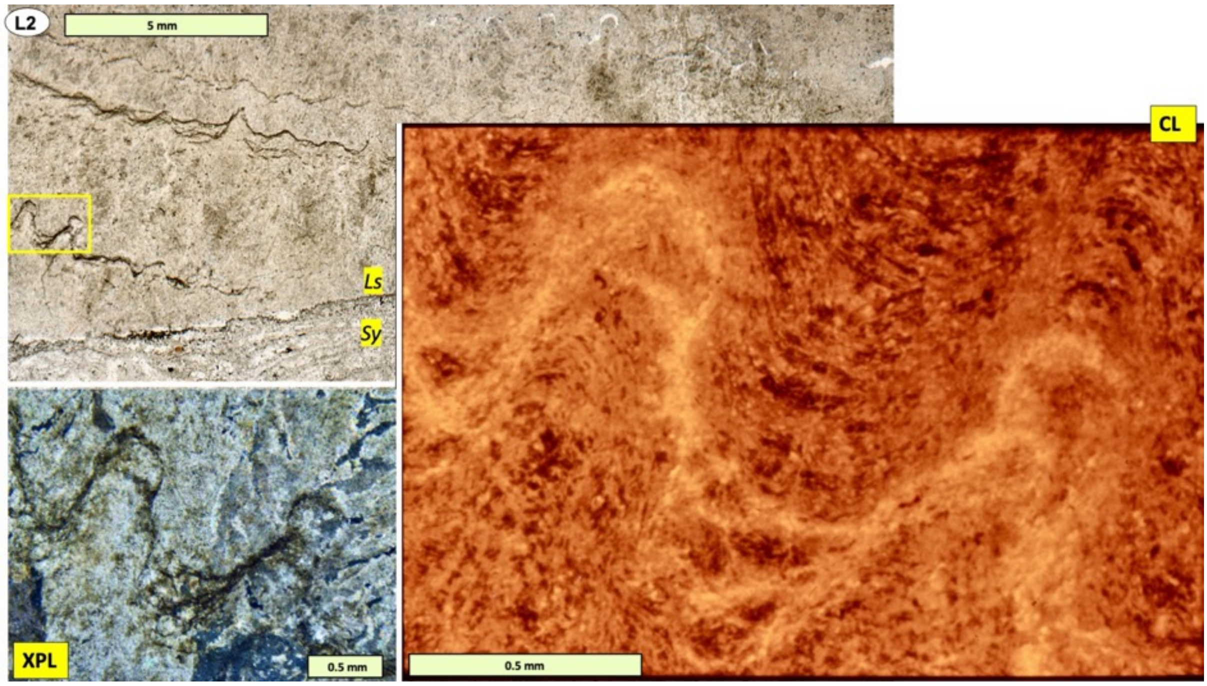


Fig. 6.1L2. Repeat of PPL and XPL images in previous figure plus matching CL image; note the laminated structure of *Ls* in CL and the growth interruption surface is picked out in brighter luminescent colour, that might reflect penetration of fluids along the interruption surface in burial diagenesis. File: 8-18-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

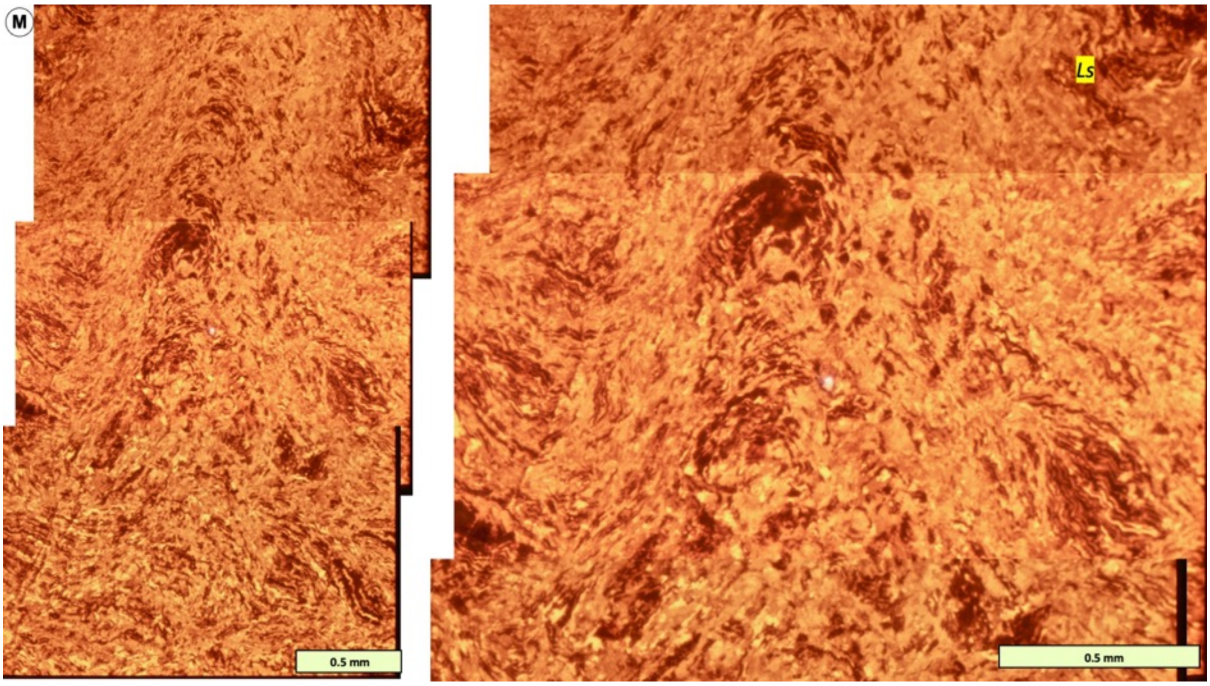


Fig. 6.1M. CL image of VS of *Ls* not matched to PPL or XPL images. This picture (enlarged on right) shows the apparent columnar structure of *Ls* comprising well-laminated structure on the left and lower right, made of elongate irregular crystals, but less well organised in the centre. This contrasts the well-organised laminations in the central part of an apparent column in Fig. 6.1K5 and also in the next figure. File: 8-19-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

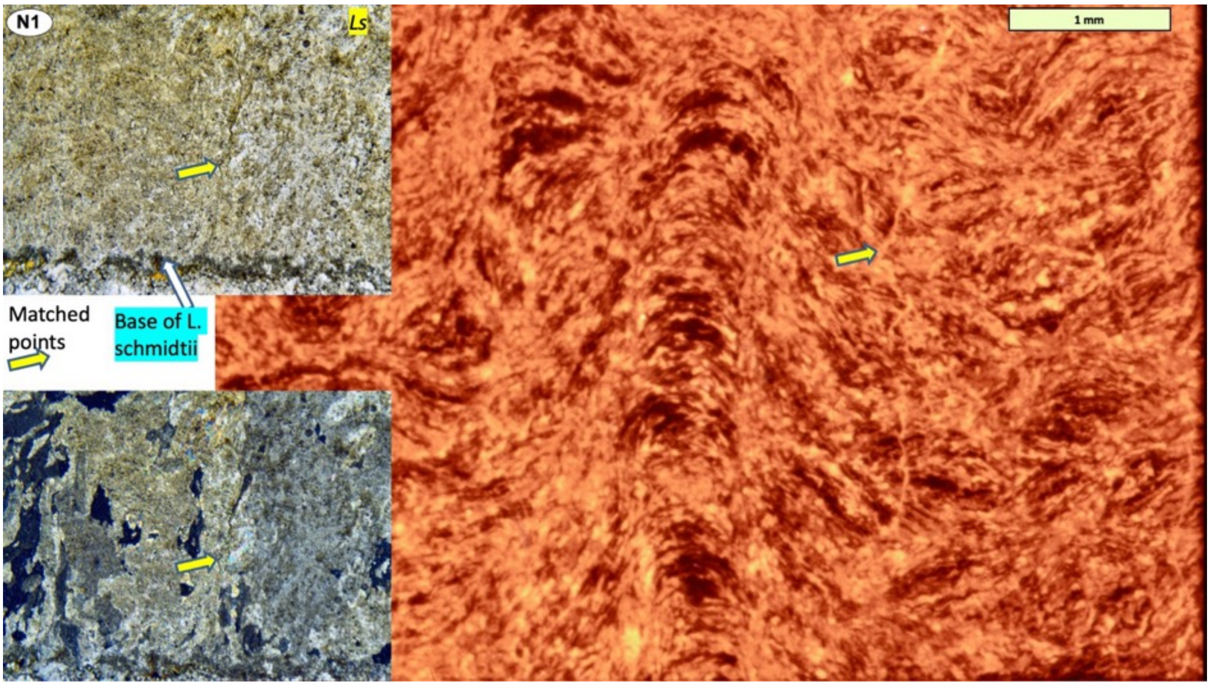


Fig. 6.1N1. VS of *Ls* showing matched PPL, XPL and CL images. In this picture the laminated structure of elongate irregular crystals comprising *Ls* is very well shown in CL, in the columnar area (centre) but less well organised each side. File: 8-20-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

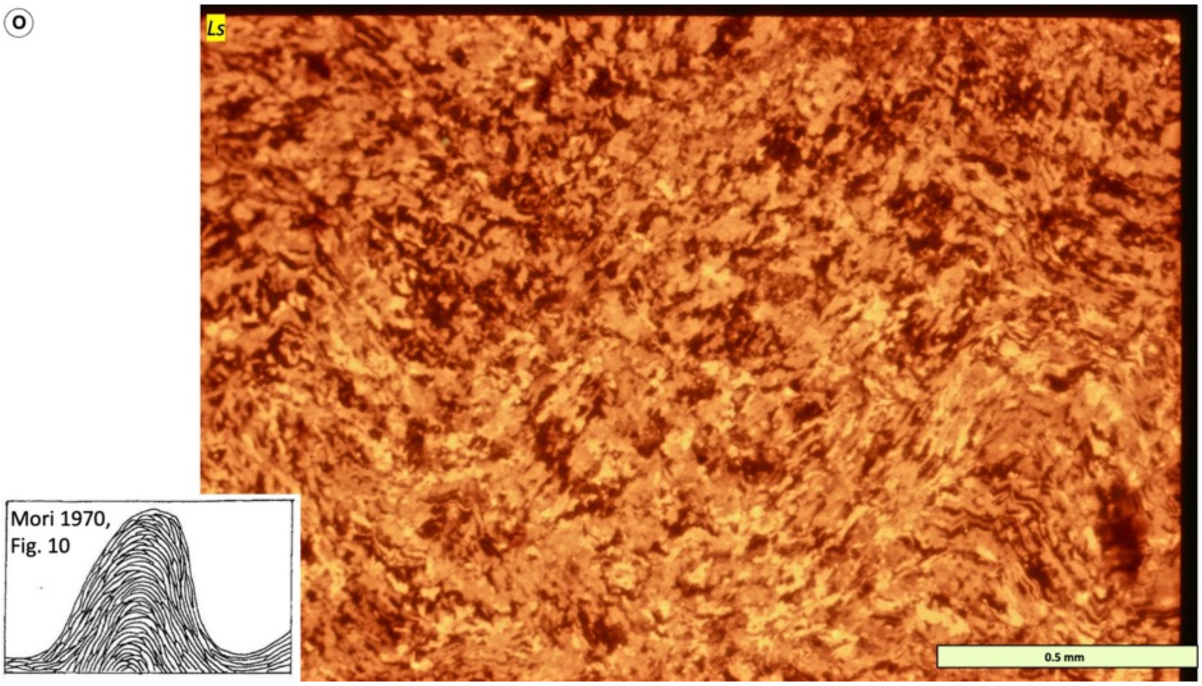


Fig. 6.1O. VS of *Ls* CL image not matched to PPL and XPL views. However, the rather coarse, poorly laminated fabric is consistent with earlier images taken from the basal part of the *Ls* so this one is interpreted to have also come from somewhere near the base. File: 8-21-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

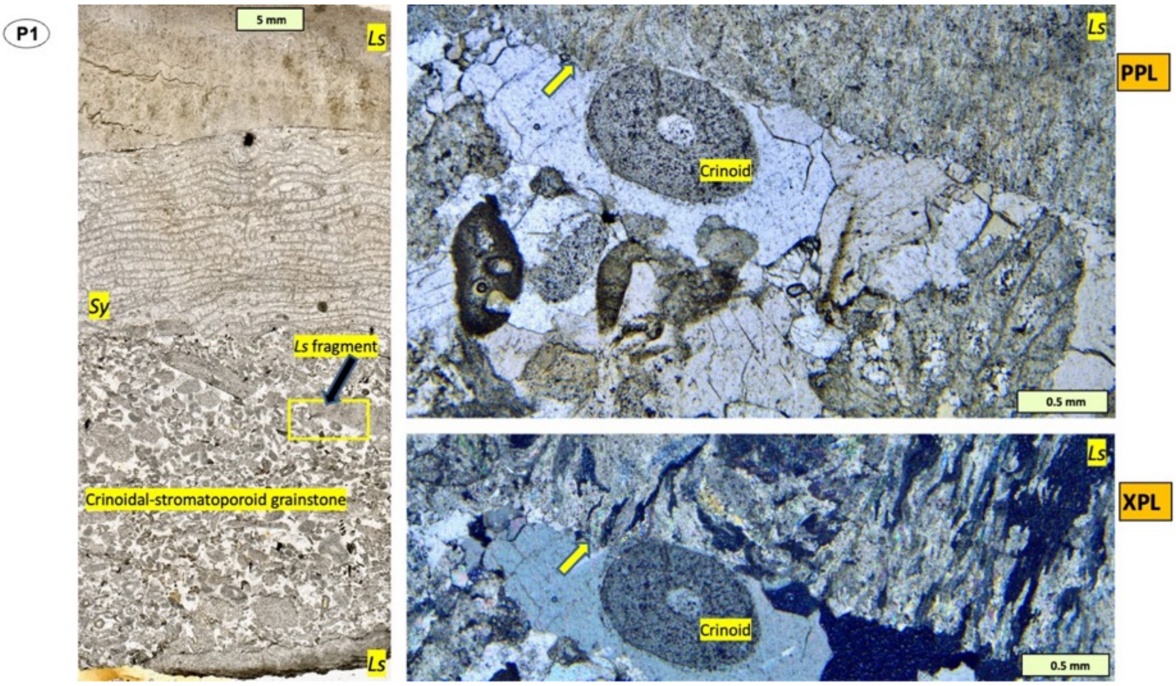


Fig. 6.1P1. PPL and XPL views of contrast between crinoid columnal and *Ls.* See enlargement in next figure. File: 8-22-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

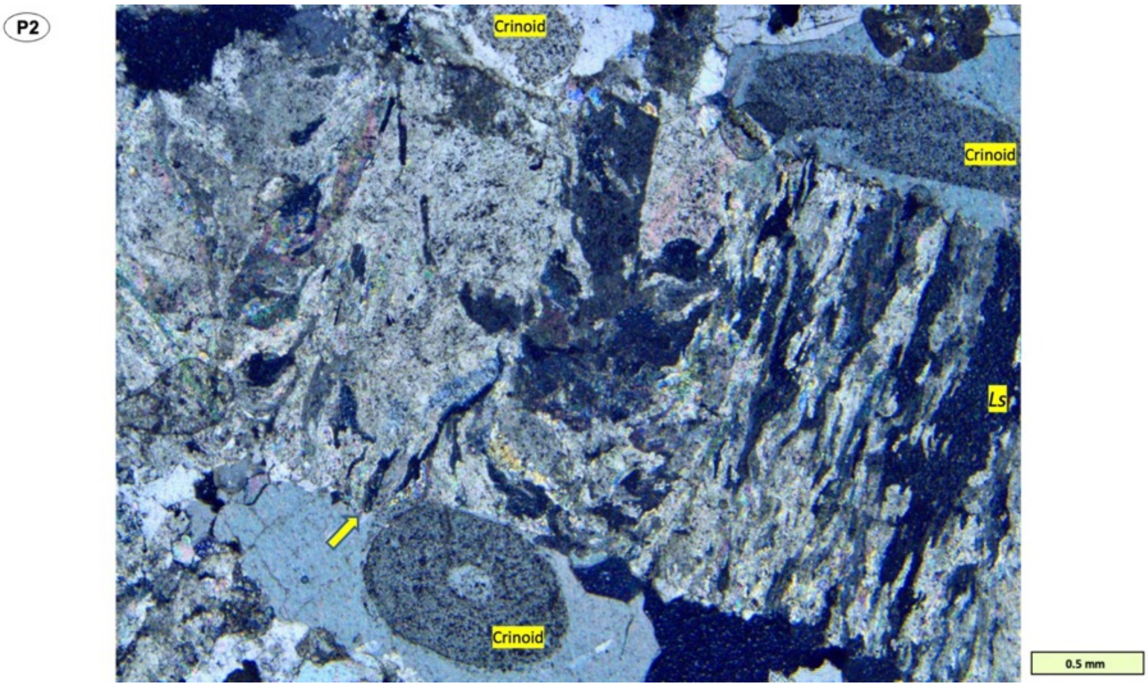


Fig. 6.1P2. XPL contrast between crinoid columnal and adjacent fragment of *Ls.* Note the syntaxial cement on the crinoid does not pass into the stromatoporoid, a feature characteristic of stromatoporoid FRIC. File: 8-23-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

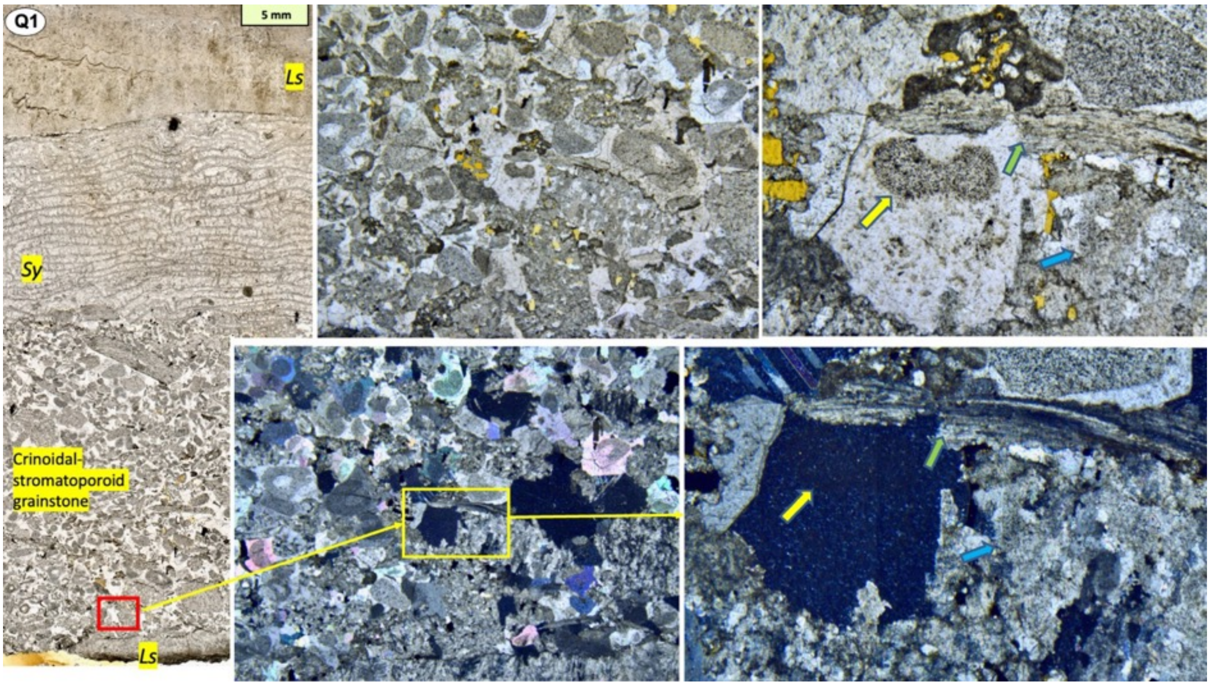


Fig. 6.1Q1. Features of grainstone in PPL and XPL in same bed as stromatoporoids illustrated in this case study. Note matched points that carry over to next two figures. File: 8-24-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

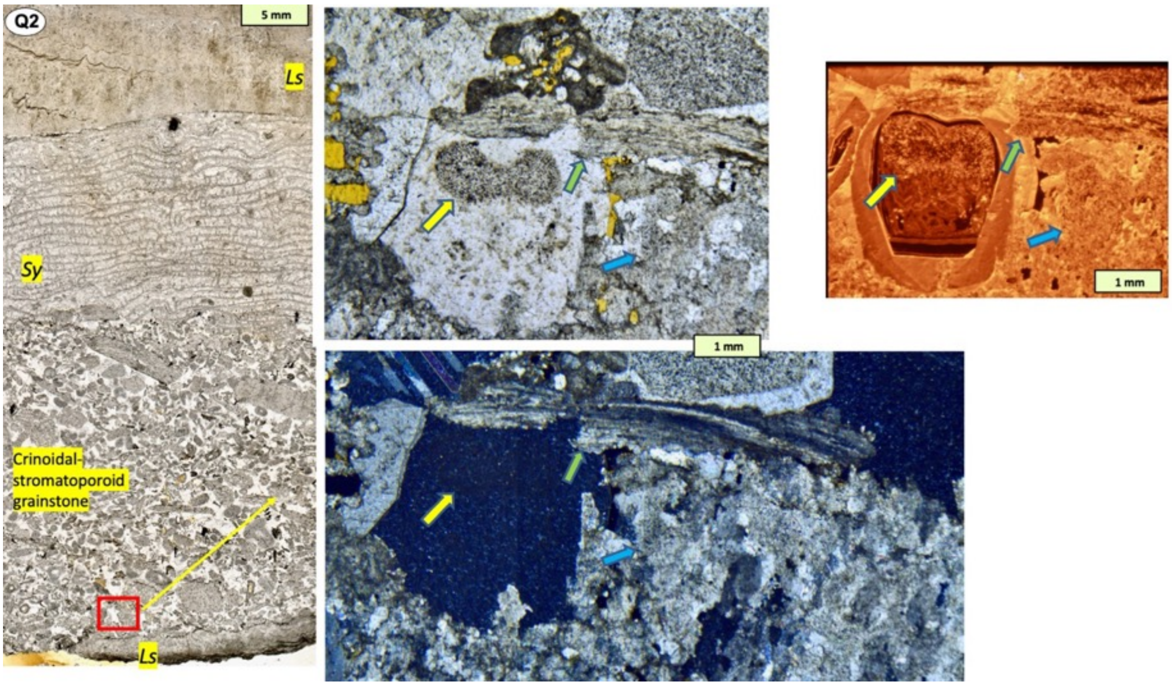


Fig. 6.1Q2. PPL, XPL and CL of crinoid (yellow arrow) and its syntaxial overgrowth; shell (green arrow) and stromatoporoid (blue arrow). File: 8-25-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

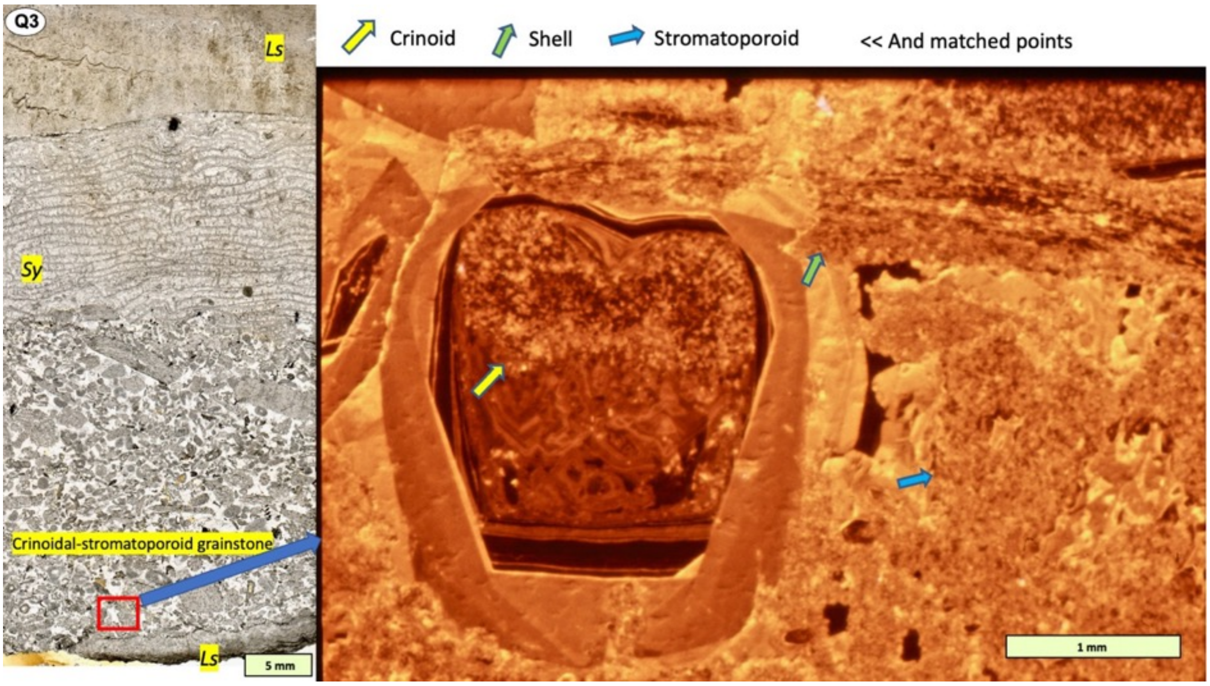


Fig. 6.1Q3. Enlargement of previous figure, showing CL zoning on the overgrowth on the crinoid, the laminated shell and speckled appearance of the stromatoporoid skeleton. File: 8-26-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

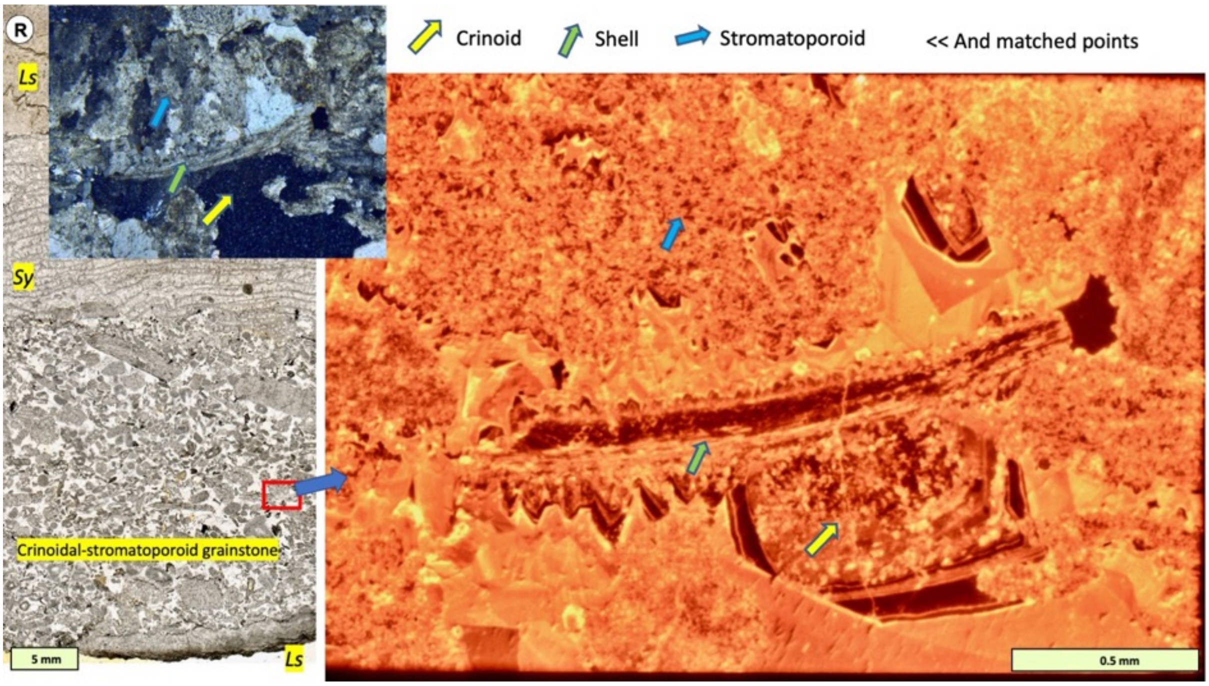


Fig. 6.1R. Another image of contrasts of CL between crinoid (and overgrowth), laminated shell, and speckled stromatoporoid. The laminated shell and crinoid have nice cement growths with bands of varying CL luminescence, reflecting fluctuations of pore waters as the crystals grew. File: 8-27-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

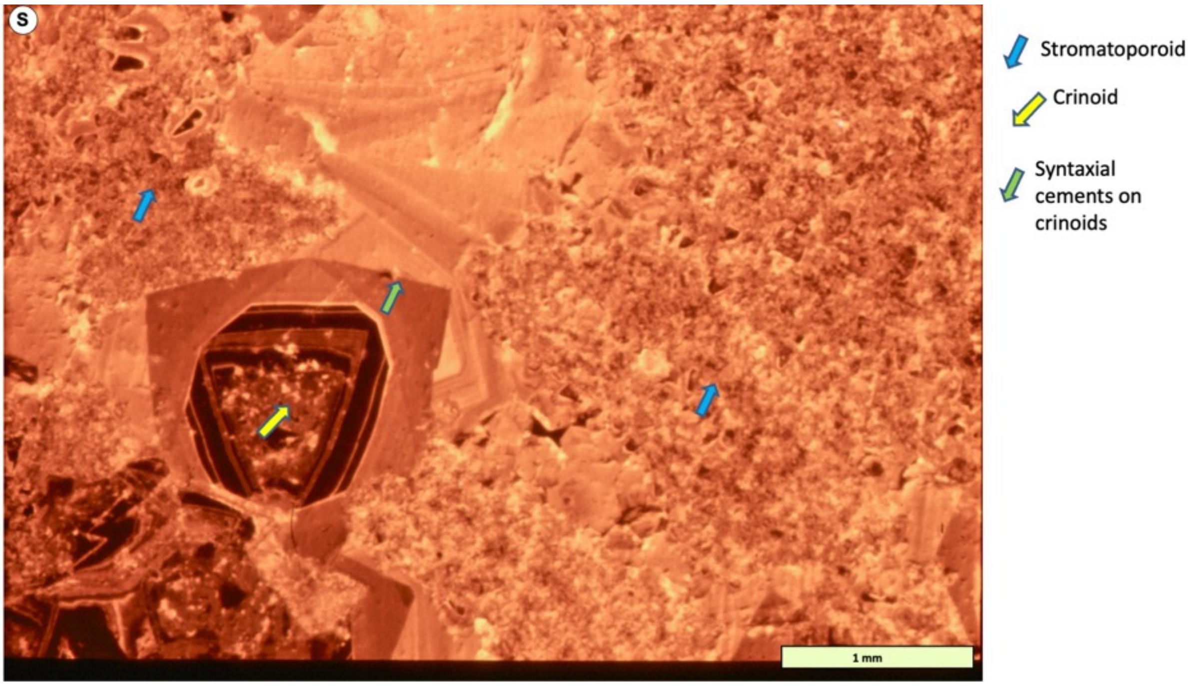


Fig. 6.1S. Another photo from the grainstone, of contrast of CL between crinoid (and its overgrowth) and stromatoporoid. File: 8-28-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

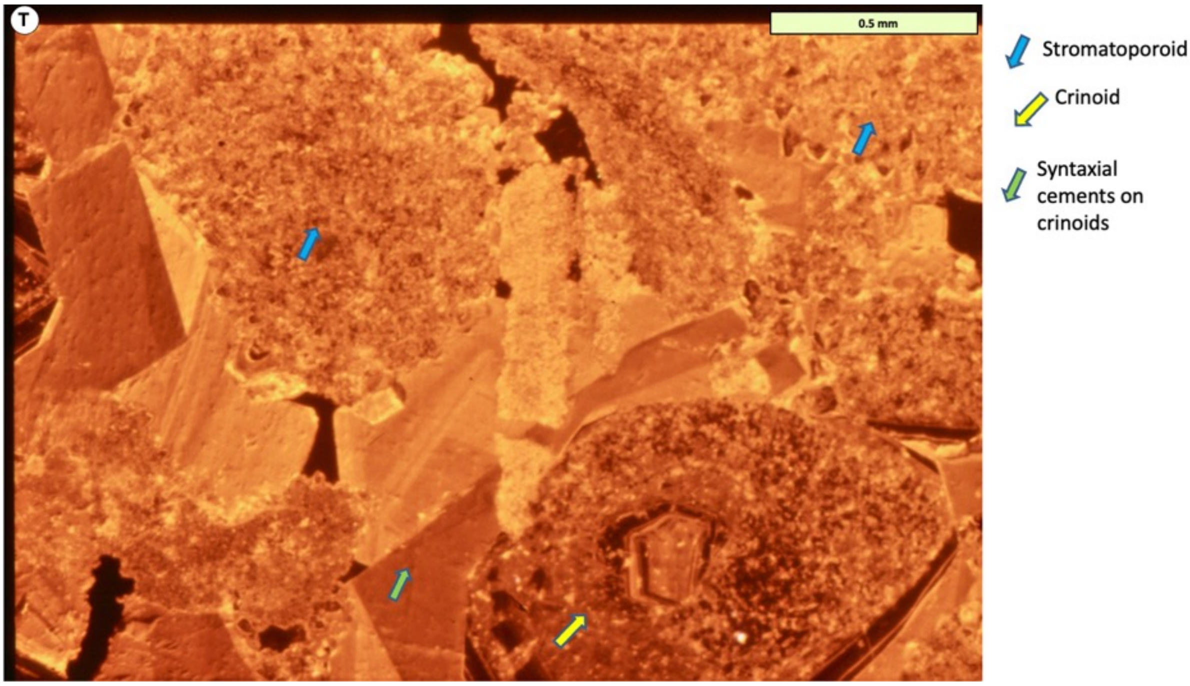


Fig. 6.1T. Yet another photo from the grainstone, of contrast of CL between crinoid (and its overgrowth) and stromatoporoid. File: 8-29-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

U

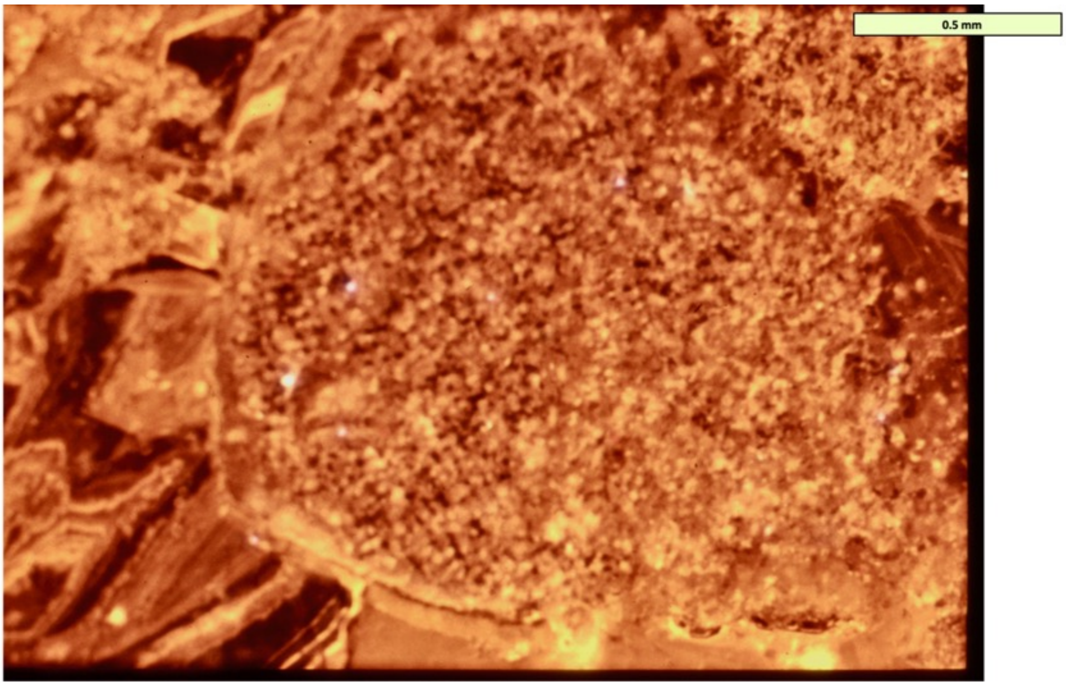


Fig. 6.1U. Yet another photo from the grainstone, of a crinoid with evidence in CL of the stereome of the crinoid, so that the porosity of the crinoid is picked out in contrasting CL in a regular frame, even though this picture is a little fuzzy. The key point of this picture is that it allows an argument that the CL image is representative of the original structure of the crinoid. Noting that the shells in previous images are also well-laminated in CL, and thus reflective of original structure, then if that logic is applied to the stromatoporoids, the CL view may be taken to represent original, or near original structure, providing confidence in interpretation that the laminated structure of *Ls* in CL is representative of its original structure. File: 8-30-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

V1

Transverse section

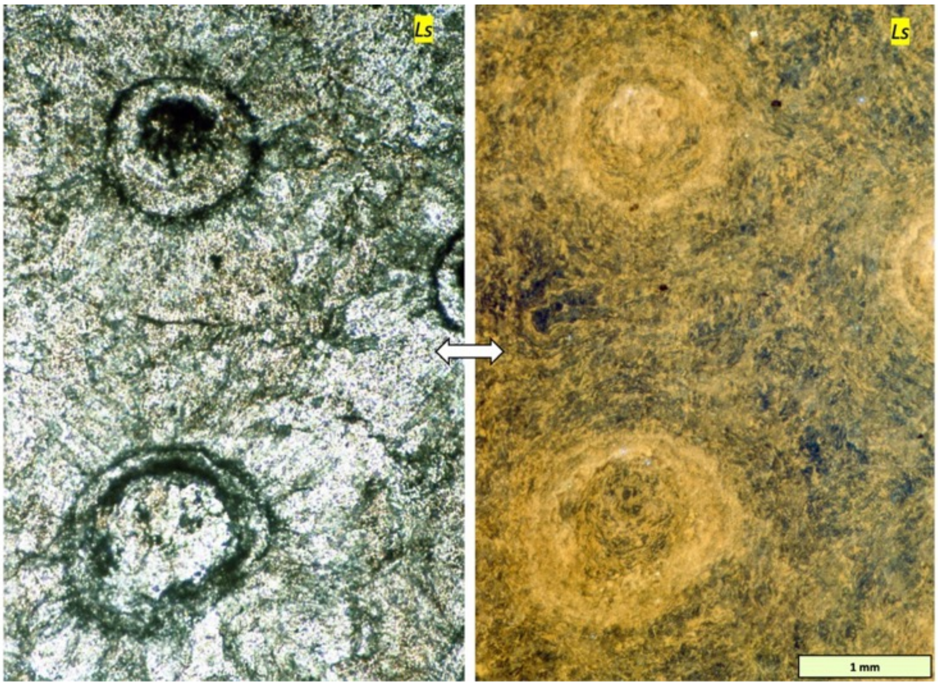


Fig. 6.1V1. TS of matched images of Ls in PPL (left) and CL (right). The circular structure is transverse section of the laminated architecture of Ls. Note in the PPL views the radial calcite crystals are not shown in the CL view, evidence of the FRIC overprinting in the PPL view, contrasting the likely original laminar structure shown in CL. Variation of CL response interestingly shows high intensity in the column centres. This is not reflected in the VS CL views in earlier figures in this case study from

the same sample, which vary in CL intensity vertically and laterally in the areas examined in CL. File: 8-31-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

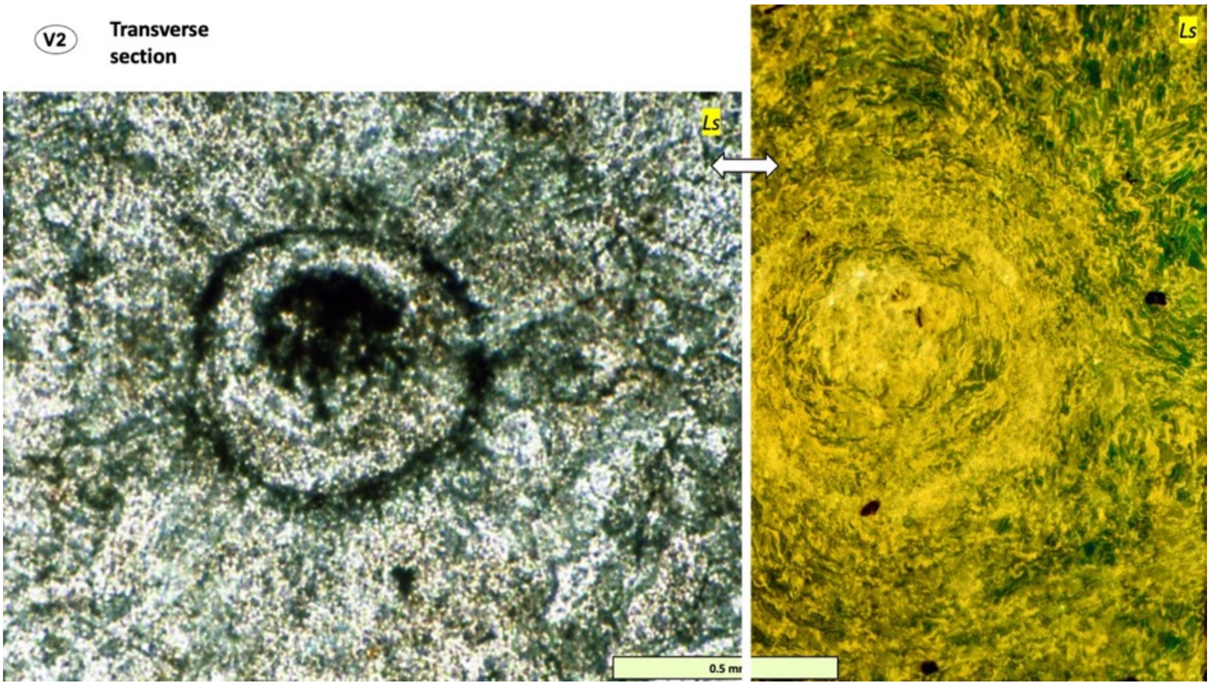


Fig. 6.1V2. Enlargement of upper part of previous figure showing the layered structure in TS, that is like contour lines on a hill, so they are cut sections through laminations in one of the columnar-like centres in *Ls.* Note the PPL photo shows the radial calcite crystals, not seen in the CL view, that shows the likely original growth layering. Note that in the CL view, the concentric circles of growth layers are TS sections through 3D curving masses of plate-like crystals that slope away from the centre in all directions, so this is NOT like the cone-in-cone structure described by Webby (2015) described in the Taxonomy section, which is diagenetic. File: 8-32-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

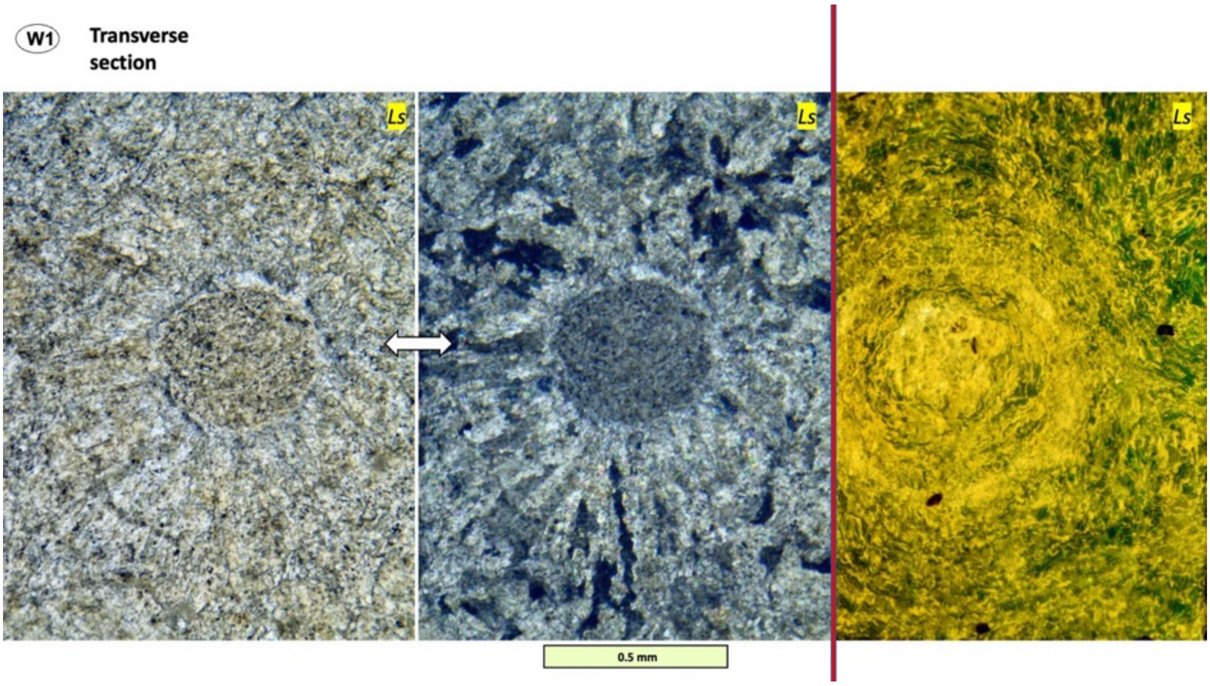


Fig. 6.1W1. Comparison of PPL and XPL of another specimen, with the CL of this case sample. Again this highlights the radial crystals of FRIC alteration that are not seen in the CL image, as shown in the previous two figures. File: 8-33-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

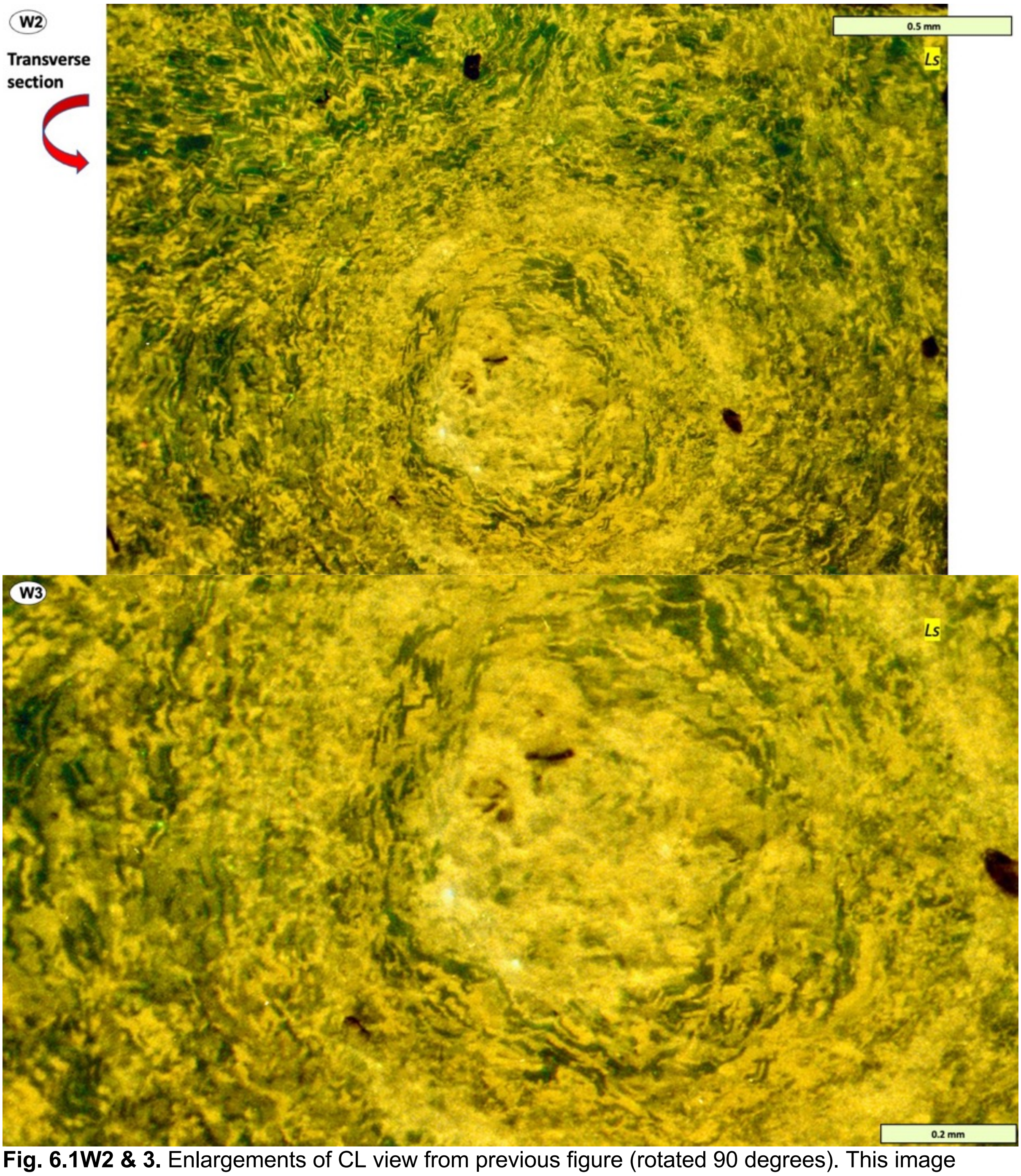


Fig. 6.1W2 & 3. Enlargements of CL view from previous figure (rotated 90 degrees). This image indicates the curved small plates made of somewhat irregular crystals envisaged by Mori (1970) shown in some figures earlier, although Mori's drawing is really too simplistic a representation of the structure of *Ls.* File: 8-34-Case01-4c1-4.83-DyLs-CL-VS-And-Ls-TS

<u>**Summary of Case Study 1, 4c1-4.83**</u>

1. The VS and TS views of *Lophiostroma schmidtii* shown in PPL, XPL and CL in this case study demonstrate the likely original structure of *Ls* consists of stacked very thin curved, discontinuous irregular crystals that give the impression of laminar sheets, thus partly

consistent with the stylised drawing by Mori (1970) shown in various figures. However, both VS and TS views show the stacked overlapping laminar thin plates are not consistently present in the CL view, raising the question about whether the entire structure was made from such thin overlapping plates, or was much more variable.

2. PPL, and especially XPL, views show 3D radially upward-expanding calcite crystals emanate from the centres of the apparent columnlike upcurves of laminations. These were formerly referred to as a type of cone-in-cone structure, but they are demonstrated here to be different and not cone-in-cone. The radial crystals are vaguely visible in PPL but very clear in XPL, yet not at all seen in CL views; this is interpreted to indicate that the CL view shows the original/near-original structure and the radial crystals are overprinting of Fabric-Retentive Recrystallisation (called FRIC – fabric-retentive irregular calcite), that is ubiquitous in stromatoporoids, and reinforces the view that *Ls* is probably best classified with the stromatoporoids.
3. Other evidence in PPL-XPL-CL comparisons of bioclasts in the grainstone within the same sample as the *Ls*, reinforce the view that the CL view of *Ls* is likely reflecting the original structure.

6.2. Case Study 2: 2c1-2.48

Sample from Kuppen 3 site, lower part of biostrome.

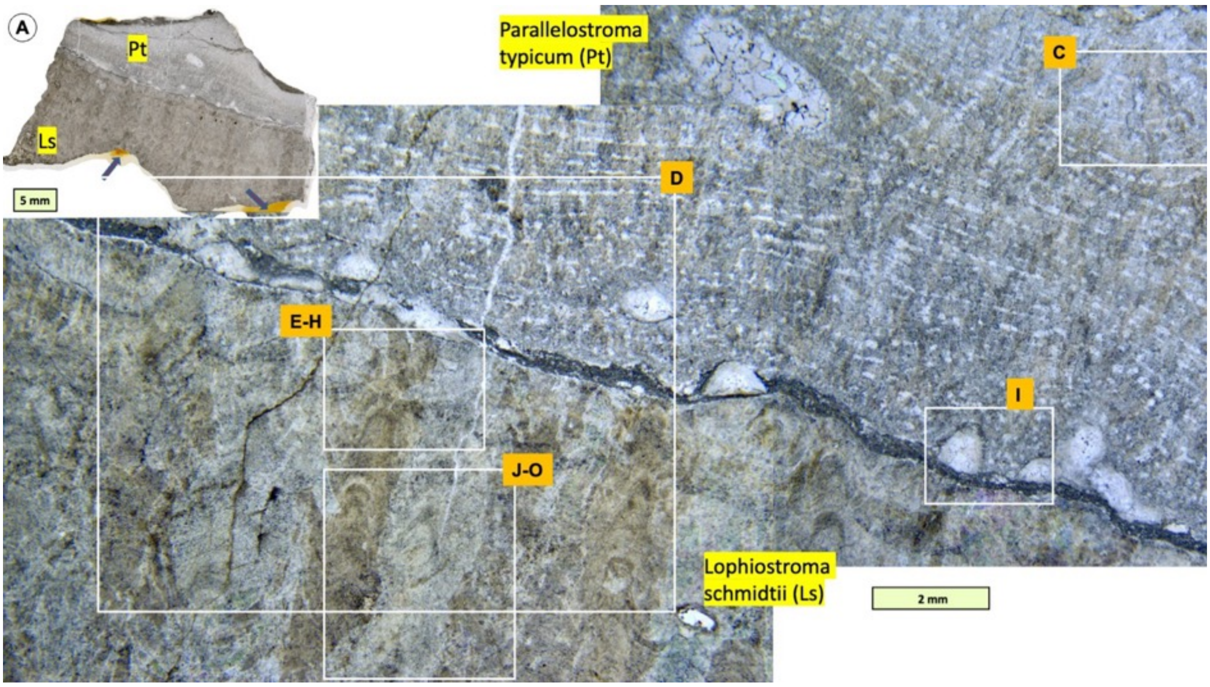


Fig. 6.2A. VS stromatoporoids. Inset shows whole thin section; black arrows indicate burn marks from CL. Main picture is a montage of PPL views that shows areas of interest with figure parts labelled. Lower stromatoporoid is *Lophiostroma schmidtii* (*Ls*), upper stromatoporoid is *Parallelostroma typicum* (*Pt*); there are some encrusting auloporids on upper surface of *LS.* File: 9-01-Case02-2c1-2.48-LsPt-VS-FineDetails-CL-Rexd

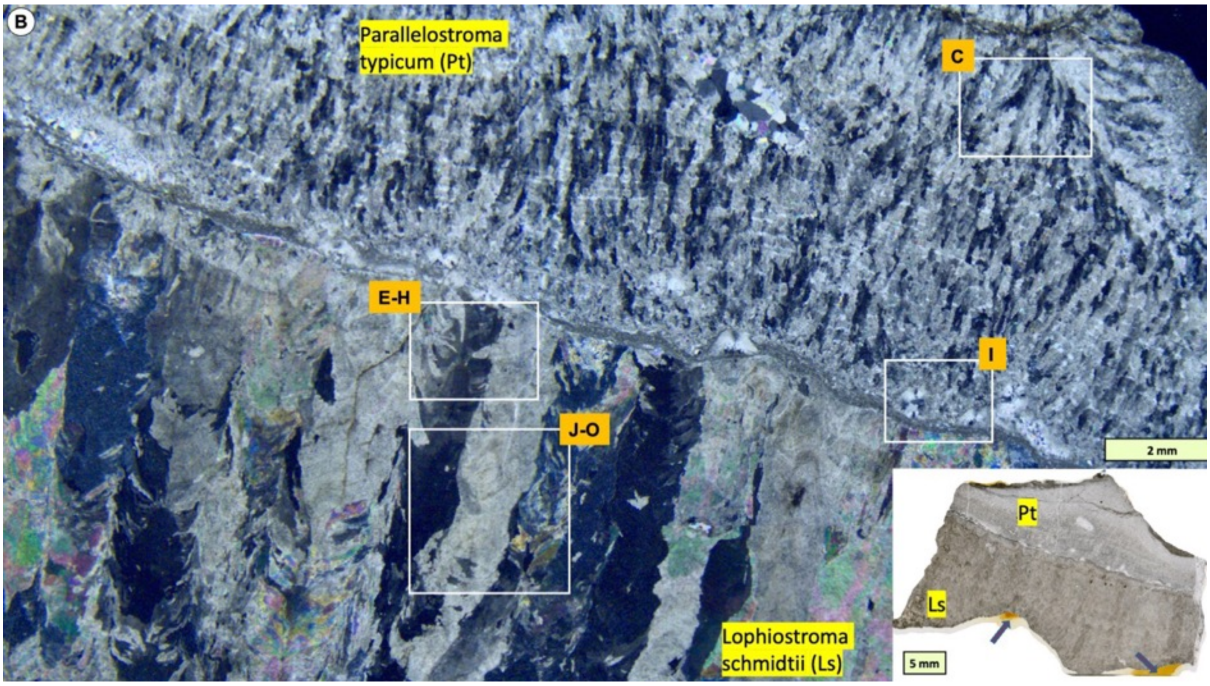


Fig. 6.2B. VS stromatoporoids in XPL, lower is *Ls*, upper is *Pt.* Boxes show areas of enlargement in subsequent figures. In *Ls*, the FRIC diagenetic overprinting clearly shown with large column-shaped crystals in extinction overprinting the layered structure. In *Pt*, the FRIC is more like normal stromatoporoid FRIC – elongate club-shaped crystals that cut across numerous laminae and in optical continuity with gallery space. File: 9-02-Case02-2c1-2.48-LsPt-VS-FineDetails-CL-Rexd

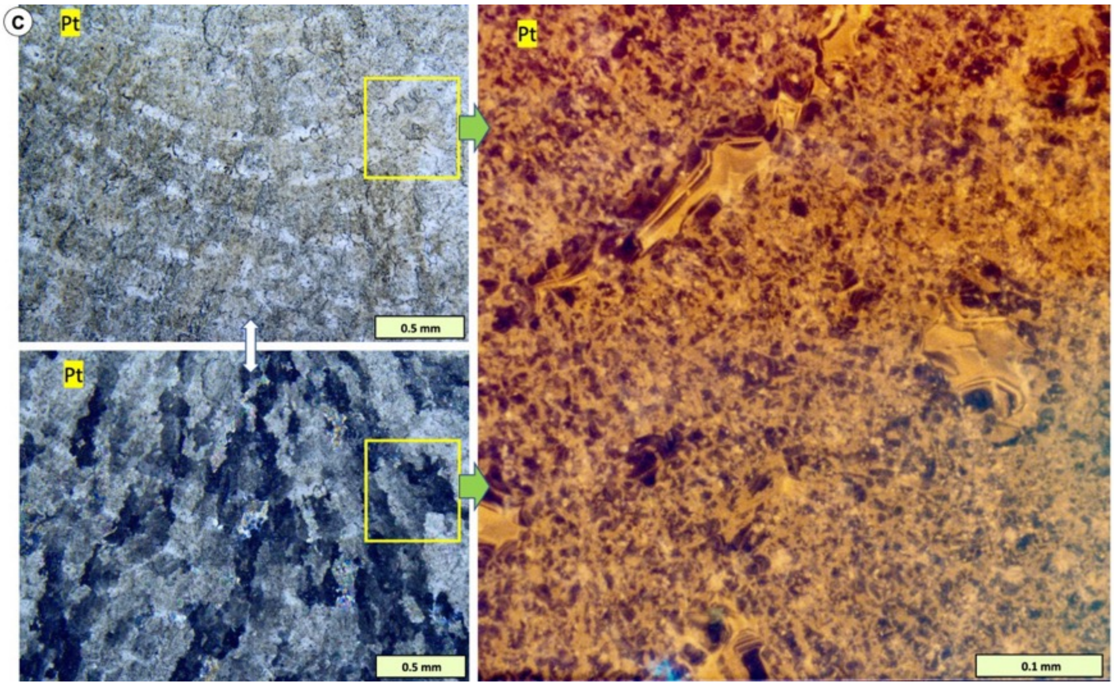


Fig. 6.2C. Enlargement of upper right part of previous two figures, showing *Pt* in PPL, XPL and CL. XPL view shows the well-formed FRIC cutting across laminae, pillars and gallery; CL view shows no evidence of FRIC, but instead shows the speckled view of stromatoporoid skeleton that is most ubiquitous in stromatoporoids; the gallery space contains zoned sparite showing several generations of sparite infill. The first sparite growth in galleries is non-luminescent and commonly interpreted as formed early, in aerobic conditions that excluded Mn and Fe. Bright luminescence occurs in thin layers, possibly indicating Mn enrichment in early sub-redox-boundary burial, and dull luminescence possibly represents addition of ferrous iron in later burial, The speckled CL response of stromatoporoid skeleton is not explained but may reflect at least part of the original texture of the skeleton. File: 9-03-Case02-2c1-2.48-LsPt-VS-FineDetails-CL-Rexd

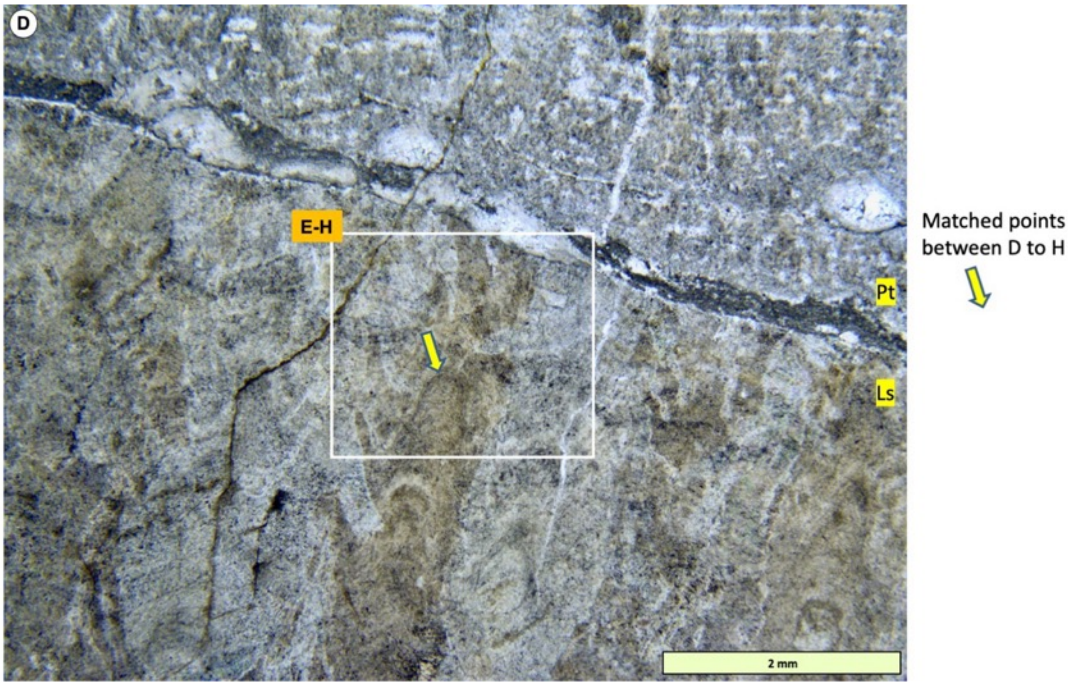


Fig. 6.2D. PPL VS view of contact area between *Ls* and *Pt. Ls* laminations and upcurving into apparent columns is visible in some parts of the section, noting that the upcurving occurs in a stacked system to create apparent columns rather than real columns. File: 9-04-Case02-2c1-2.48-LsPt-VS-FineDetails-CL-Rexd

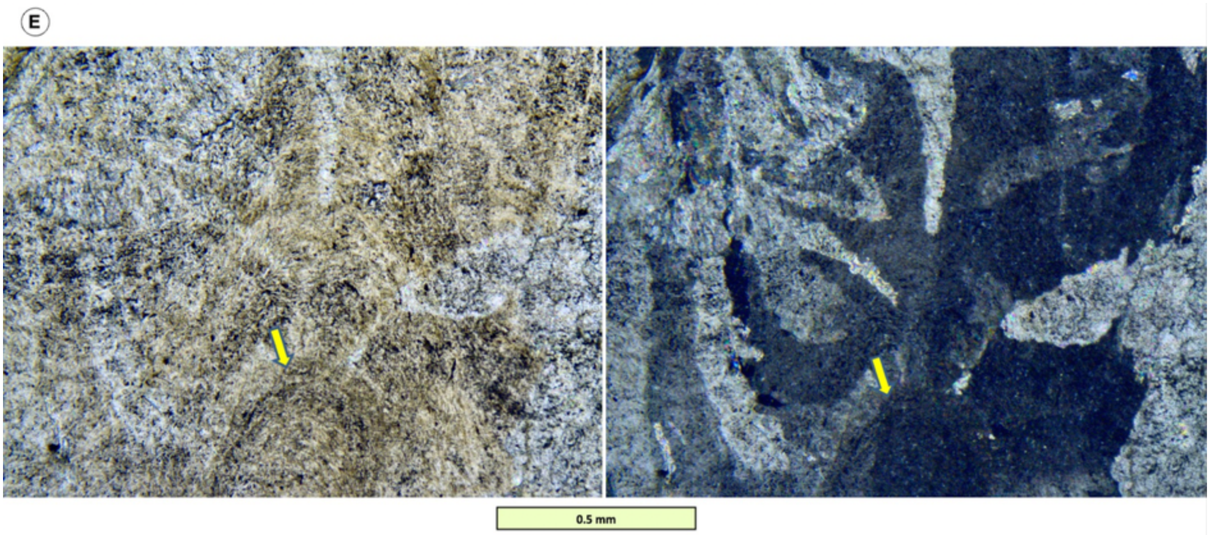


Fig. 6.2E. Enlargement of white box in previous figure showing PPL (left) and XPL (right). Bottom centre of each picture is the top of a prominent area of upcurving laminae seen in darker brown on PPL image (yellow arrow). XPL view shows splay of FRIC emanating from the upcurving area and is approximately 90 degrees to the orientation of the layering, thus broadly consistent with FRIC in other stromatoporoids; however, in this view the FRIC is more irregular. File: 9-05-Case02-2c1-2.48-LsPt-VS-FineDetails-CL-Rexd-Cut

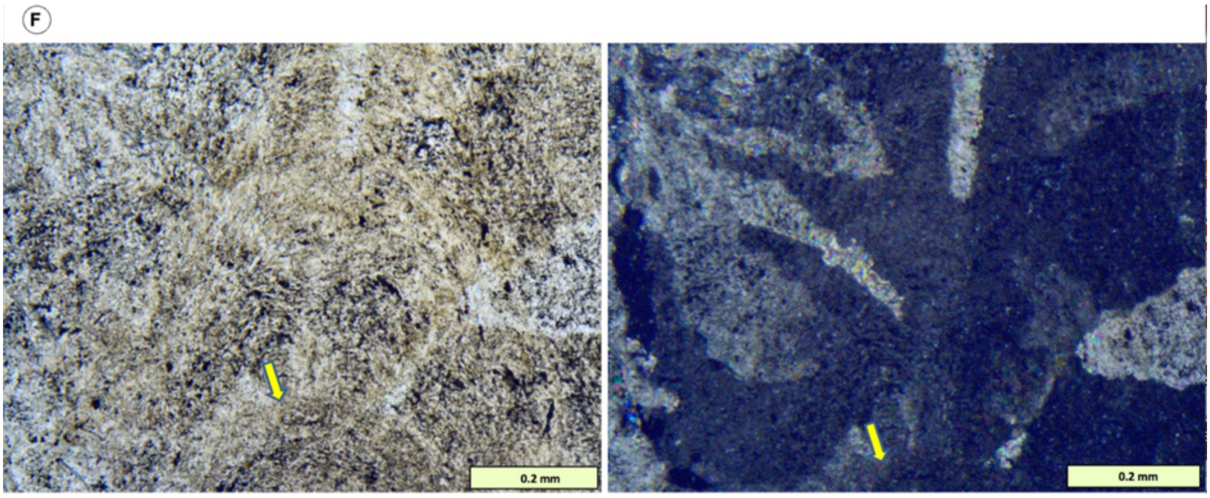


Fig. 6.2F. Enlargement of previous figure, showing the fabrics in PPL and XPL in more detail. File: 9-06-Case02-2c1-2.48-LsPt-VS-FineDetails-CL-Rexd-Cut

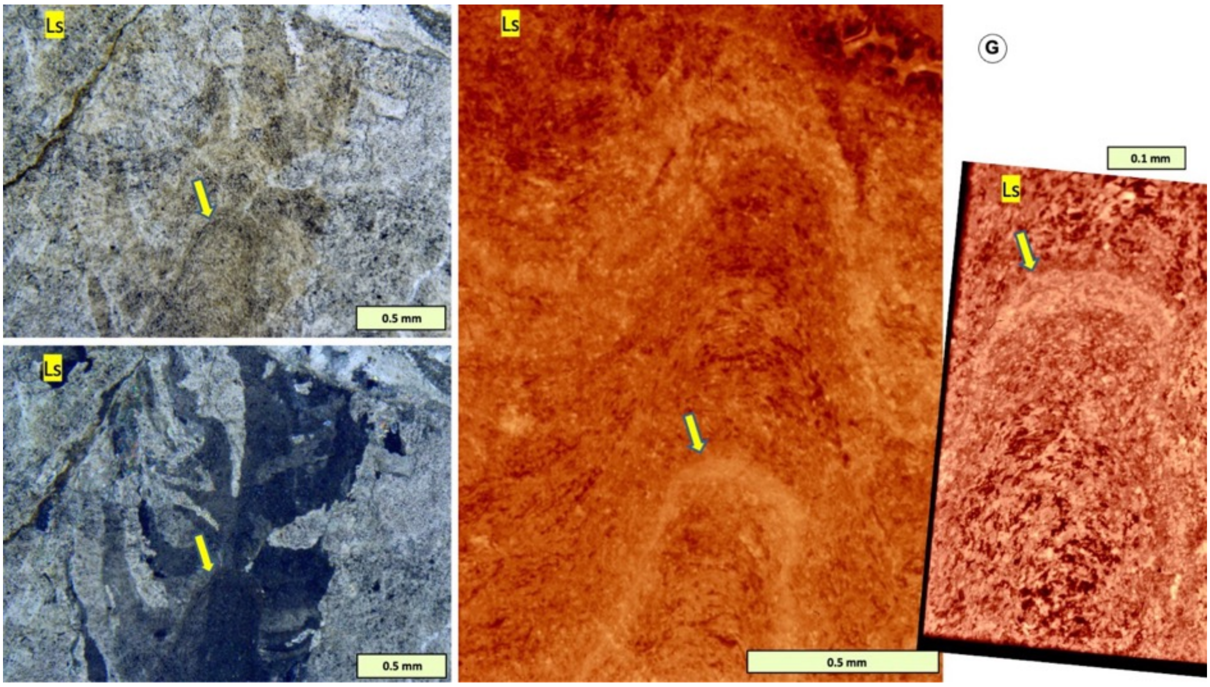


Fig. 6.2G. Repeat of previous pictures but adds a CL image (note yellow arrows are matching points). Key to this is that the CL layering matches the PPL layering but is not influenced by the FRIC overprinting in XPL. Right image shows enlargement of CL, with more detail of the layering revealed as a coarsely crystalline vaguely layered mass curving around in the image. File: 9-07-Case02-2c1-2.48-LsPt-VS-FineDetails-CL-Rexd

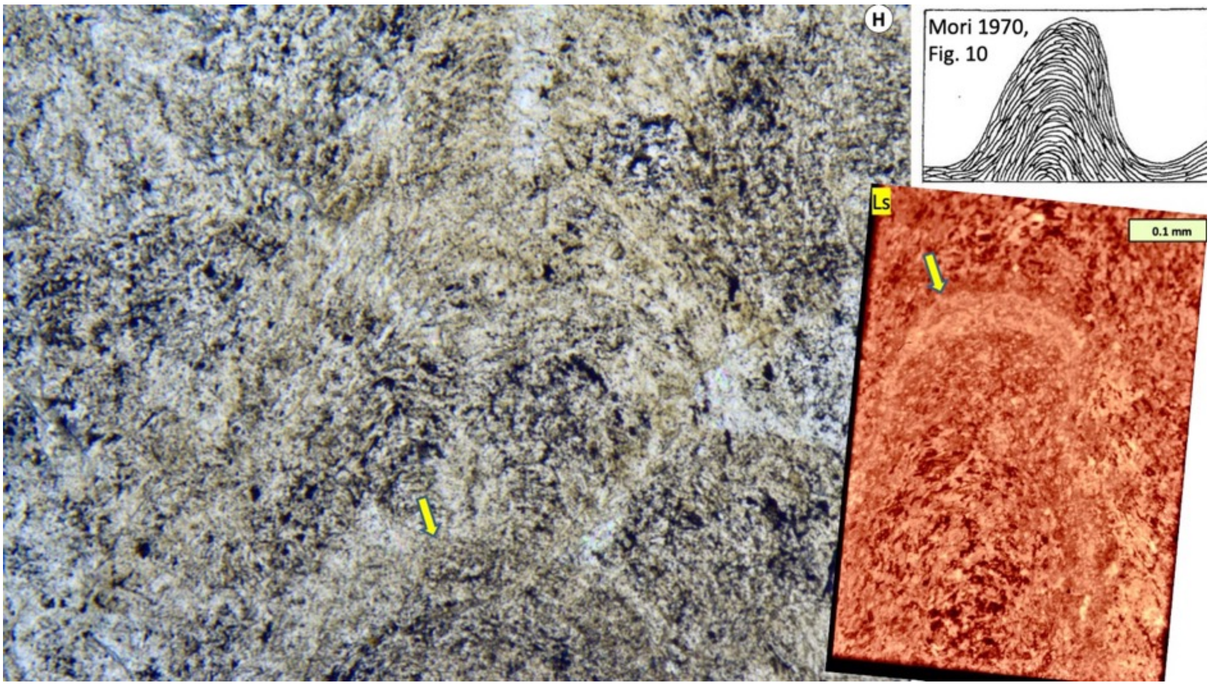


Fig. 6.2H. Enlargment of previous figure, showing the CL layering matching layering in PPL view of the main picture. There is a vague impression of stacked overlapping plates as in Mori's (1970) drawing upper right, although this fabric is not really clear on the PPL picture; neither is the CL fully representative of Mori's drawing. My interpretation is that Mori's drawing is rather simplistic and that the structure of the *Ls* skeleton is really made of masses of elongate irregular plates aligned to form wavy structure. File: 9-08-Case02-2c1-2.48-LsPt-VS-FineDetails-CL-Rexd

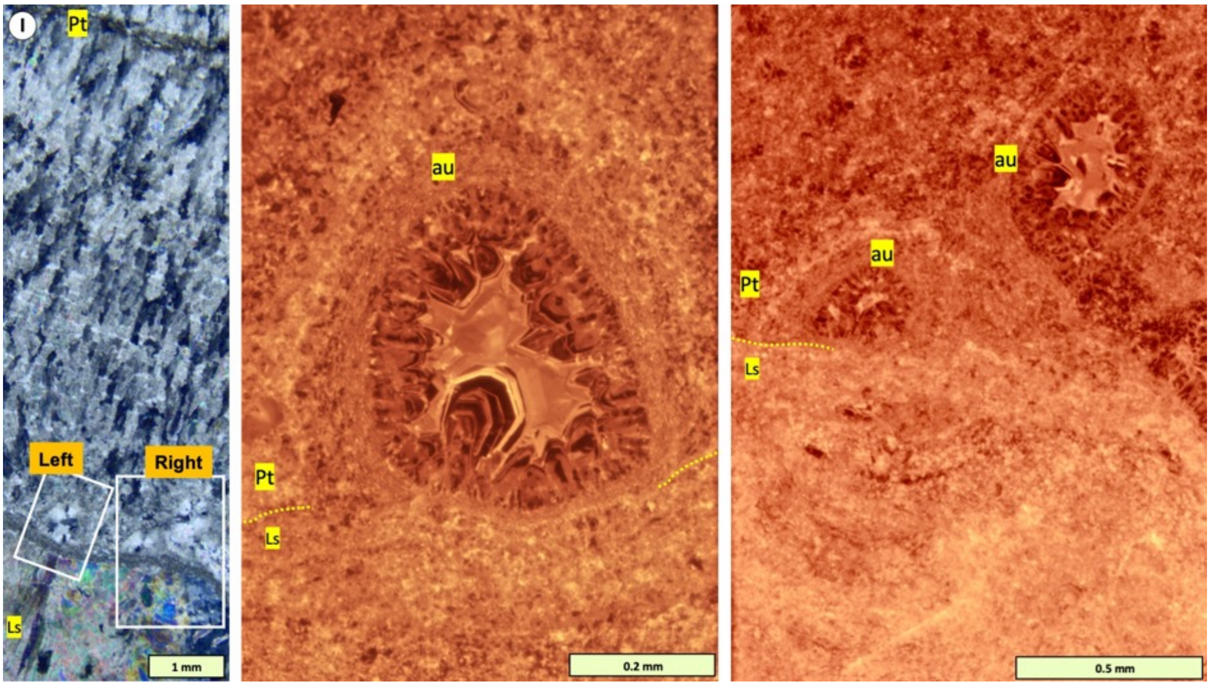


Fig. 6.2I. Left image is XPL view of contact area between *Ls* and *Pt,* showing very nice FRIC in *Pt* that contrasts the FRIC of *Ls.* The two CL photos focus on the encrusting auloporids (au), showing their laminated structure and tight cementation onto the top surface of the *Ls.* File: 9-09-Case02-2c1-2.48-LsPt-VS-FineDetails-CL-Rexd

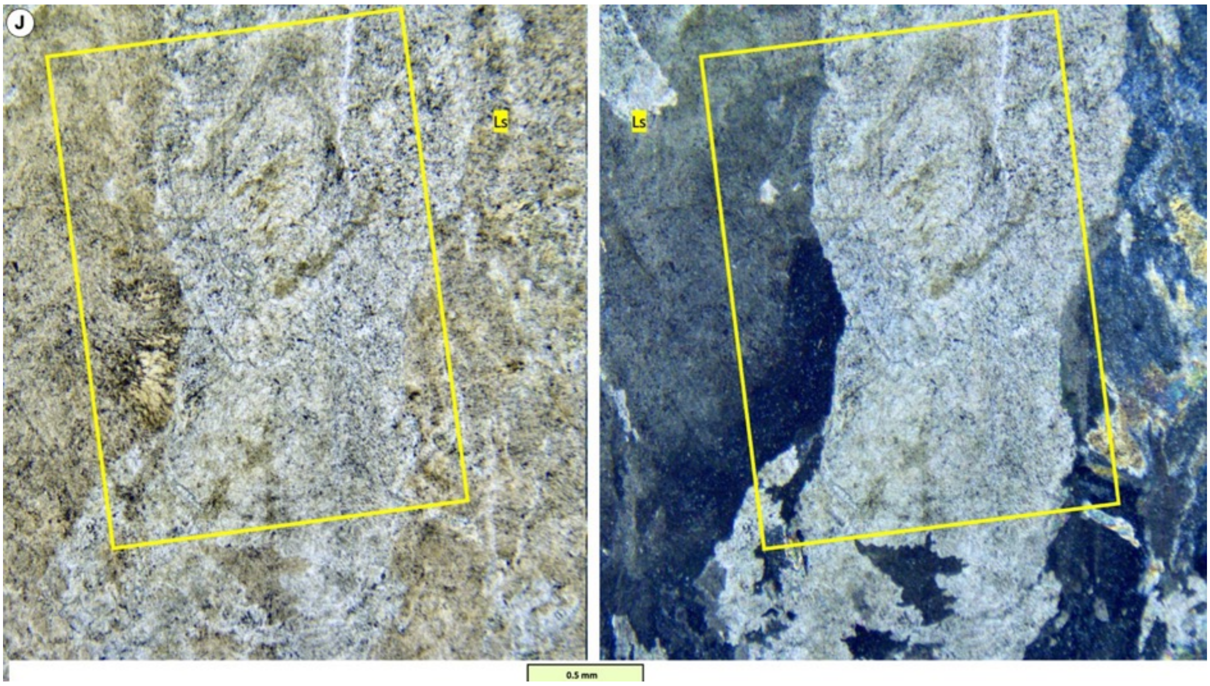


Fig. 6.2J. VS matched PPL and XPL sections showing poor evidence of laminations, but interestingly an area of slightly more prominent yellow-coloured fabric in lower left part of yellow box. In XPL this area is in optical continuity with surrounding calcite, and in this photo it is in extinction and not visible. Compare with CL photo in next figure. File: 9-10-Case02-2c1-2.48-LsPt-VS-FineDetails-CL-Rexd

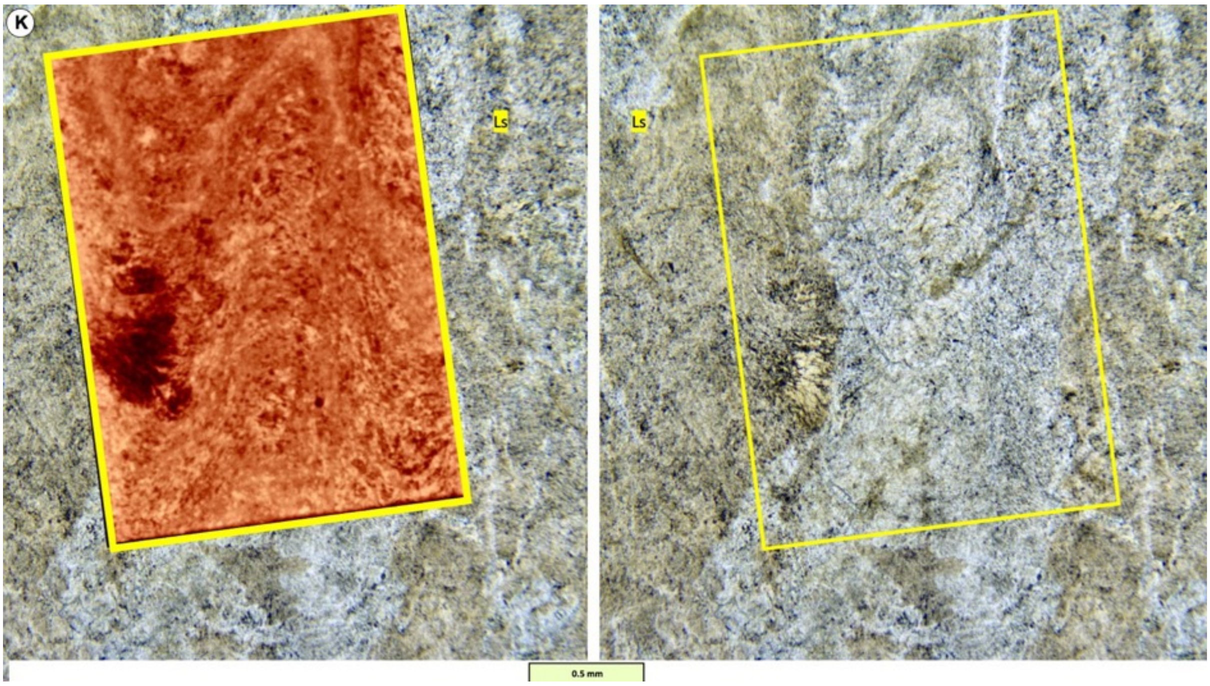


Fig. 6.2K. Same area as previous figure, in PPL on right, and CL on left. The vague laminations seen in PPL are prominent in CL, particularly down the middle of the yellow box. Note the area of more strong colour in PPL is non-luminescent. This difference in CL is interpreted to indicate an area of alteration that occurred before the FRIC diagenesis seen in XPL. Other thin sections shown later display similar areas of strong colour that are also overprinted by FRIC in XPL, but no other CL images are currently available to investigate any variations. This small area of stronger colour in the PPL view is a small area of the "vaguely-fibrous calcite" early diagenetic change that is present in some samples of *Ls.* The dark CL in the area of the vaguely-fibrous calcite may indicate early diagenesis in the oxygenated zone in shallow burial. More on this in later figures. File: 9-11-Case02-2c1-2.48-LsPt-VS-FineDetails-CL-Rexd

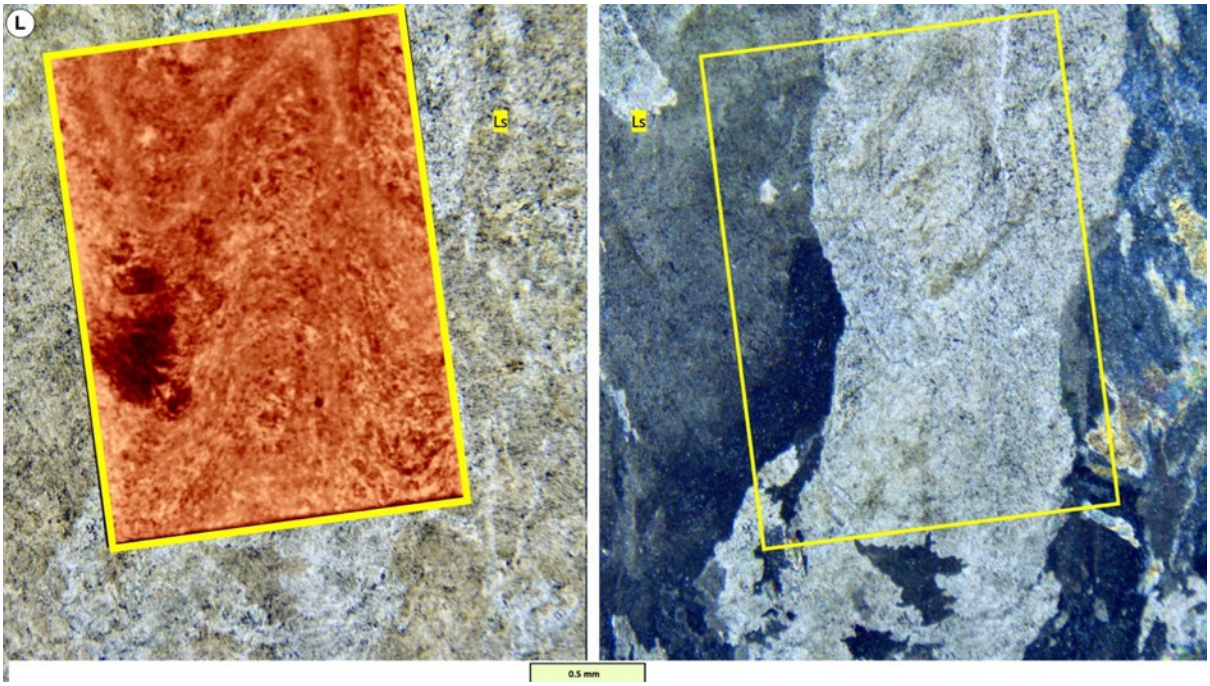


Fig. 6.2L. Comparison of CL with XPL. File: 9-12-Case02-2c1-2.48-LsPt-VS-FineDetails-CL-Rexd

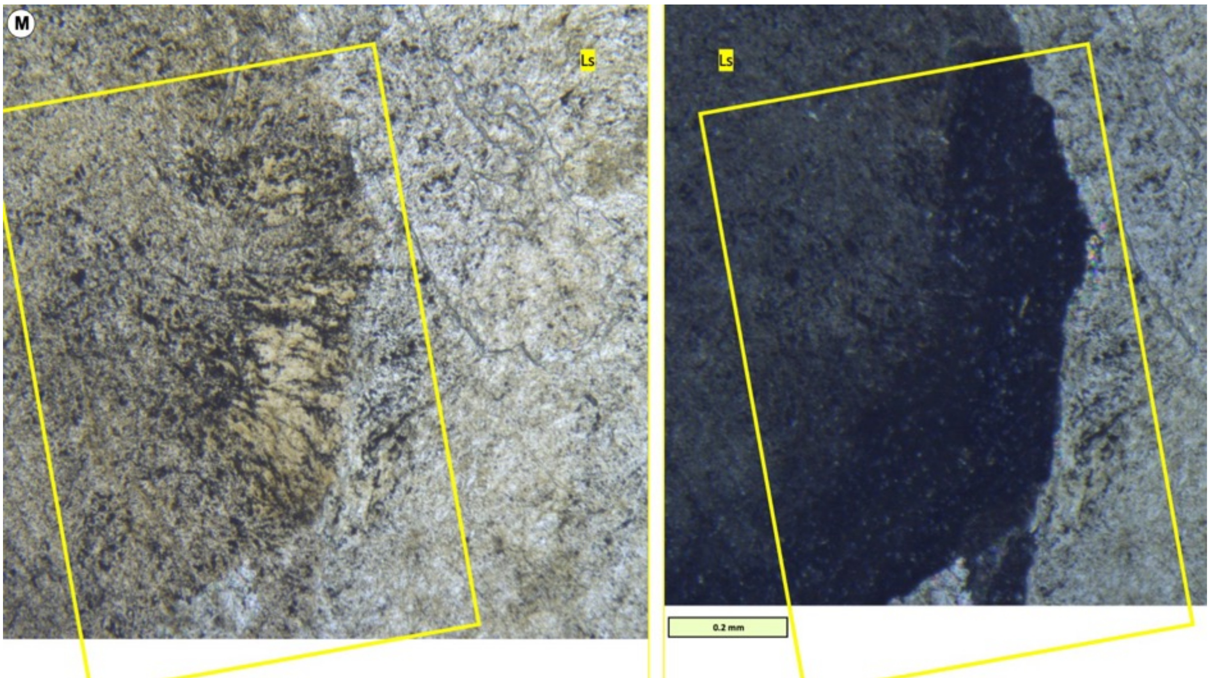


Fig. 6.2M. Enlargement of area of stronger colour in PPL (left) with XPL (right). File: 9-13-Case02-2c1-2.48-LsPt-VS-FineDetails-CL-Rexd

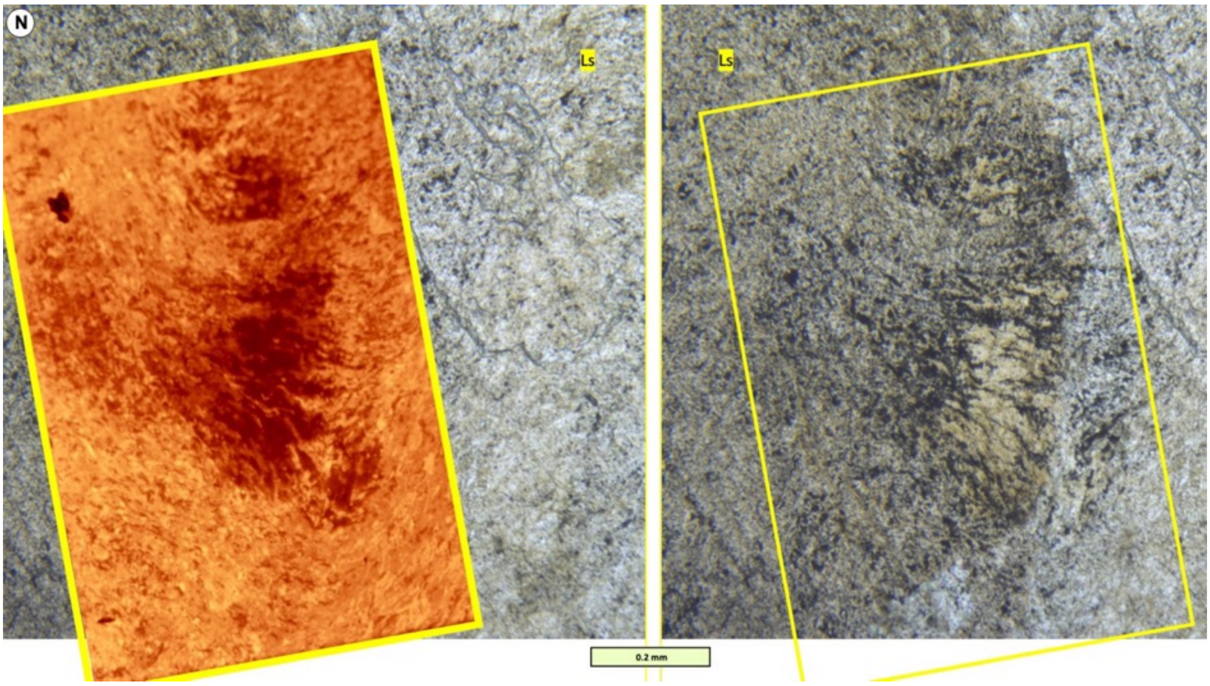


Fig. 6.2N. Enlargement of previous figures showing detail of the stronger colour area of the vaguely-fibrous calcite that represents earliest diagenesis in *Ls* in PPL with the overlain CL image. File: 9-14-Case02-2c1-2.48-LsPt-VS-FineDetails-CL-Rexd

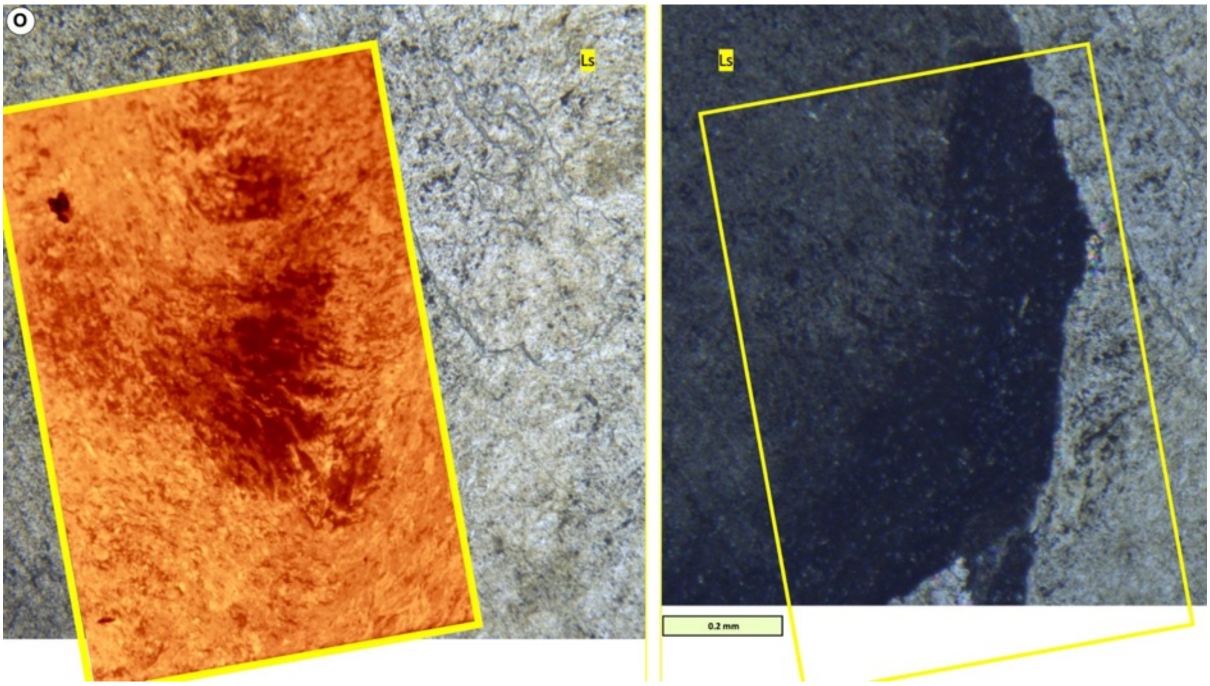


Fig. 6.2O. As previous figure, matching CL and XPL areas, showing the area of stronger colour if vaguely-fibrous calcite is not discernible in XPL, despite its strong difference in CL image. The nature of this stronger colour area is not understood but from this image it is interpreted to be a very early diagenetic change that is overprinted by the later-occurring FRIC. More images of this occur in later figures which show it to occupy significant parts of thin sections of *Ls.* File: 9-15-Case02-2c1-2.48-LsPt-VS-FineDetails-CL-Rexd

6.3. Case Study 3: 2c1-3.26

From Kuppen 3, in lower part of biostrome. This sample shows evidence of physical trauma prior to diagenesis.

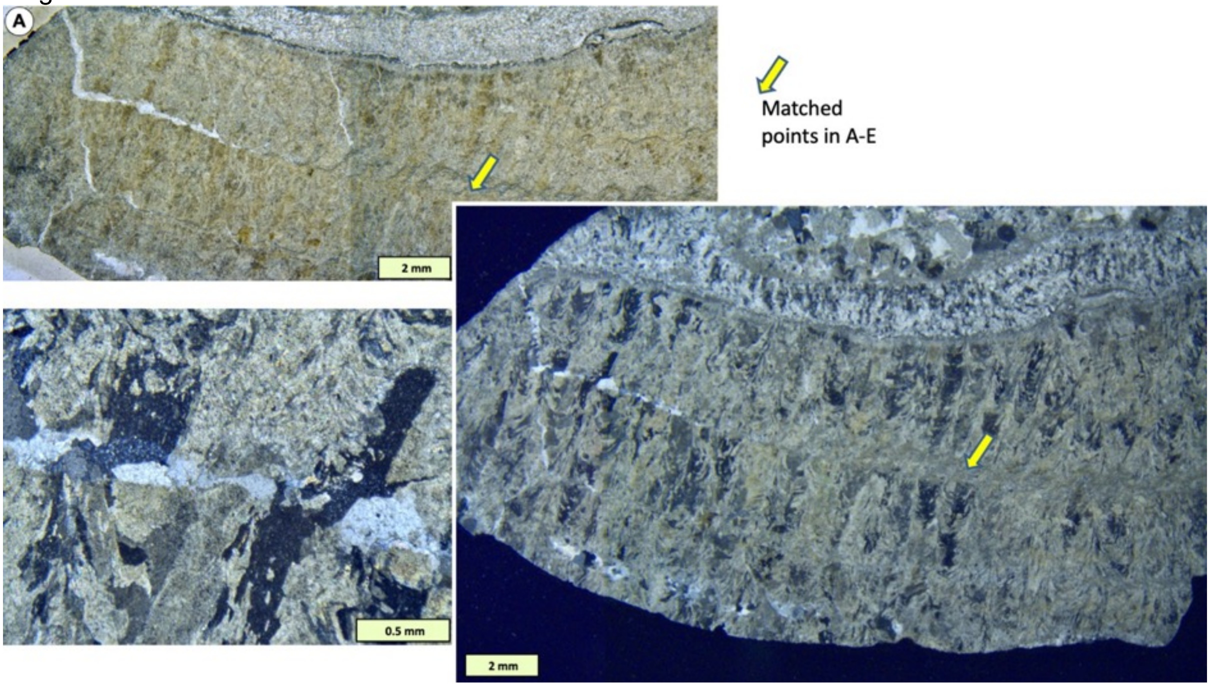


Fig. 6.3A. VS of *Lophiostroma schmidtii* (*Ls*): **Upper Right:** PPL; **Lower photos:** XPL. **Bottom left:** the XPL view shows a fracture filled with sparite that is in optical continuity with the stromatoporoid's diagenetic FRIC; this indicates the fracture occurred before the diagenesis, so was an early fracture in the skeleton. **Bottom right:** shows the apparent columnar structure in XPL comprises crystals that terminate at layers, but more details in next figure. The fracture in lower left picture, that is an enlargement of left side of the two larger pictures, is parallel to the growth interruption surface. Yellow arrow shows matched points. File: 10-1-Case03-2c1-3.26-Ls-CrackCementAndShearZone

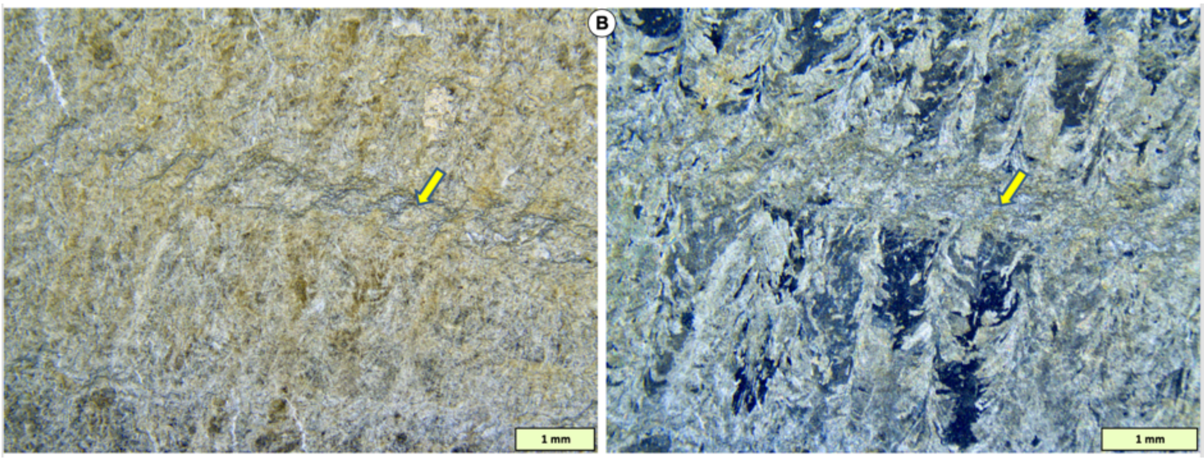


Fig. 6.3B. Enlargement of central part of Fig. 3A Lower Left, showing the growth interruption level is actually a zone that possesses en-echelon lines along the zone. The XPL view shows a mish-mash of diagenetic calcite coinciding with the en-echelon lines. This is left-lateral shear as viewed on these images, but because it is a VS, the upper side has moved to left in comparison with lower side, thus is the action of a thrust. See further enlargements in next Figure. File: 10-2-Case03-2c1-3.26-Ls-CrackCementAndShearZone

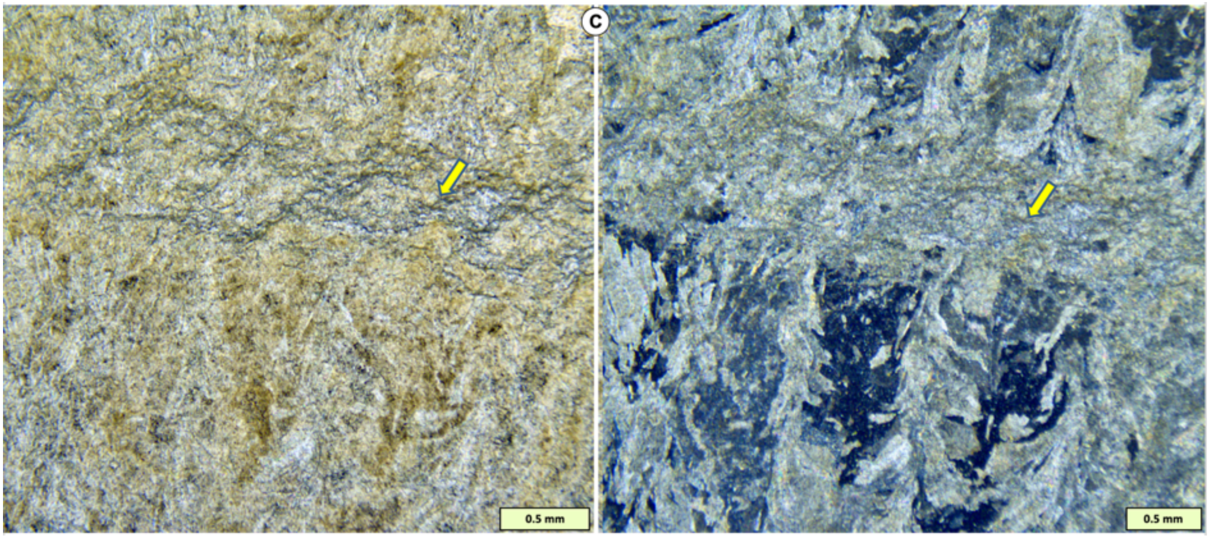


Fig. 6.3C. Details of en-echelon lines in PPL (left) coinciding with crushed mass of XPL crystals (matched yellow arrows). The en-echelon lines also appear as seams with dark stringers of likely clays, the process seems to be associated with pressure solution. File: 10-3-Case03-2c1-3.26-Ls-CrackCementAndShearZone

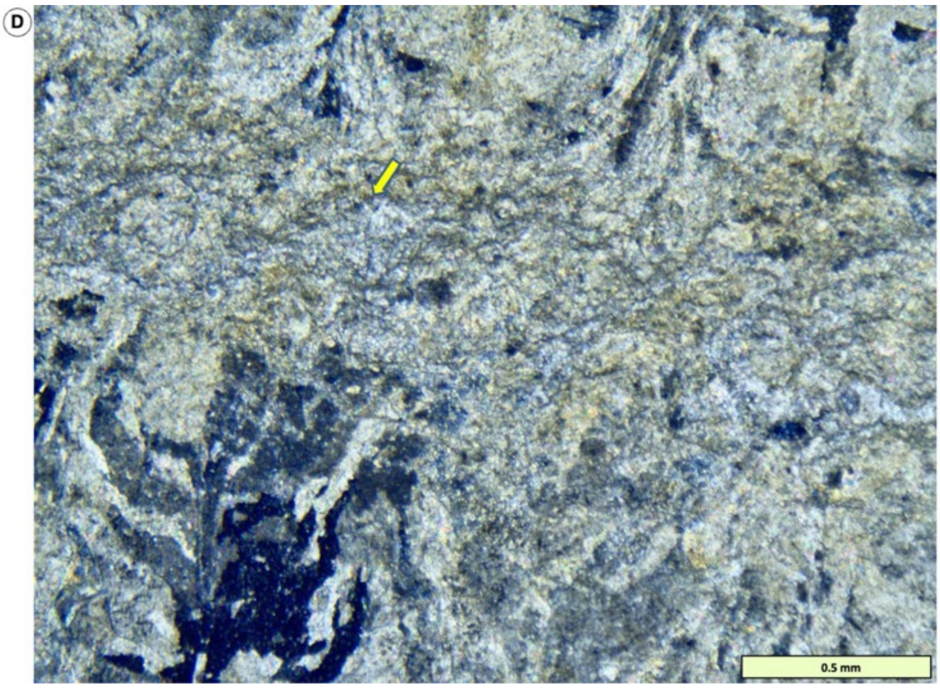


Fig. 6.3D. Detail of sheared zone, showing fine stringers of what may be pressure solution seams as part of a crush zone – see even greater enlargement in next figure. This looks like the growth interruption in Fig. 6.3A was a surface of weakness. File: 10-4-Case03-2c1-3.26-Ls-CrackCementAndShearZone

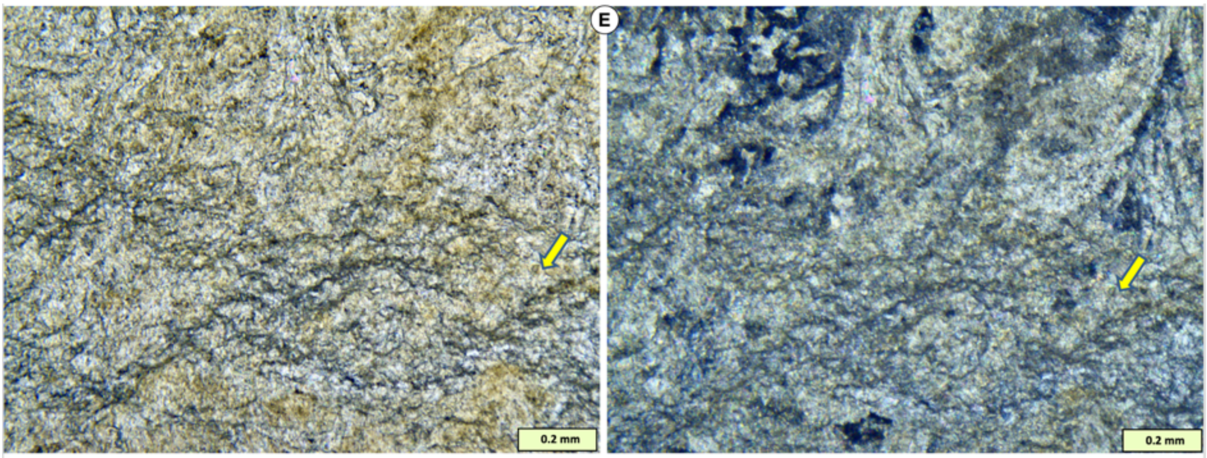


Fig. 6.3E. Fine detail of disturbance zone with stringers of dark material that may be clay. In XPL view the structure looks crushed into a mash of skeletal material. File: 10-5-Case03-2c1-3.26-Ls-CrackCementAndShearZone

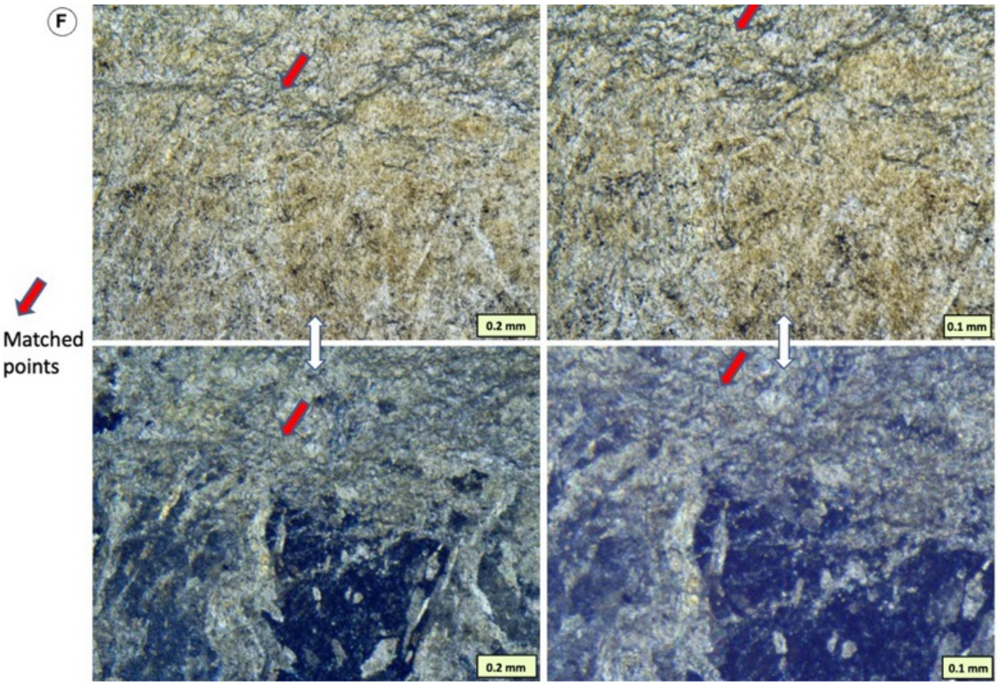


Fig. 6.3F. These images show the sharp boundary between the coherent diagenetic crystals in extinction (lower half) and the crush zone of the failed growth interruption level (upper half). File: 10-6-Case03-2c1-3.26-Ls-CrackCementAndShearZone

Summary of Case Study 4 - 2c1-3.26

This is the only specimen in the sample suite that shows what is interpreted here as a shear zone passing horizontally through the sample. The question is how did this happen? If it was in burial by tectonic micro-movements then why are not all the other samples affected? Also Gotland sits in the centre of the Baltic Craton and is a very stable region; there are few faults on Gotland, for comparison. The most likely cause is a physical shock to the specimen that is easily explained by storm action known to have affected the biostrome, because of numerous layers of coarse grainstone debris that occur in the biostrome's stratigraphy. The diagenetic alteration of the stromatoporoid must have happened after the fracture formed (Fig. 6.3A) because the sparite in the fracture is in optical continuity with the altered stromatoporoid skeleton. So, in the absence of any other evidence, the current information points to an early fracture, probably on the sea bed, that mashed up the *Ls* stromatoporoid skeletal architecture along a weakness plane of a growth interruption surface; thus when diagenesis occurred the crushed zone lacked crystalline coherence to maintain the optical continuity of diagenetic change in the sample. HOWEVER, this is only one sample; in order to verify or deny this interpretation more samples are needed to test these ideas – such is the nature of science!!!!

6.4. Case Study 4: 2c7-8.76

This case shows *Ls* in VS and demonstrates two aspects:

1) a peculiar overprinting of the skeletal structure of *Ls* with a form of vaguely fibrous $CaCO_3$ that is itself overprinted by the recrystallisation so that in XPL the fibrous calcite is in optical continuity with the adjacent skeletal material that is not within the fibrous calcite area; thus the fibrous calcite is an early stage of recrystallisation that occurred before the FRIC developed. Note that its CL views show the vaguely-fibrous calcite is non-luminescent, and thus can be explained as very early, in shallow burial but in the oxygenated zone. No other stromatoporoids in the same or other outcrops containing *Ls* show this early stage alteration. Likewise in outcrops where *Ls* is not present, this early stage is not observed; thus it seems to be a peculiarity of *Ls*; weird, needs more investigation.
2) Primary spaces within the *Ls* structure containing calcite cement that is in optical continuity with the FRIC overprinting of the *Ls* structure. This is interpreted to indicate those spaces were open at the time that FRIC developed and thus the spaces were filled with calcite that grew in continuity with the FRIC recrystallisation of the *Ls* structure. This is in contrast to other cases of cement-filled spaces, within *Ls* and other stromatoporoids, where the cement fill is not in continuity with the FRIC as is interpreted to have been an earlier cement-filling of the cavities, so that the FRIC was not able to overprint it when diagenesis occurred. Thus there are two cases of cement infills of primary cavities; one that is in optical continuity with the stromatoporoid skeleton indicating the caviy was open when diagenesis happened; and the other where there is no optical continuity and so the cavity was already occupied by cement when the diagenesis of the stromatoporoid occurred. There is a fuller discussion of this aspect of stromatoporoid diagenesis in Kershaw et al. (2021 – Facies paper on diagenesis of stromatoporoids).

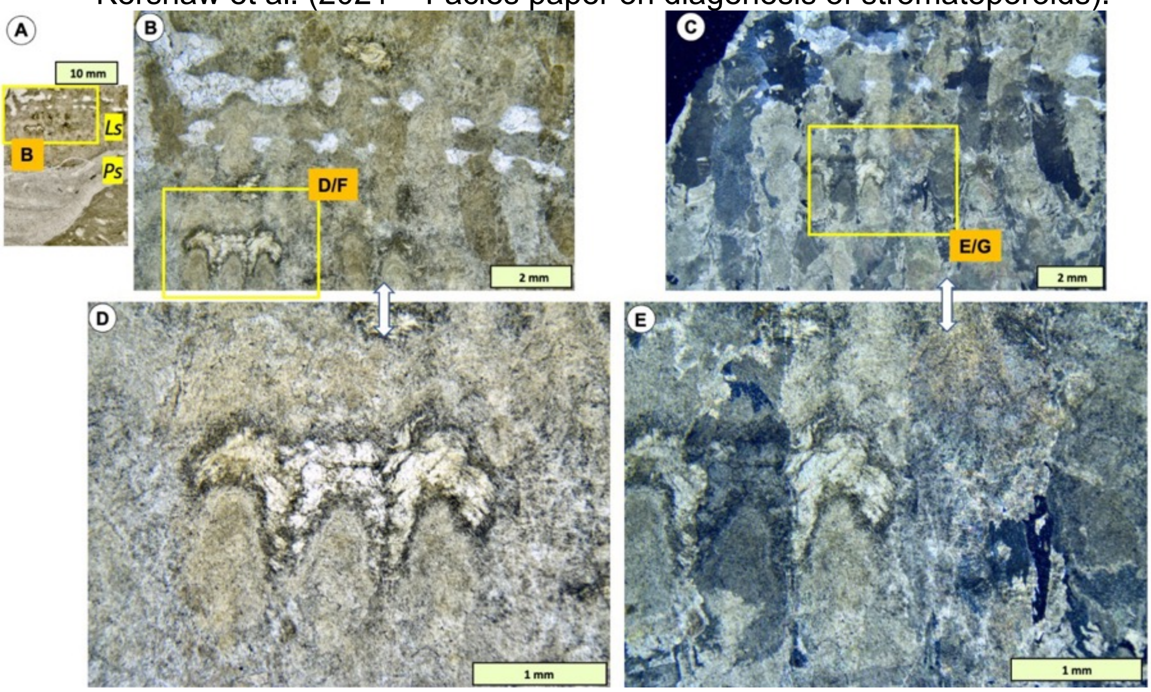


Fig. 6.4-1A-E. A. VS whole thin section view showing *Ls* encrusting *Ps*. Yellow box shows location of B. **B-C.** PPL (B) and XPL (C) enlargements showing the general view of presence of early vaguely-fibrous diagenetic calcite (in the shape of a two-headed horse !!!) overprinted by FRIC in continuity with the surrounding *Ls* skeleton. **D-E.** Enlargements of yellow boxes in B & C respectively, demonstrating more detail of this early vaguely-fibrous calcite cement overprint on the *Ls* structure. File: 11-1-Case04-2c7-8.76-Sed-Ps-Ls-VS-LsCements.

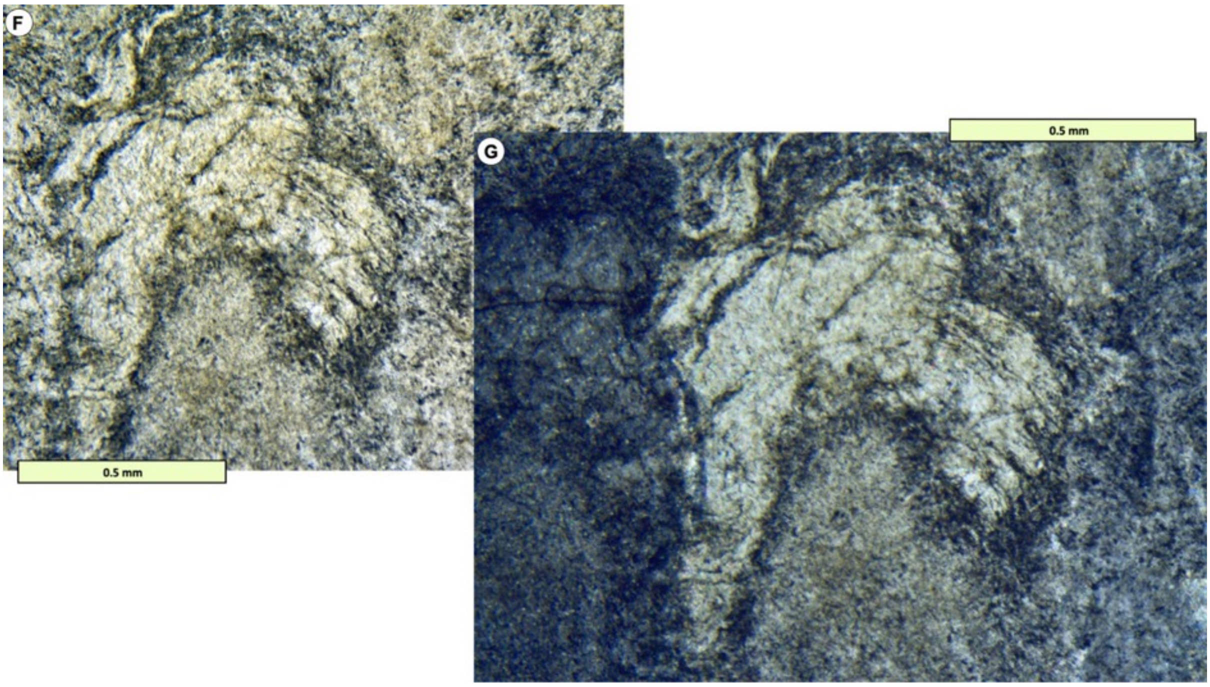


Fig. 6.4-1F-G. PPL and XPL enlargements of D & E showing detail of overprinting of the *Ls* structure by vaguely-fibrous calcite prior to FRIC alteration that overprints the structure. File: 11-2-Case04-2c7-8.76-Sed-Ps-Ls-VS-LsCements

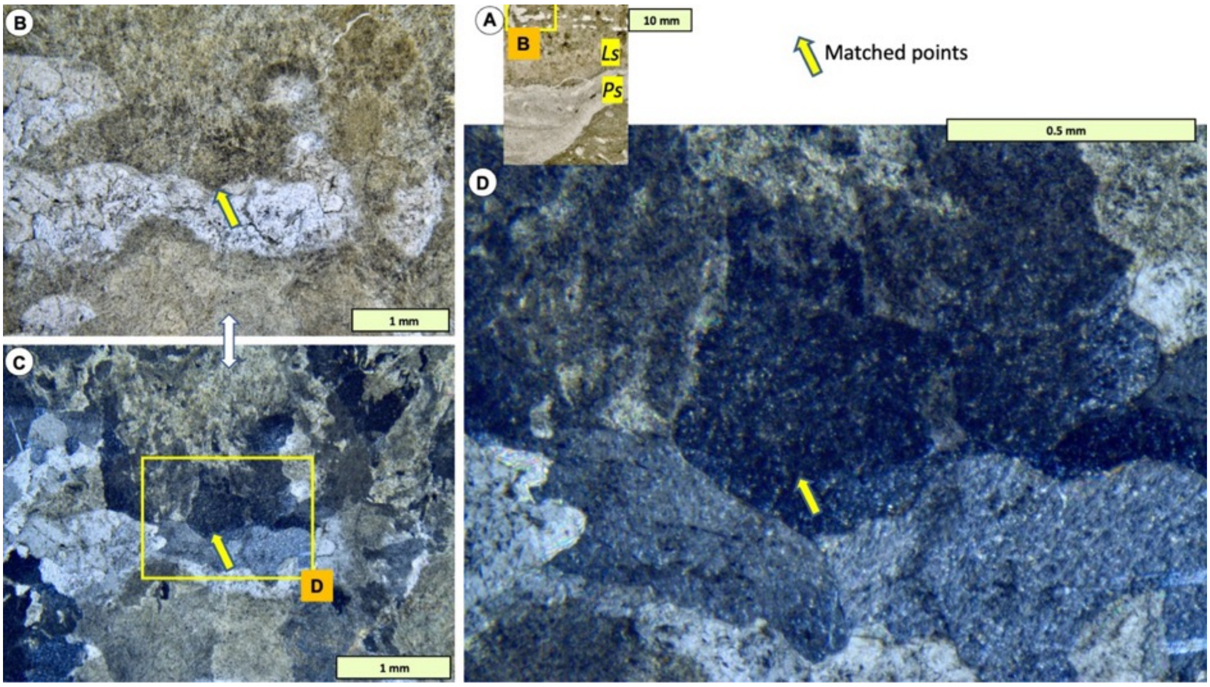


Fig. 6.4-2A-D. PPL (A & B) and XPL (C & D) showing primary cavities in VS of structure of *Ls*. The skeleton is overprinted by FRIC that is in optical continuity with the cement in the cavities. This is interpreted to indicate the spaces were open when the overprinting diagenesis occurred. If the space had been filled with cement prior to recrystallisation of the *Ls*, then it would be expected that the overprinting diagenetic calcite would stop sharply at the contact with the cavities. These pictures present evidence of early diagenetic alteration of the *Ls*, if the cavity space was still open. Such is consistent with all other stromatoporoids, and is part of the evidence that *Ls* is best considered to be included within the stromatoporoid group. File: 11-3-Case04-2c7-8.76-Sed-Ps-Ls-VS-LsCements

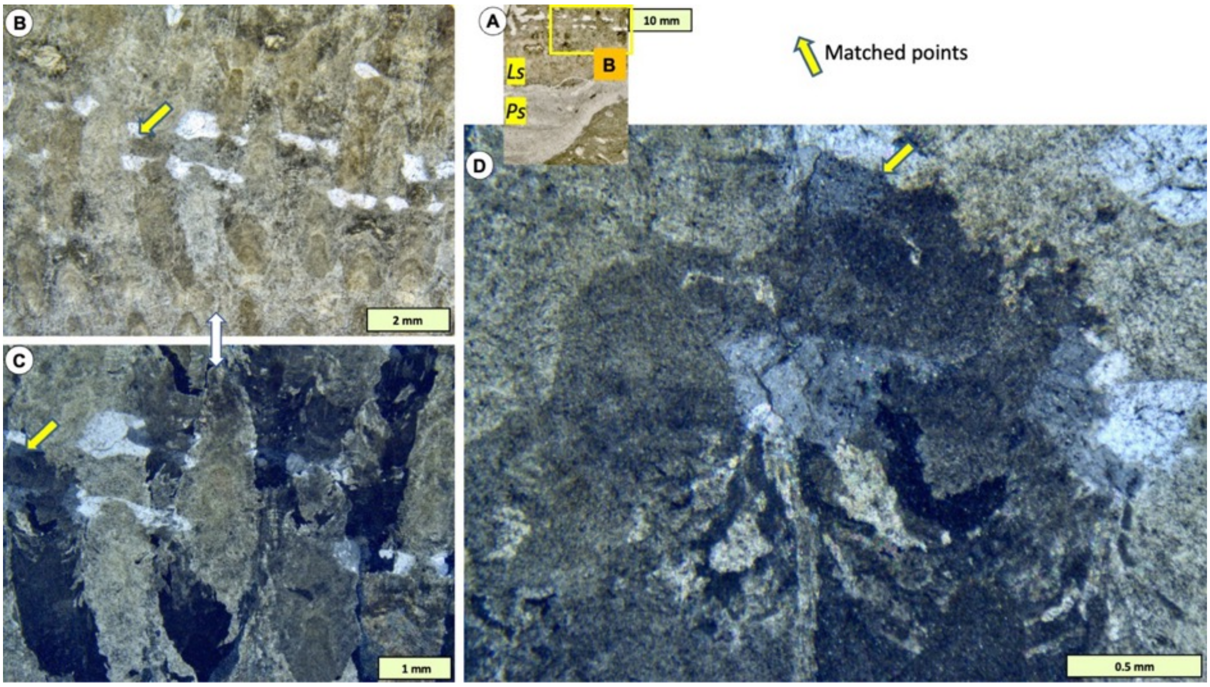


Fig. 6.4-3A-D. Similar to the previous figure, showing more evidence of the overprinting diagenesis of the stromatoporoid that passes into the cavity space, and thus indicates early diagenetic alteration of the stromatoporoid. File: 11-4-Case04-2c7-8.76-Sed-Ps-Ls-VS-LsCements

6.5. Case Study 5: 2c6-9.63

This nice sample shows the highly diverse features of *Lophiostroma schmidtii* (*Ls*) structure in XPL. The images below are interpreted to indicate the range of diagenetic alteration from its early stage of small crystals modifying the original structure, followed by aggrading neomorphism to form larger crystals that end up as single large crystals abutting each other in competition for space within the skeleton.

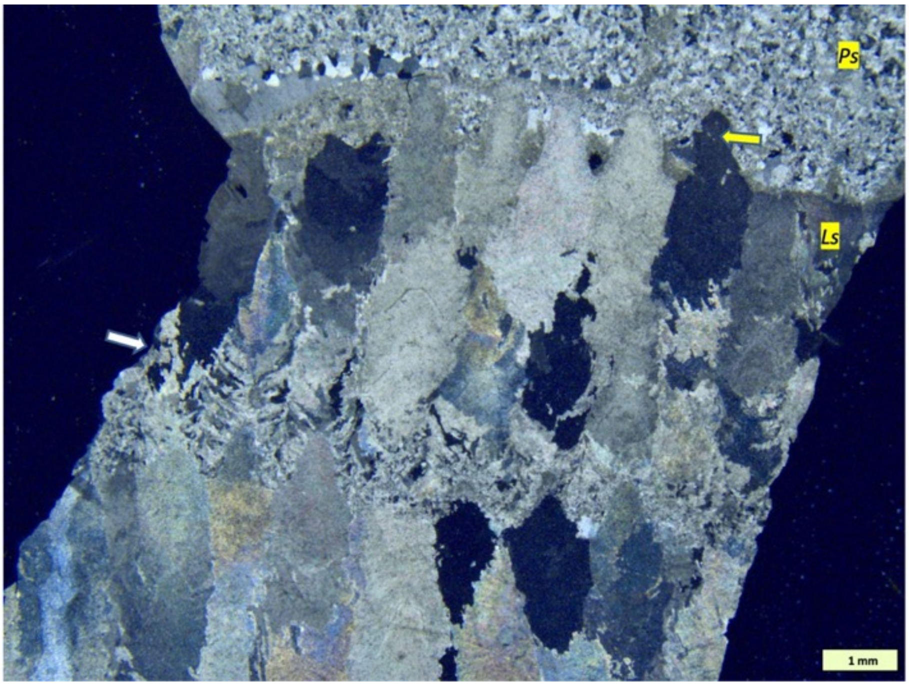


Fig. 6.5-1. VS XPL thin section through upper part of a sample of *Lophiostroma schmidtii* showing variation of diagenetic fabric including the interpreted aggrading neomorphic amalgamation of structure into vertically-orientated large crystals. Lamination within the skeleton is shown by a zone of smaller crystals (level of white arrow). Below that level, papillae are visible in various stages of extinction in XPL, marking the top of the lower layer. The upper layer begins with the zone of smaller crystals which show upward-curving character of radiating crystal fans (recognisable from the TS views below), passing up into larger crystals. This zone of small crystals varies from left to right, showing prominent upcurving on the left, grading into less clearly visible upcurving crystals to the right. The top of the upper layer marked by a yellow arrow, shows more papillae at the top of the specimen. Encrusting the top surface of the *Ls* is another stromatoporoid, *Plectostroma scaniense* (*Ps*) (although it is not clearly identifiable from this particular photo, it is known from the thin section in PPL. Overall, this specimen shows contrast of diagenetic fabric between *Ls* and *Ps,* and shows variation of diagenetic character within *Ls* that plays a part in understanding the diagenetic process in *Ls*. More details in subsequent figures. File: 12-1-Case05-2c6-9.63-Ls-VSTS-ii

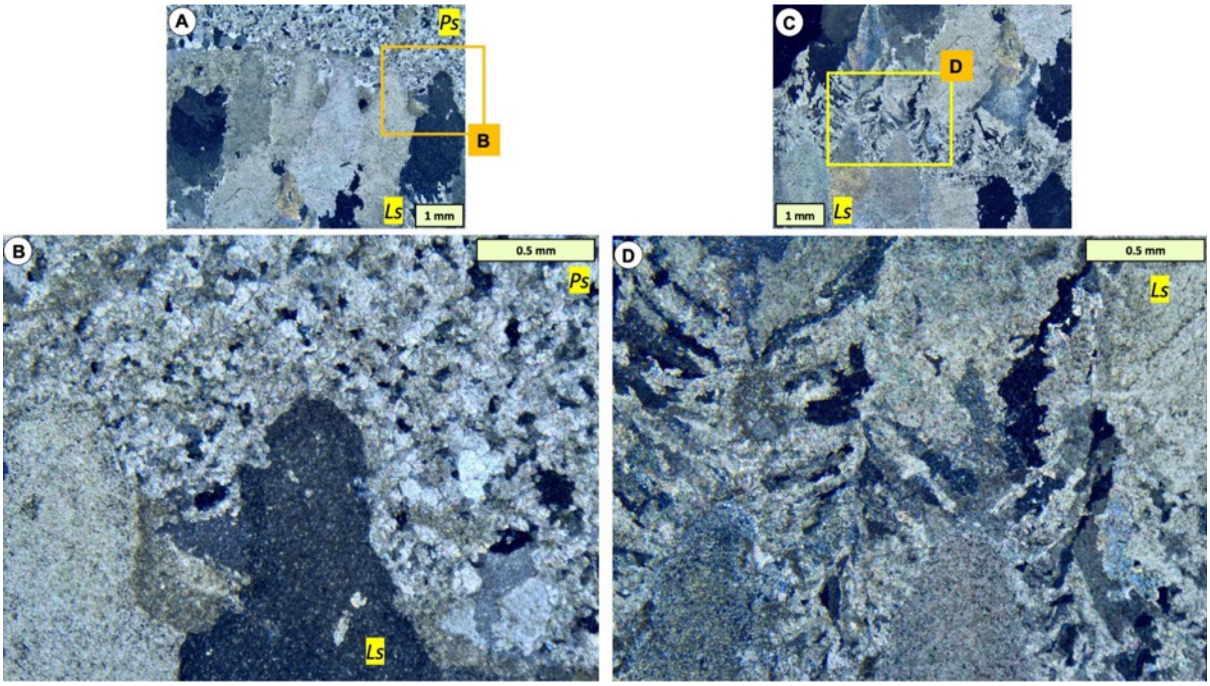


Fig. 6.5-2. A-B. Enlargements of top of *Ls*, in contact with overlying encrusting *Ps*, showing the diagenetic crystals of each taxon do not pass into the other, characteristic of stromatoporoids. This photo also shows the single-crystal nature of the papillae in the top of the *Ls*, but with some inclusions of small crystals, that are considered remnants of the earlier complexity of the diagenetic fabric, more of which is shown in C & D. **C-D.** Enlargement of the growth interruption level between the lower and upper layers of the *Ls* sample, showing the top of the lower layer made of single crystals is overgrown by a mass of small crystals at the base of the upper layer growing on tops of papillae of the lower layer. Note how the small upcurving crystals grade upwards into a more amalgamated structure, so that at top left, the upcurving is within larger crystals and at top centre and top right the upcurving character has disappeared, instead there are large single crystals present. This changing character is interpreted as diagenetic evolution within the crystals, so that diagenesis began as thin upcurving masses of crystals, but these amalgamated by neomorphic reorganisation into larger crystals. Thus this sample shows the range of diagenetic change within *Ls*, from its early stage of small upcurving crystal fans to single crystal columns. Furthermore, between columns, there is compromise crystal reorganisation, resulting in single large columnar diagenetic crystals abutting each other. This arrangement is also seen in TS views of the same sample in the next two figures. Nevertheless, one feature is that the centres of all the papillae in both the top surface and central part of the specimen are made of single crystals, **even though** the crystals above are 3D crystal fans of small crystals. This characteristic is present in all the case study samples presented in this atlas; not clear why it is the case – perhaps it just happens that **all** the specimens illustrated show this and there may be other structures that will emerge if more samples are studied. File: 12-2-Case05-2c6-9.63-Ls-VSTS-ii

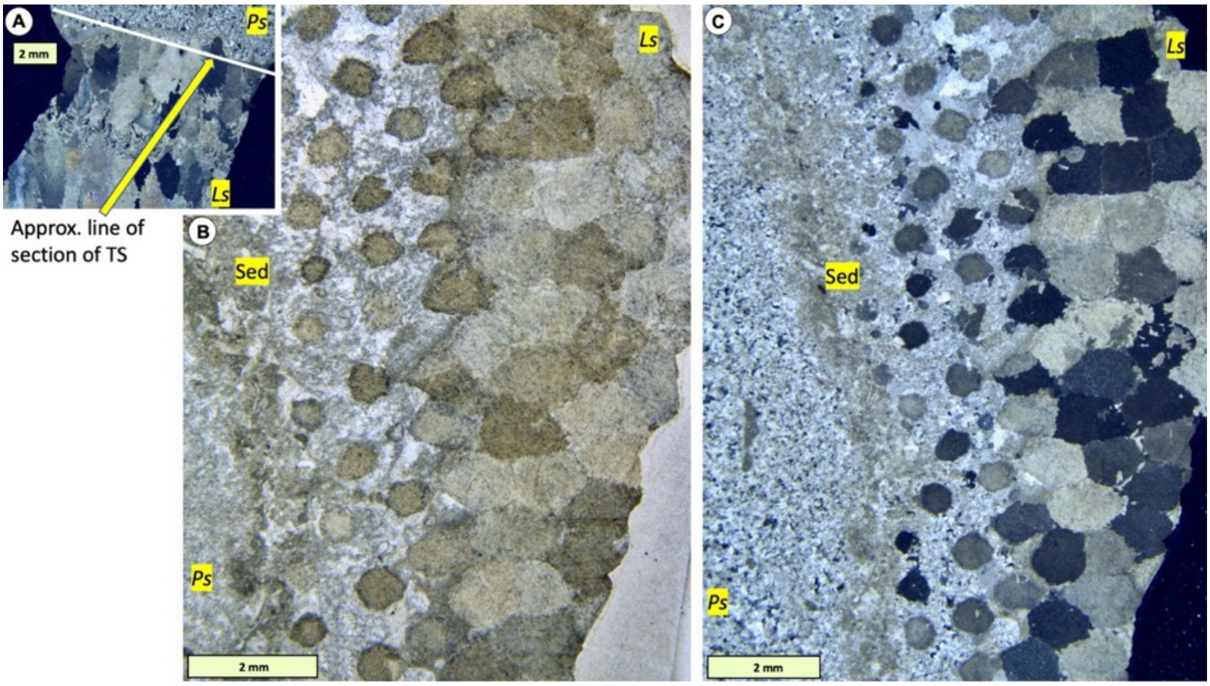


Fig. 6.5-3. TS in PPL (B) and XPL (A & C). These photos show the TS cuts through the top of the *Ls* covered by sediment, so the individual papillae are clearly shown in TS. The right-hand side of the PPL and XPL images show the tight abutting fit of adjacent calcite crystals that are cross sections through the vertically-orientated crystals seen in the VS views of photos above. File: 12-3-Case05-2c6-9.63-Ls-VSTS-ii

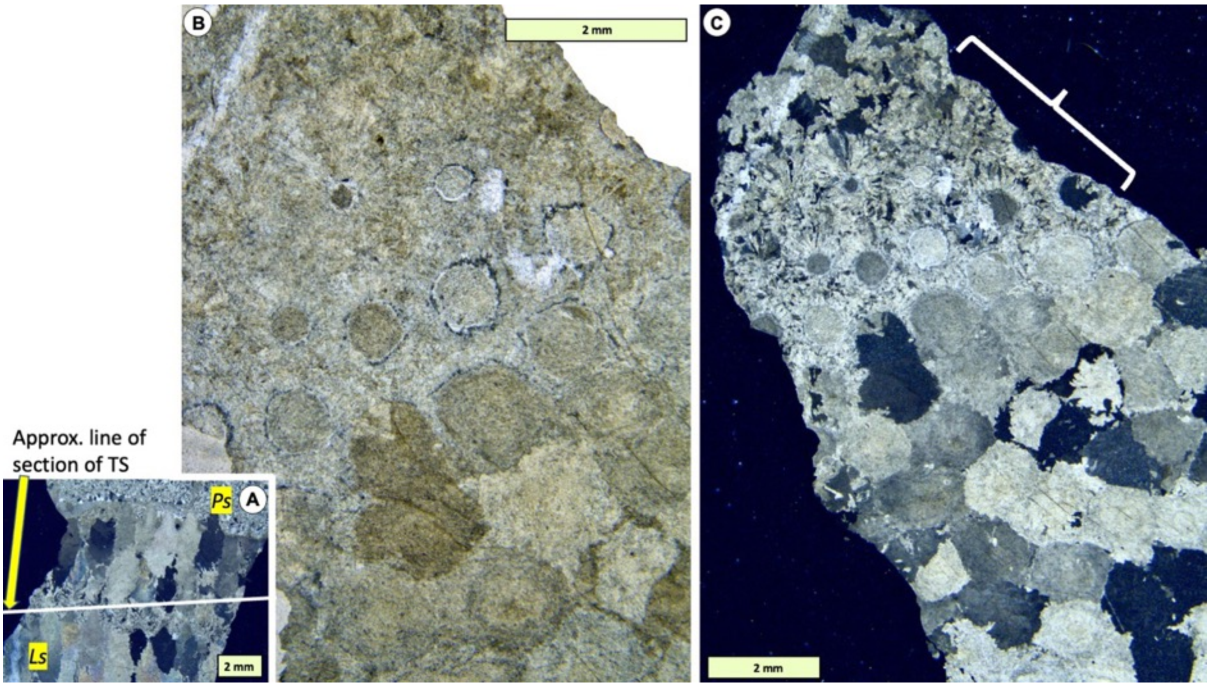


Fig. 6.5-4. Another TS through the same specimen, obliquely cutting the layer of small crystals seen in the VS views so that the section passes into the part of the structure of largely single crystals that are interpreted as having developed aggrading neomorphism, so that the crystals comprise a mixture of single large crystals and smaller crystals encased within the larger crystals. Thus a reasonable model is that the small crystals that comprised the 3D crystal fans gradually amalgamated into larger crystals via aggrading neomorphism, and this sample shows stages within this process. File: 12-4-Case05-2c6-9.63-Ls-VSTS-ii

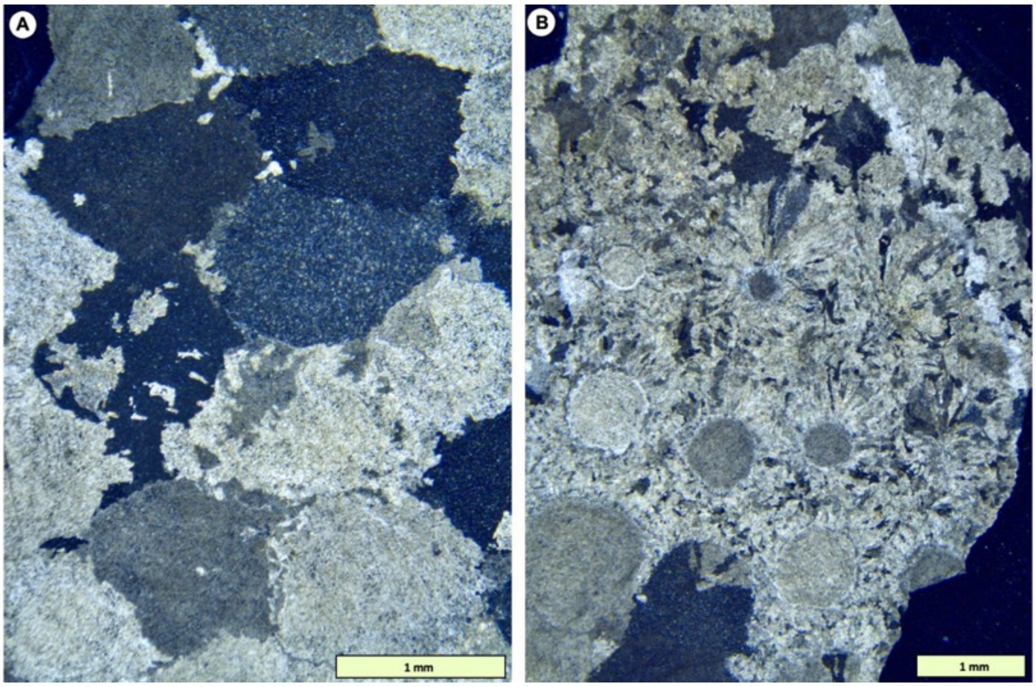


Fig. 6.5-5. Details of previous figures showing variations of crystal size in TS of *Ls*, interpreted here to indicate different stages of diagenetic alteration, starting with formation of crystal fans of small crystals that then become recrystallised into larger crystals by aggrading neomorphism, the final stage being a set of contiguous single crystals with compromise boundaries. File: 12-5-Case05-2c6-9.63-Ls-VSTS-ii

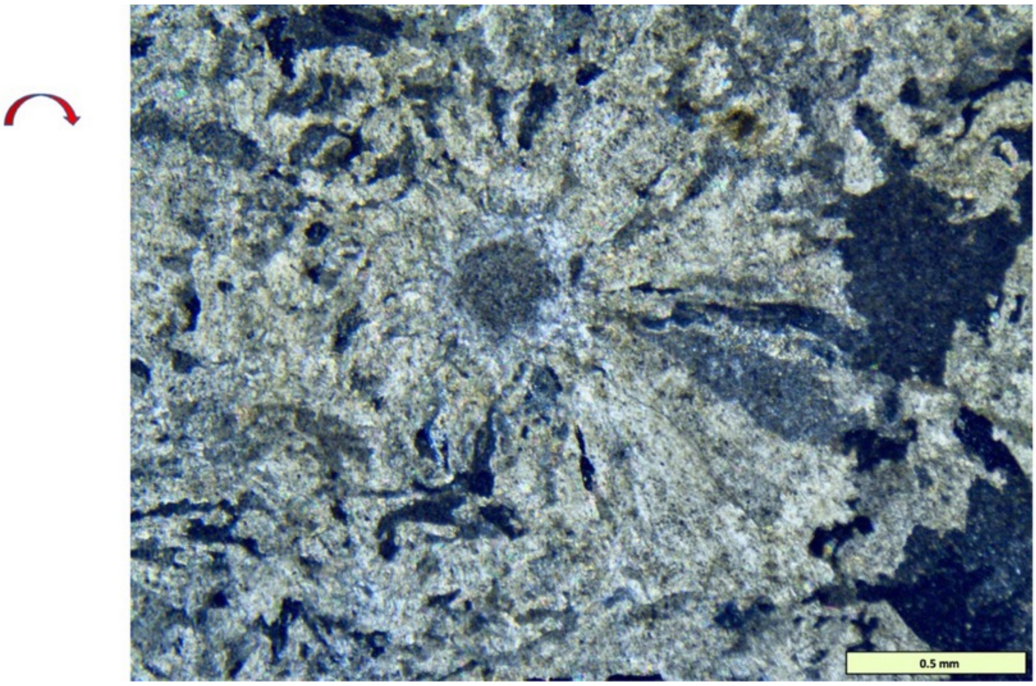


Fig. 6.5-6. Detail of central part of Fig. 6.5-5B (rotated 90 degrees) showing variation of crystal size as described in the caption of previous figure. File: 12-6-Case05-2c6-9.63-Ls-VSTS-ii

6.6. Case Study 6: KLoose47

This sample shows VS views of a sample of *Lophiostroma schmidtii* (*Ls*), encrusted by *Plectostroma scaniense* (*Ps*) that has encrusting corals within the *Ps*. The *Ls* shows a growth interruption surface with primary cavity space beneath the succeeding growth of *Ls*. The primary cavity space is filled with cement that is partly in optical continuity with the recrystallised *Ls* structure, but some of it is NOT in optical continuity and is thus evidence that at least part of this cavity space was filled with cement BEFORE the stromatoporoid diagenesis occurred, in contrast to other samples in this atlas that have cavities with cement that is fully in optical continuity with the recrystallised stromatoporoid adjacent to it. From this distinction it is possible to therefore identify different timings of infilling of cavities by calcite cement; this character is described in detail in Kershaw et al. (2021, Facies paper) and is part of the logic behind considering *Ls* as a member of the stromatoporoid group, rather than belonging to another group of organisms, despite its lack of the normal stromatoporoid structure.

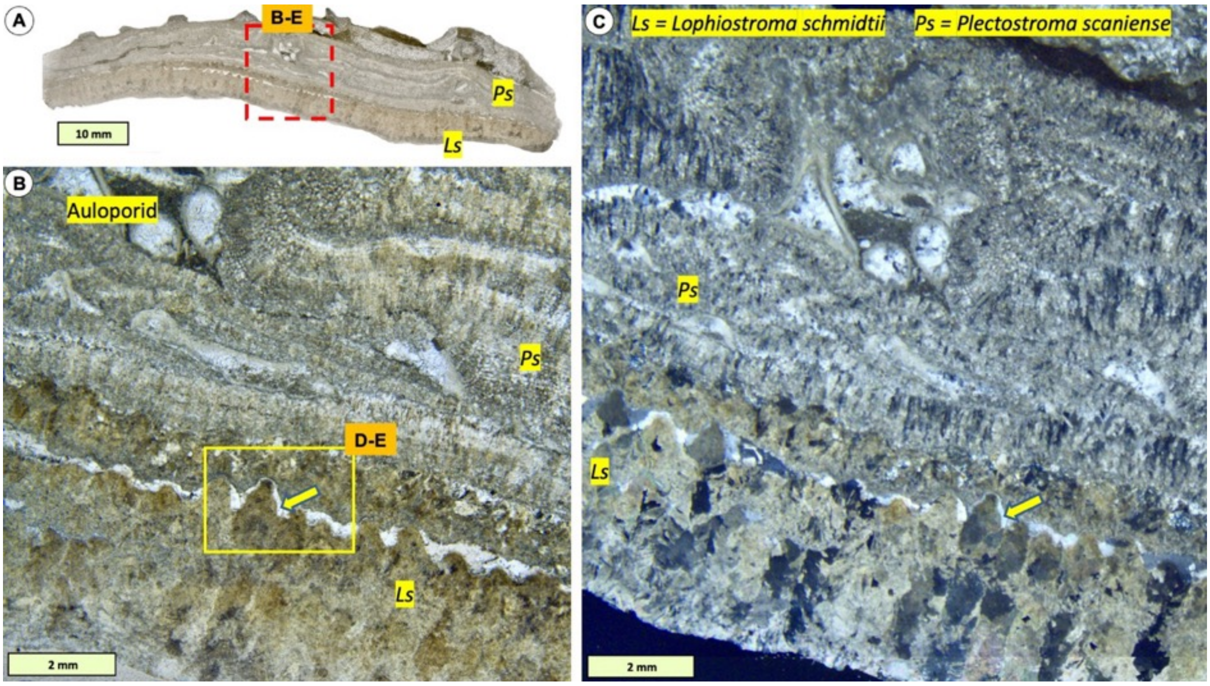


Fig. 6.6A-C. VS in PPL (B) and XPL (C), showing *Ls* at the base, with a growth interruption surface that has a primary cavity below the final layer of *Ls*, which is the focus of this case study (yellow box in B). Note the yellow arrows show a matched point, highlighted in next figure. Note the contrast in XPL structure between *Ls* and the encrusting *Ps*. File: 13-1-Case06-KLoose47-i

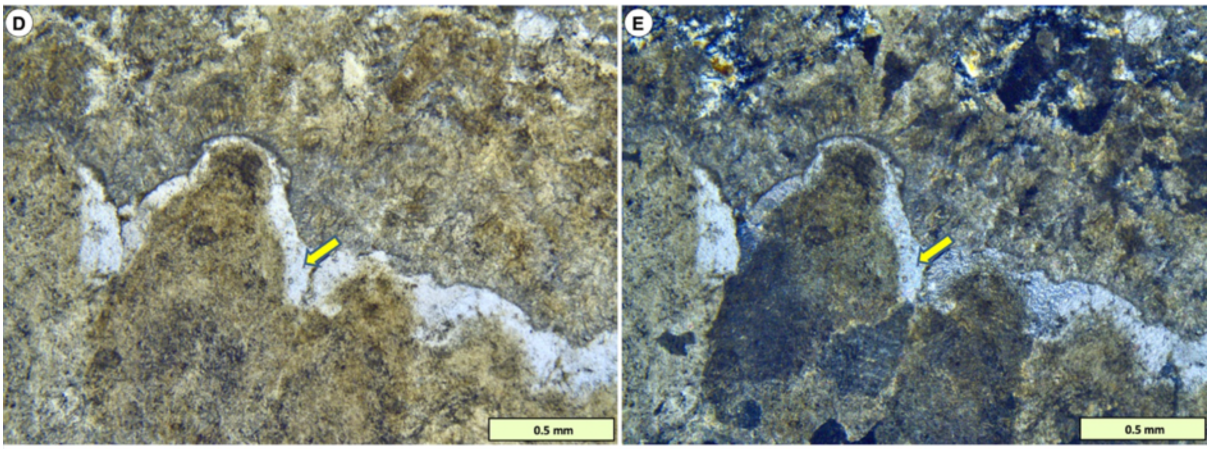


Fig. 6.6D-E. Enlargement of yellow box in B, showing cement in the primary cavity is not in optical continuity with the *Ls* skeletal structure. Yellow arrows are same matched points as in D & E. File: 13-2-Case06-KLoose47-i-Cut

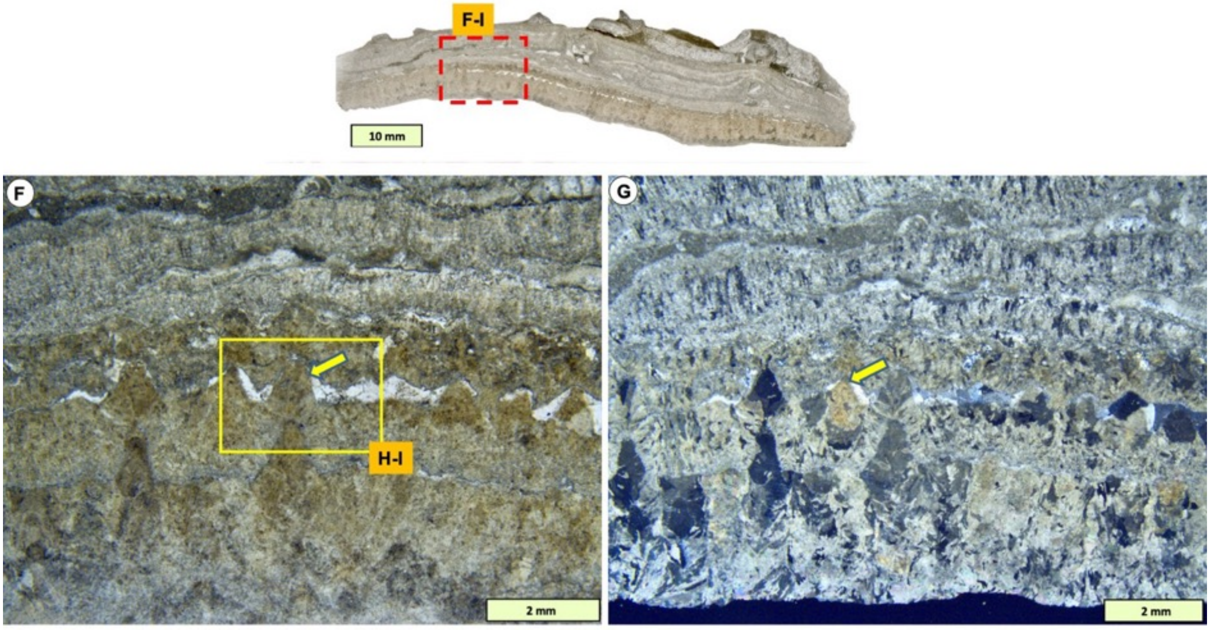


Fig. 6.6F-G. Another view of the primary cavity between the two layers of *Ls*, Enlargements in next photos. File: 13-3-Case06-KLoose47-i

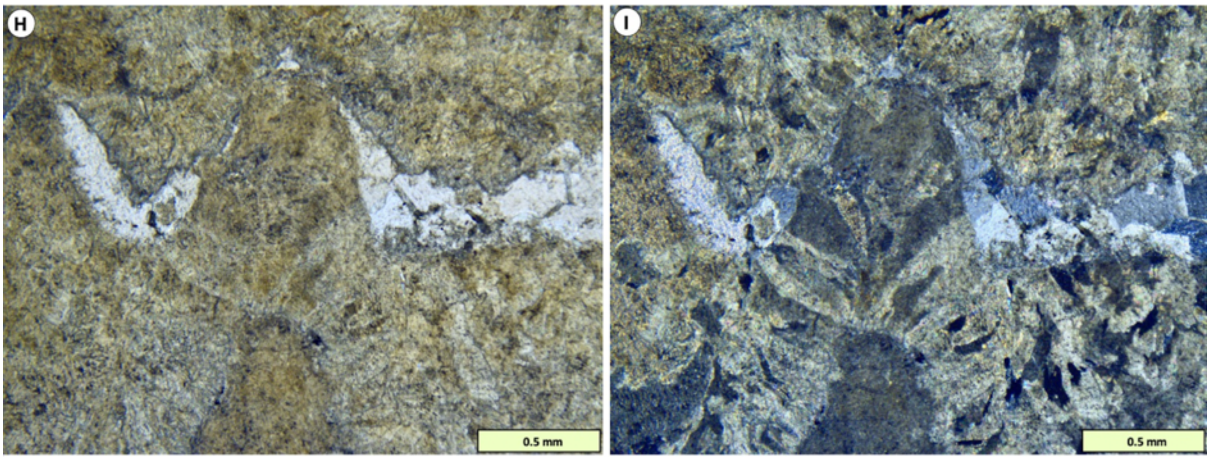
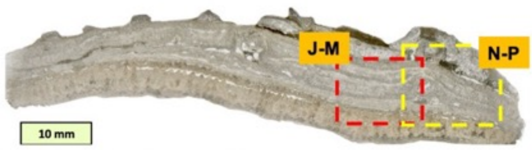


Fig. 6.6H-I. These pictures show some ambiguity of relationship between orientations of crystals in extinction in diagenetic featues of *Ls*, and the extinction of cement crystals in the primary cavity. Note that some of the crystals in the primary cavity seem to be in optical continuity with the *Ls* (left side of the papilla (centre), but on the right side they are not. It is not fully clear why this difference exists, perhaps part of the cavity was cement-filled before diagenesis of *Ls* and part filled in continuity with *Ls* diagenesis. This sample needs some CL work to help resolve its cements!!!! File: 13-4-Case06-KLoose47-i-Cut



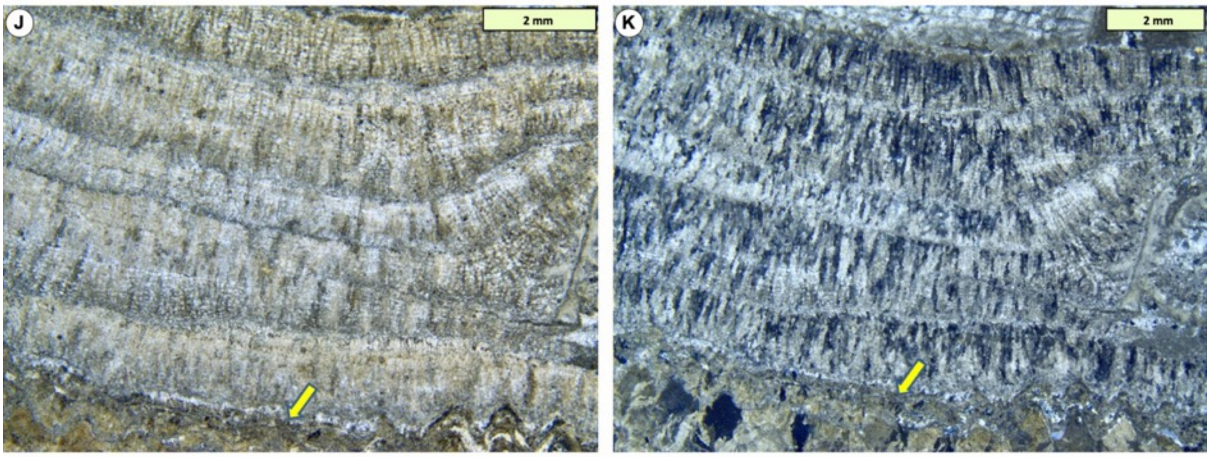


Fig. 6.6J-K. Another part of the sample showing 1) contact between *Ls* and encrusting *Ps*, where part of the *Ls* top surface has prominent papillae right side), compared with the rest of the *Ls* surface that lacks papillae (yellow arrow, that also indicates matched points). Note the *Ps* shows about 5 growth interruption surfaces, where the diagenetic alteration of the *Ps* skeleton does not pass across the interruption surfaces, normal in stromatoporoids, BUT in *Ls* the diagenesis passes easily across interruption surfaces in most samples. File: 13-5-Case06-KLoose47-i

6.7. Case Study 7: KLoose23-ii

This case shows *Ps* encrusting *Ls*, and there is a rugose coral within the *Ps*. This thin section was thinned to slightly thinner than normal 30 microns, in an attempt to show the structure in XPL in greater resolution than is normally achieved in stromatoporoids. Note that the taxonomy of stromatoporoids is normally undertaken using thin sections about 50 microns thick so that the skeletal structure has a greater contrast to the gallery cement. Unfortunately, because stromatoporoids are always recrystallised to some extent, the use of normal-thickness sections usually leads to lack of clarity in the skeletal features because of the overprinting of diagenetic calcite across both the skeleton and gallery spaces (FRIC), which makes the skeleton difficult to see clearly. However, use of 50-micron sections has the other effect that thick sections under a microscope cannot be fully in focus, because the focal range of microscope objectives is less than the thickness of the thin section, so that the skeleton appears fuzzy at high resolutions; such are the inherent problems of stromatoporoid study.

Ls is described as comprising very thin plates with tiny space between them, so that in 50 micron sections, you see an apparent solid mass, shown in earlier images. However, thinner sections do not help very much, as shown in Case Study 6.2, where details of the skeleton in PPL show that the composition of very thin plates described as the component of *Ls* are difficult to resolve. The CL photos in Case 6.2 and earlier photos show that the likely-original structure of *Ls* may indeed consist of plates but is more complex, and also shows elongate irregular calcite crystals stacked in layers.

However, this Case Study (6.7) is designed to show more details of the structure in XPL, therefore focussing on the diagenesis of *Ls*. The spectacular XPL images here show sharply the nature of the diagenetic overprinting and also demonstrate that it varies from what is interpreted as early-stage 3D crystal fans, evolving to later stage aggrading neomorphism to larger crystals that abut each other horizontally, leading to vertical palisades of crystals. Those give the impression that the structure of *Ls* is composed of thick vertical pillar-like elements, but that is interpreted here as a false impression, created by the diagenesis, not reflecting the growth of the skeleton (which is interpreted here as comprising synchronous wavy masses of very thin plates and flat irregular crystals).

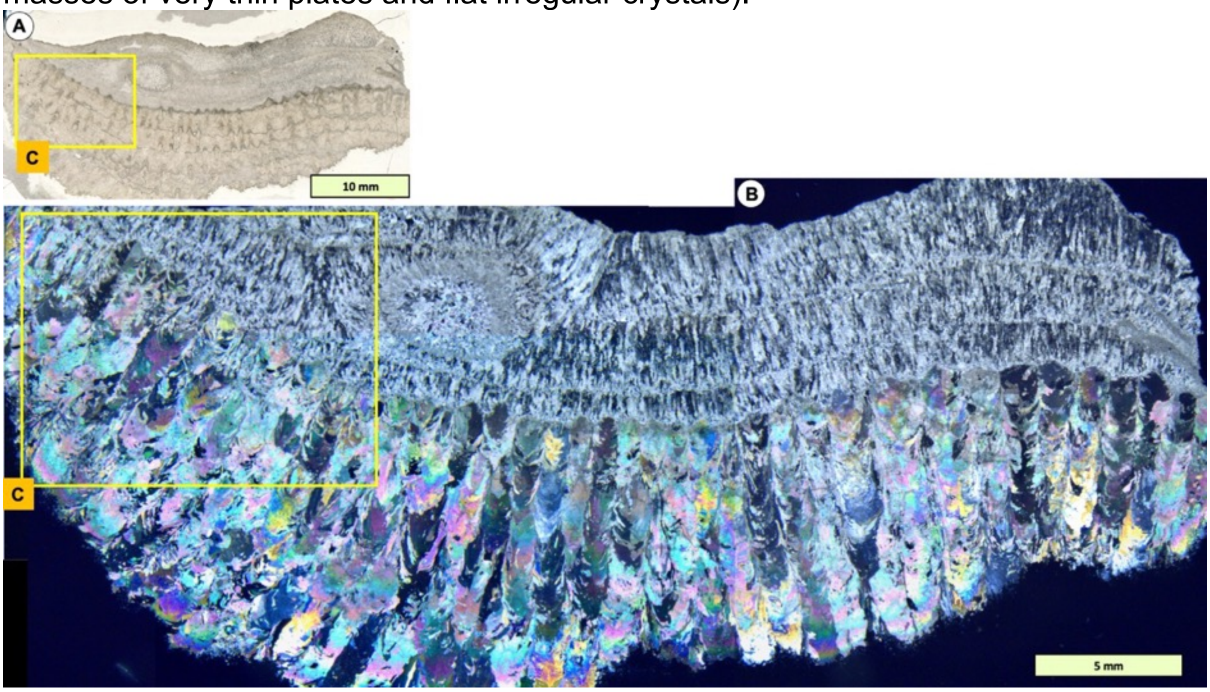


Fig. 6.7-1A-B. VS of whole thin section in PPL (A) and XPL (B), showing overall contrast between *Ls* (lower stromatoporoid and *Ps* (upper). File: 14-01-Case07-KLoose23-ii-Ls-Ps

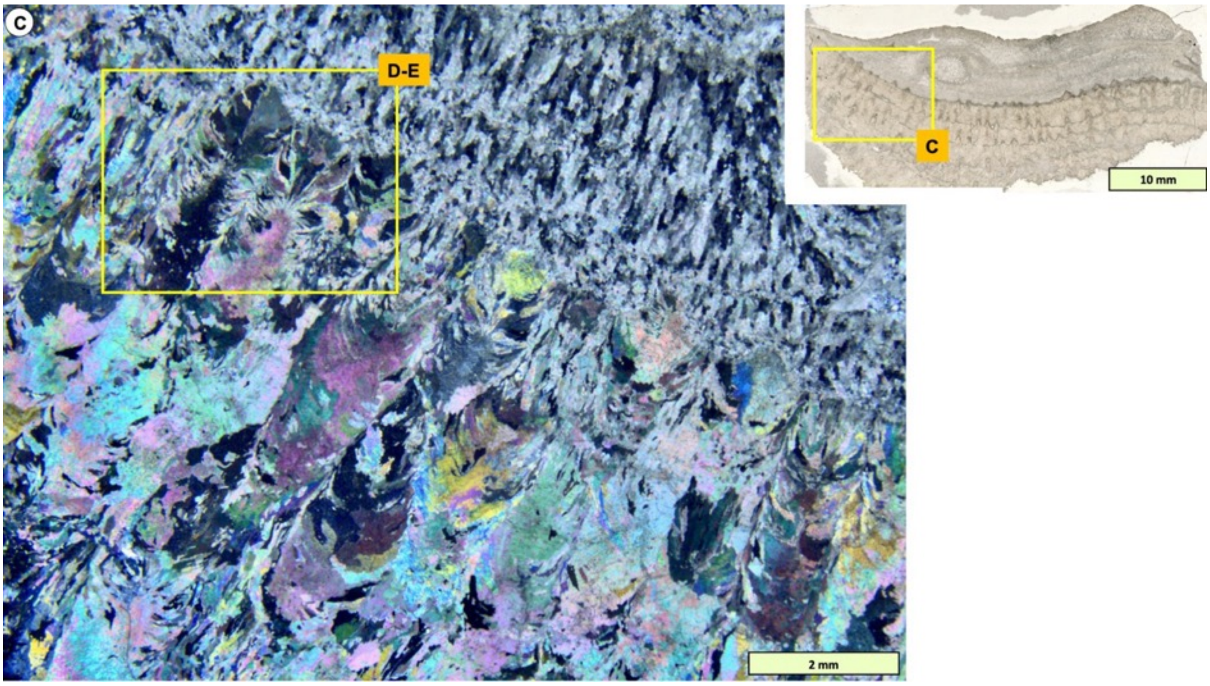


Fig. 6.7-1C. VS of enlargement of box in A&B, showing more detail of difference between *Ls* and *Ps*. File: 14-02-Case07-KLoose23-ii-Ls-Ps

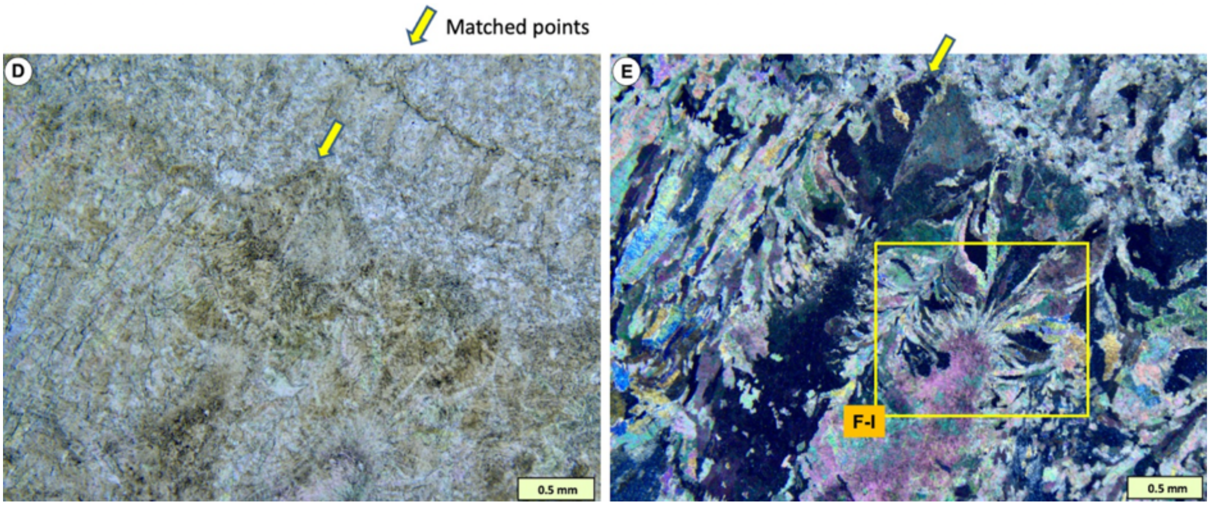


Fig. 6.7-1D-E. Enlargement of box in C showing contact between *Ls* and *Ps* in ppl (D) and XPL (E), including the top of a papilla (arrowed). Note that the structure of *Ls* is shown as 3D crystal fans emanating from peaks of the wavy skeleton, but also that the thin crystals in the 3D mass pass into larger areas of single crystals, especially well seen at the top of the *Ls* where it meets the *Ps* that encrusts it. The papilla in E (arrowed) shows features of both states, i.e. the radiating 3D crystal mass is still recognisable in the large crystals in extinction, that are interpreted as having formed due to aggrading neomorphism of the skeletal calcite. File: 14-03-Case07-KLoose23-ii-Ls-Ps-Cut

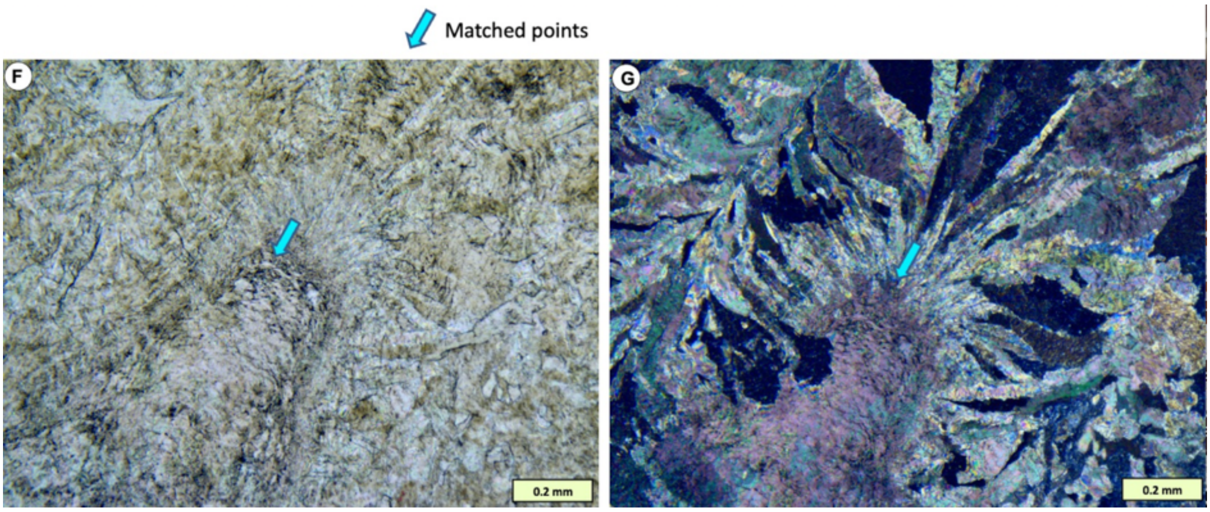


Fig. 6.7-1F-G. Enlargement of yellow box in E showing the radiating crystal mass of Ls in both PPL (F) and XPL (G) together with merging to larger crystals, especially at the top of the photo in G. The curving plate-like structure (of which the Ls is described as being composed) is vaguely visible in both PPL and XPL views. File: 14-04-Case07-KLoose23-ii-Ls-Ps-Cut

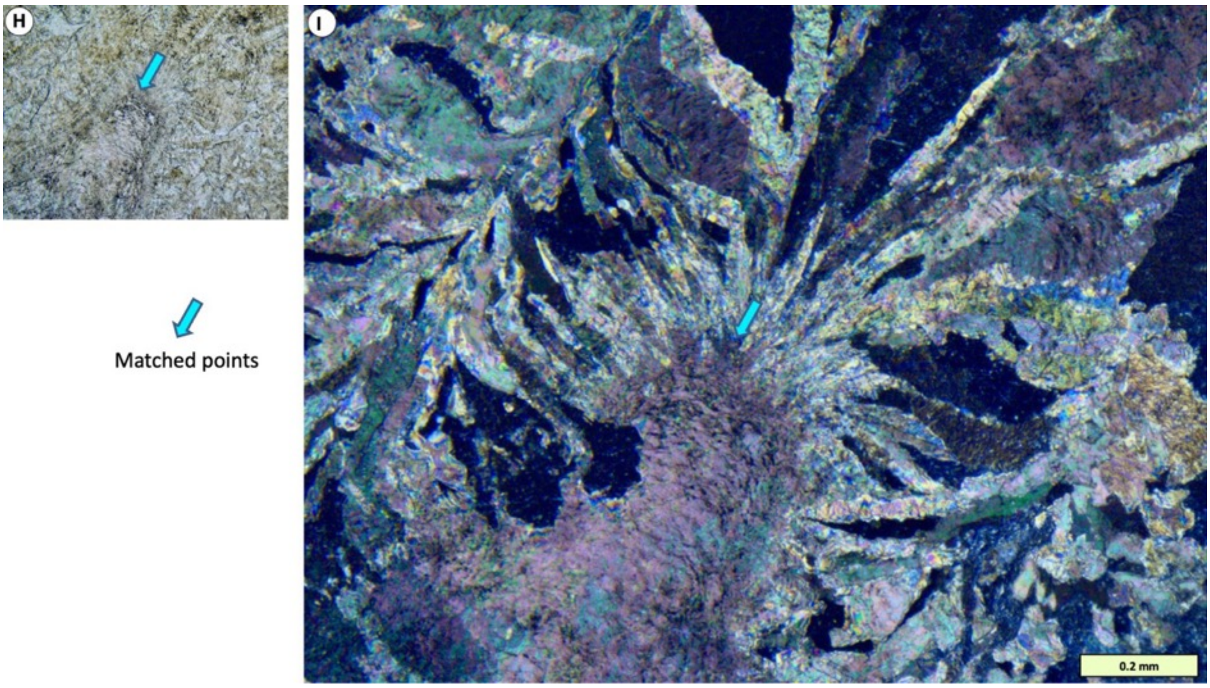


Fig. 6.7-1H-I. Repeat of F & G, showing the XPL view (I) in a larger image to emphasise the details of its diagenetic structure (and its amazingly beautiful features). This picture also shows the contrast between the fine 3D crystal fan crystals and the single crystal in the centre from which they radiate, **except** that the left side has two blobs in extinction (these are not holes, you can see that from the PPL view). This unusual sample shows there is more complexity in the central portions than their being single crystals shown in other figures. I suspect that with more samples in the future, more details will emerge of these central areas. File: 14-05-Case07-KLoose23-ii-Ls-Ps

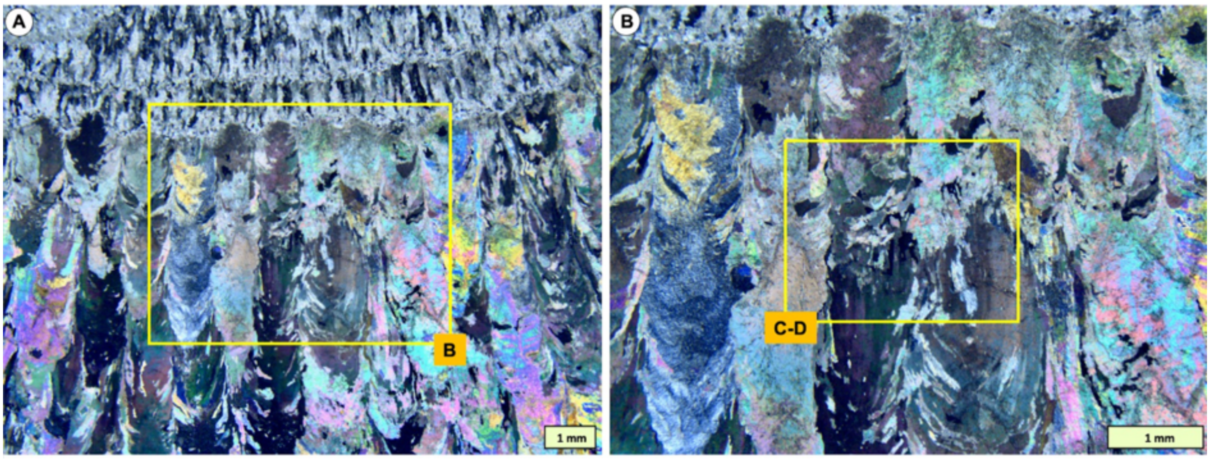


Fig. 6.7-2A-B. Enlargements in XPL of the central part of the thin section in Fig. 6.71, showing a mixture of 3D crystal fan early diagenesis of *Ls*, together with the interpreted aggrading neomorphic merging of small crystals to larger single crystals, particularly well seen in extinction. File: 14-06-Case07-KLoose23-ii-Ls-Ps-Cut

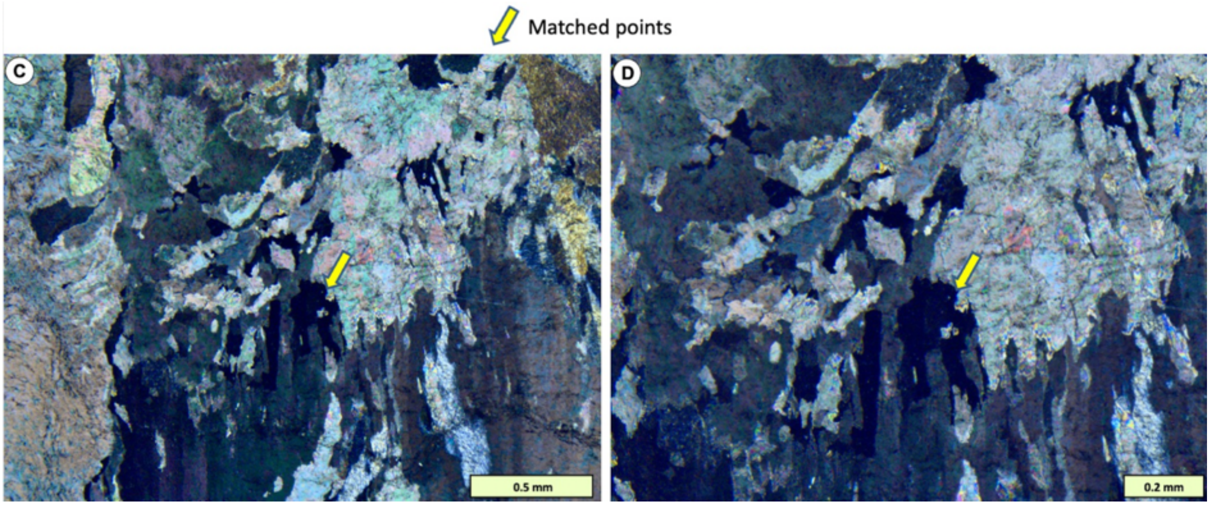


Fig. 6.7-2C-D. Enlargement of box in A&B to show the crystals in greater detail. File: 14-07-Case07-KLoose23-ii-Ls-Ps-Cut

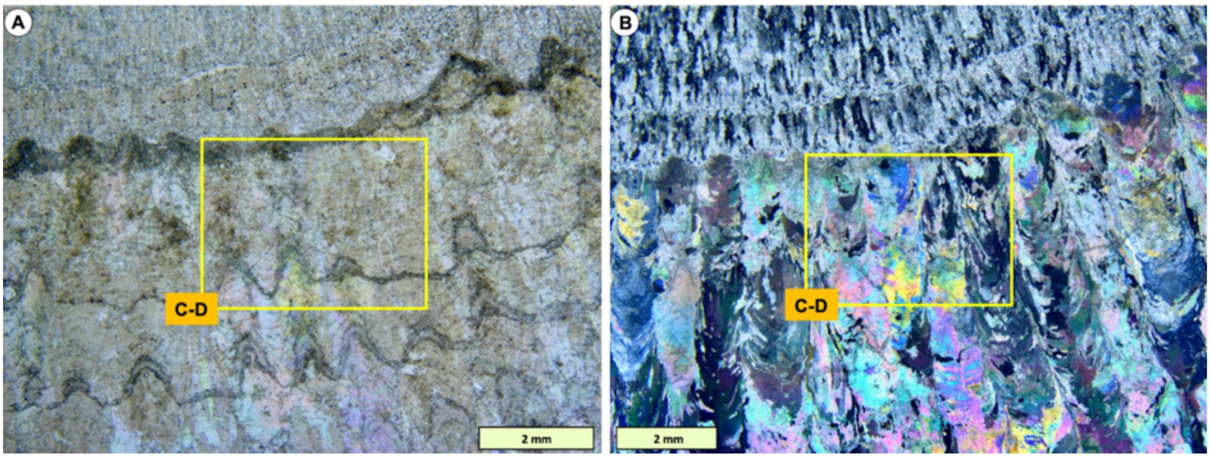


Fig. 6.7-3A-B. Another view of this thin section, of VS of *Ls*. **A.** The *Ls* (lower 2/3 of photo) shows prominent wavy layering of minor growth interruptions, and also the top of the *Ls* (encrusted by *Ps*) has variable papillae, as described in earlier photos. **B.** Shows layering within the *Ls* but also in the overlying *Ps*, where there are minor growth interruptions not visible in the PPL view (A). In *Ps* the overprinting diagenetic FRIC crystals do not pass from one layer to the ones above and below, in contrast to *Ls* which shows the crystal masses develop down through the skeleton to give the impression of large pillar-like structures (that are interpreted in this document to be diagenetic). File: 14-08-Case07-KLoose23-ii-Ls-Ps-Cut

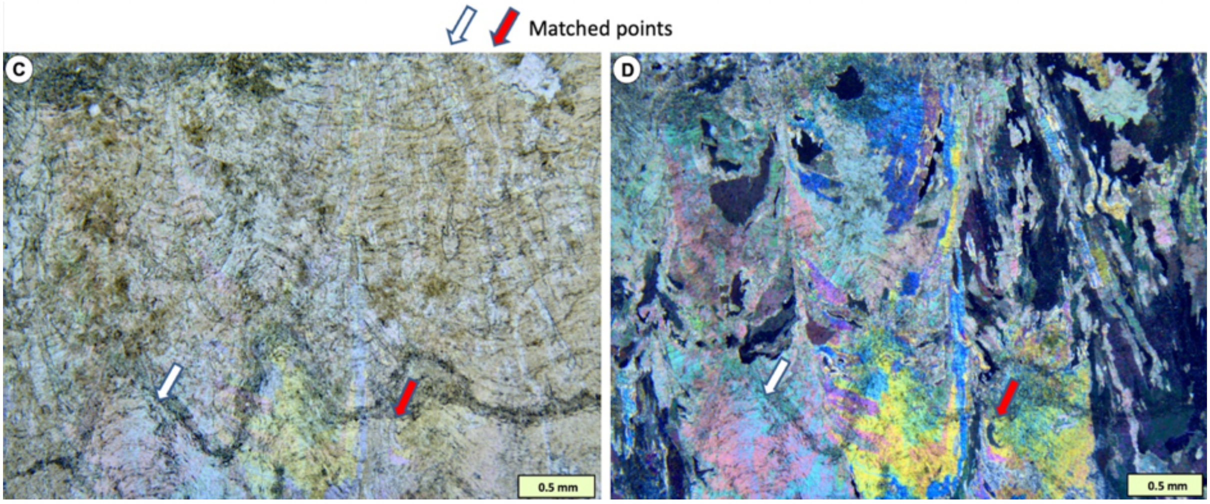


Fig. 6.7-3C-D. Enlargement of box in A&B showing the PPL and XPL views. A growth interruption surface in C is visible in D (arrows) overprinted by the FRIC diagenesis, with the crystals passing through the growth interruption surface, in contrast to the state in other stromatoporoids, seen well in *Ps* in other images in this Case Study. File: 14-09-Case07-KLoose23-ii-Ls-Ps-Cut

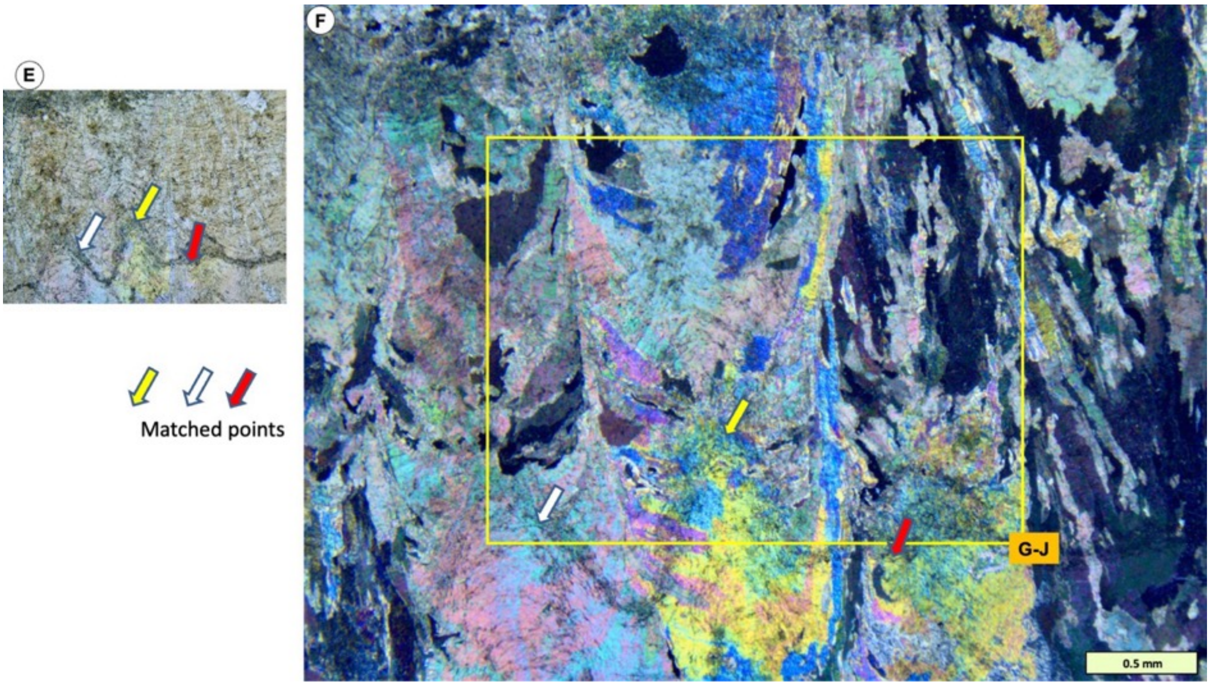


Fig. 6.7-3E-F. Repeat of C & D to show the structure in XPL in greater detail. File: 14-10-Case07-KLoose23-ii-Ls-Ps

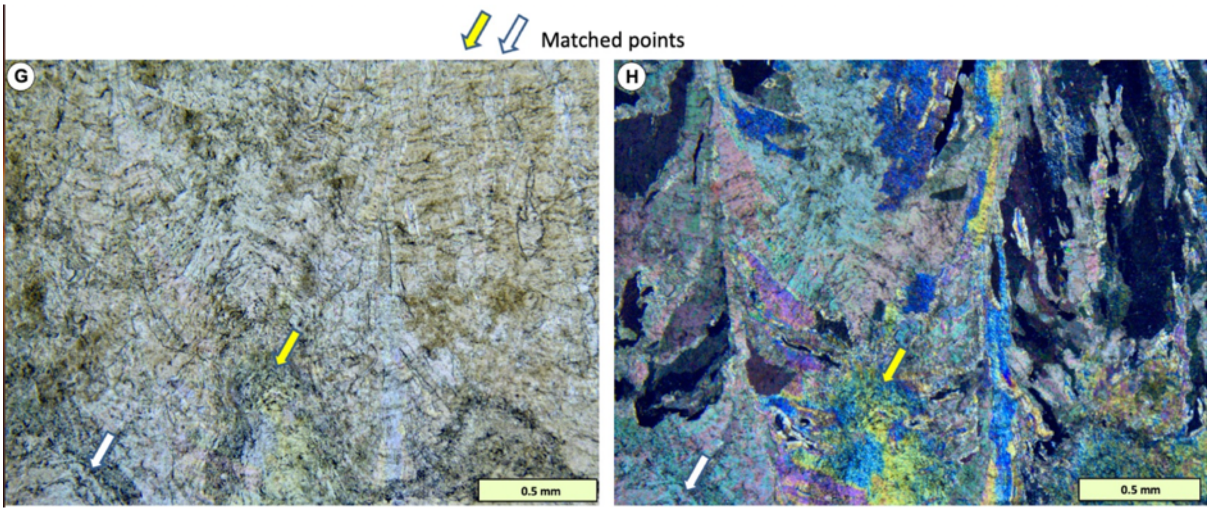


Fig. 6.7-3G-H. Enlargement of box in F to show more detail. File: 14-11-Case07-KLoose23-ii-Ls-Ps-Cut

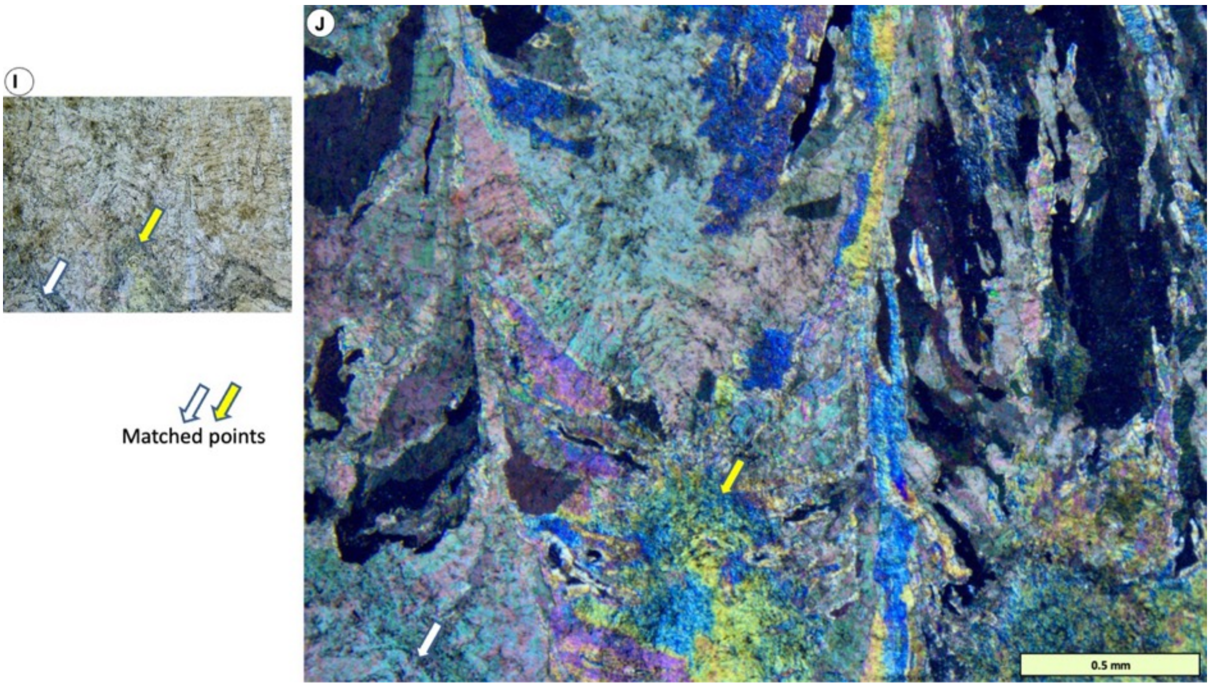


Fig. 6.7-3I-J. Repeat of G & H to show more detail in the XPL view. This picture shows the interpreted pathway to increasing crystal size as part of the aggrading neomorphic process envisaged to account for the later diagenetic changes in *Ls.* File: 14-12-Case07-KLoose23-ii-Ls-Ps

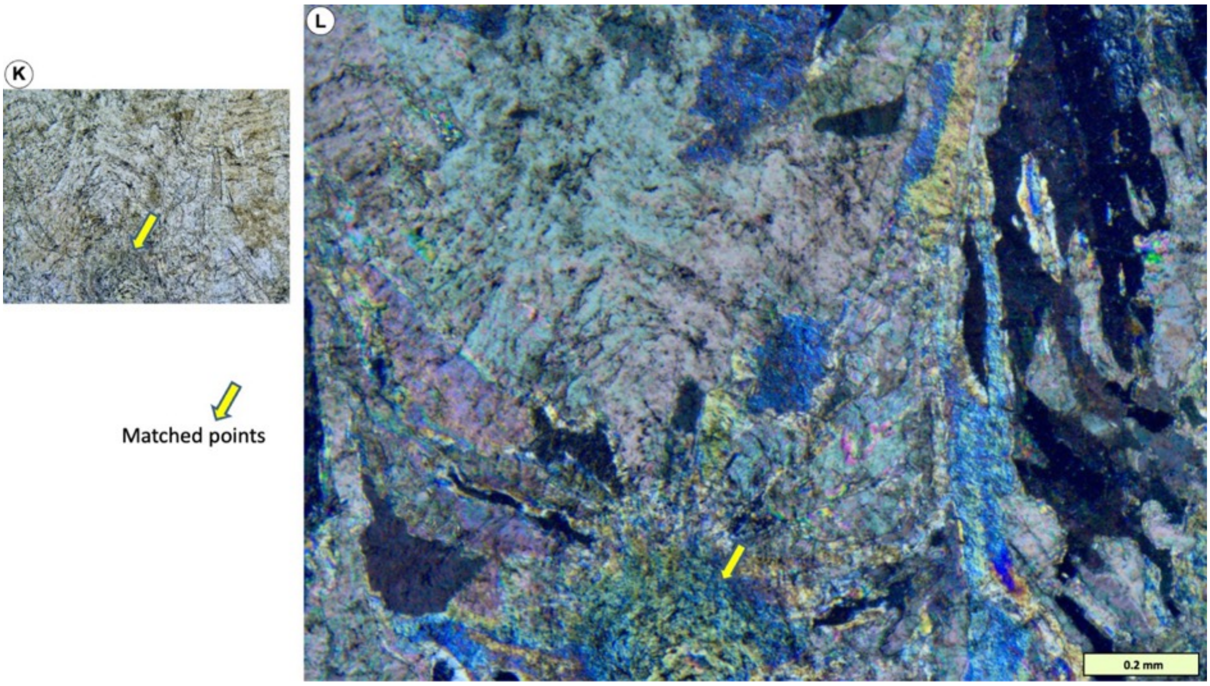


Fig. 6.7-3K-L. Further enlargement of J showing more detail of the crystal structure in XPL. File: 14-13-Case07-KLoose23-ii-Ls-Ps

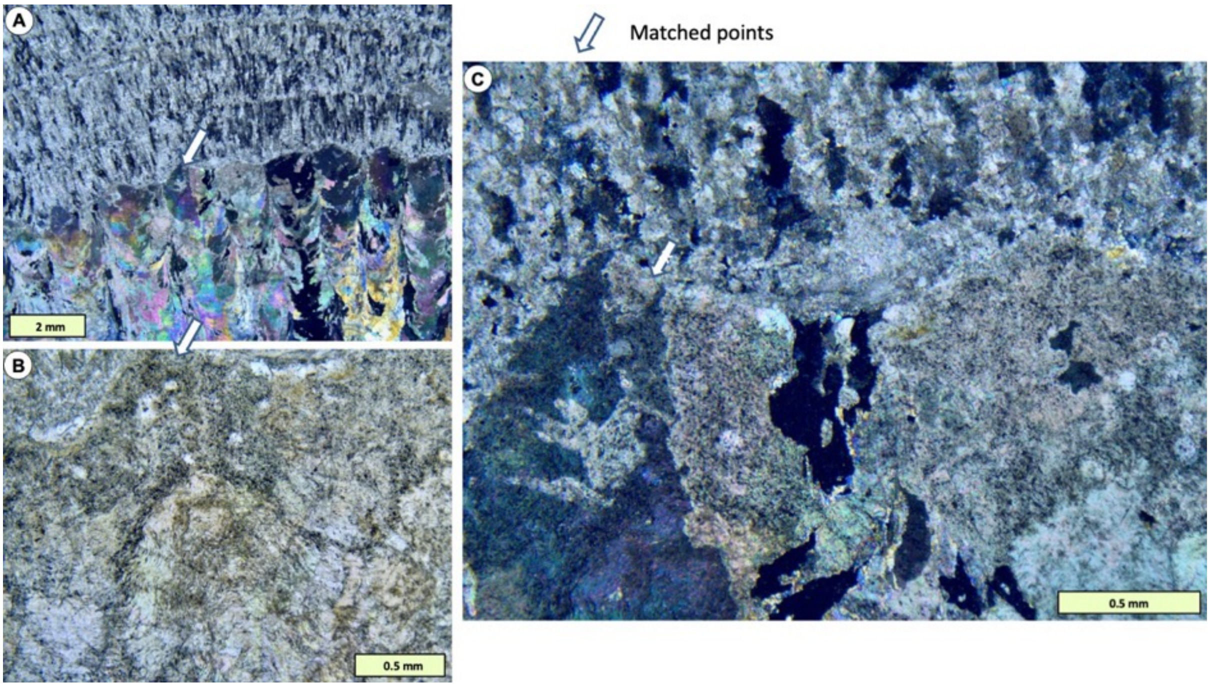


Fig. 6.7-4A-C. View of contact between *Ls* and *Ps,* showing that the diagenetic crystal structure of both taxa does not pass into the other, as is the case with all stromatoporoids that show a tight adjacent contact relationship. This specimen is also different from other images of *Ls* shown in this atlas because the papilla centre (white arrow) is **not** made of a single crystal, but show some evidence of remnant 3D crystal fans, **plus** the feature that this papilla has two crystals in different orientations regarding extinction. File: 14-14-Case07-KLoose23-ii-Ls-Ps

6.8. Case Study 8: KLoose54

This case is similar to 6.7, a vertical thin section of *Ls* using a rather thin section compared to the normal thicker sections used in stromatoporoid work. Thus in PPL and especially in XPL, the diagenetic structures are seen more easily.

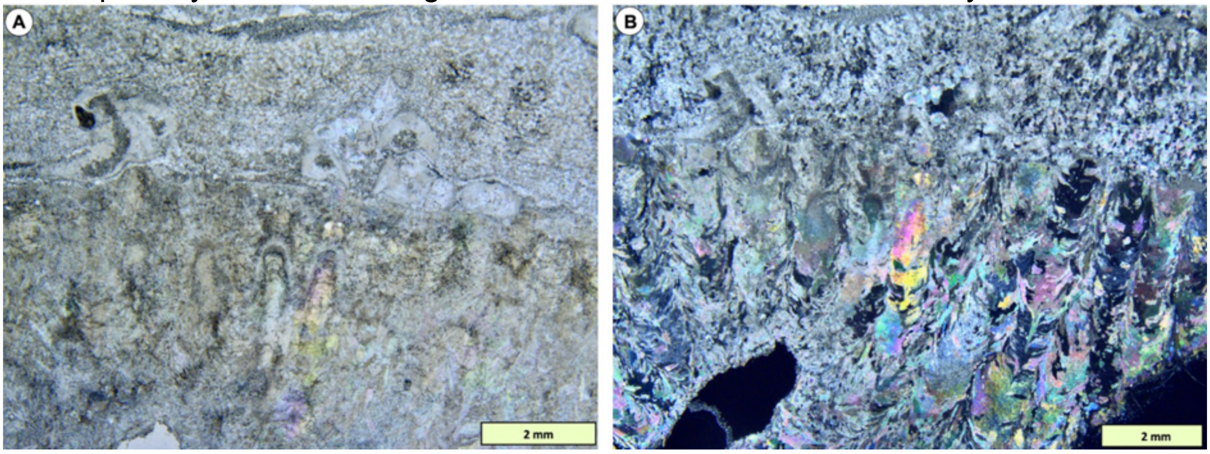


Fig. 6.8-1A-B. VS views of PPL (A) and XPL (B) of Ls encrusted by Ps (the difference between these taxa is easily seen in PPL but also the XPL view shows the finer structure in diagenesis of the Ps. In XPL, the black tongue-shaped object lower left is a tightly curved basal part of Ls, showing the Ls grew over an object on the sea floor, illustrated in Fig. XX. Matching points between the two pictures can be identified by the irregular top of this curved basal structure, and also by the darker curved feature left centre (looks a bit like an ear in PPL with a black small dot, that can be seen in XPL. File: 15-1-Case08-KLoose54-Ls-Diagenesis-Cut

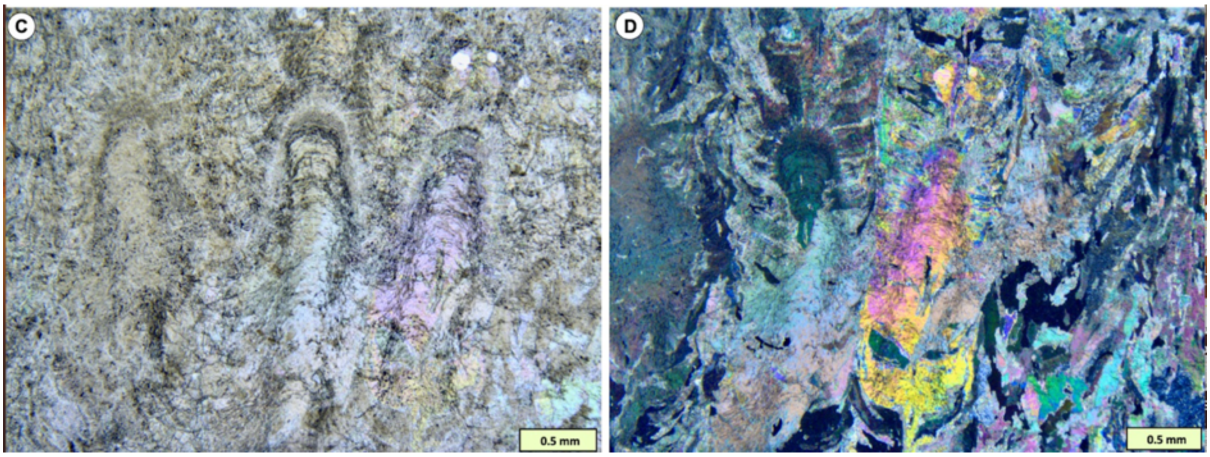


Fig. 6.8-1C-D. Enlargement of central parts of A & B showing the tight curved structure of Ls in PPL and the overprinting diagenetic calcite in XPL, that shows 3D crystal fans centre left, which in other parts of the XPL photo are interpreted as recrystallising due to aggrading neomorphism to larger crystals that abut each other to give the impression of columns. File: 15-2-Case08-KLoose54-Ls-Diagenesis-Cut

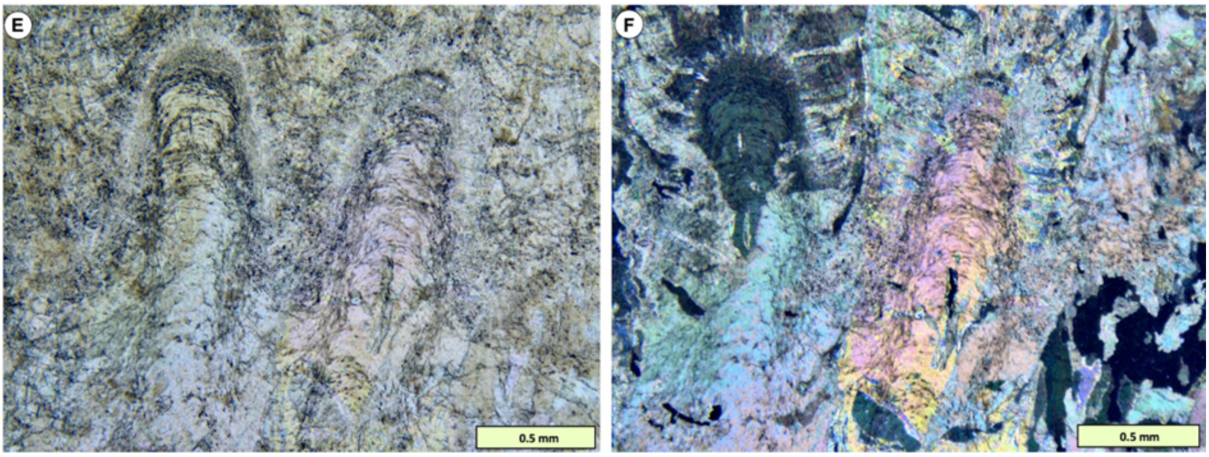


Fig. 6.8-1E-F. Enlargements of central part of C & D showing more detail of the tightly curved structure in PPL and the complex diagenetic overprinting in XPL. Note that the complexity of diagenesis in XPL is interpreted here to be relatively straightforward – that is initial recrystallisation to form 3D crystal rays centred on the peaks of the wavy structure of Ls, followed by aggrading neomorphism of those 3D crystal rays into singe large calcite crystals, shown partly in extinction in XPL. File: 15-3-Case08-KLoose54-Ls-Diagenesis-Cut

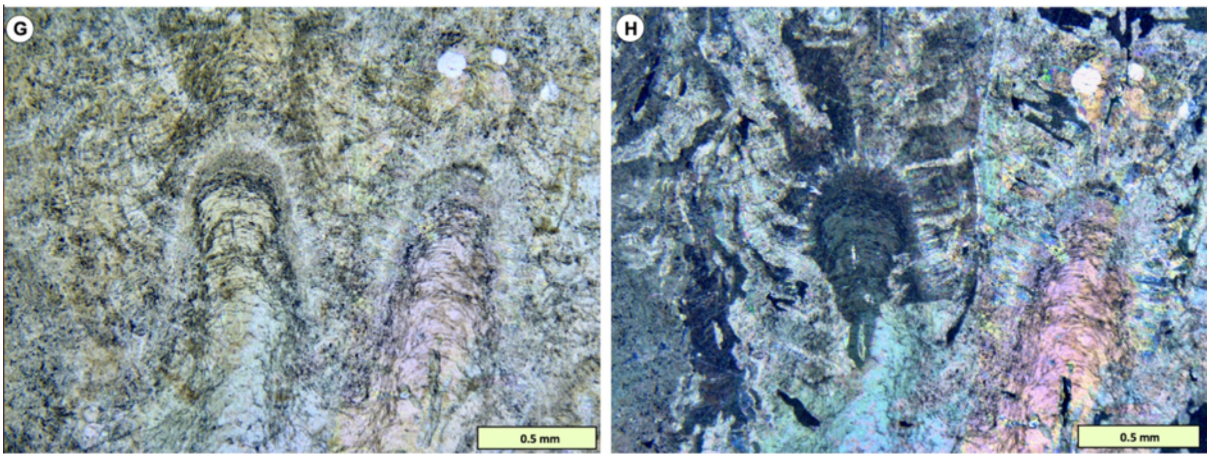


Fig. 6.8-1G-H. Two more photos at same scale as E & F in slightly different positions, showing the structure in PPL and XPL. File: 15-4-Case08-KLoose54-Ls-Diagenesis-Cut

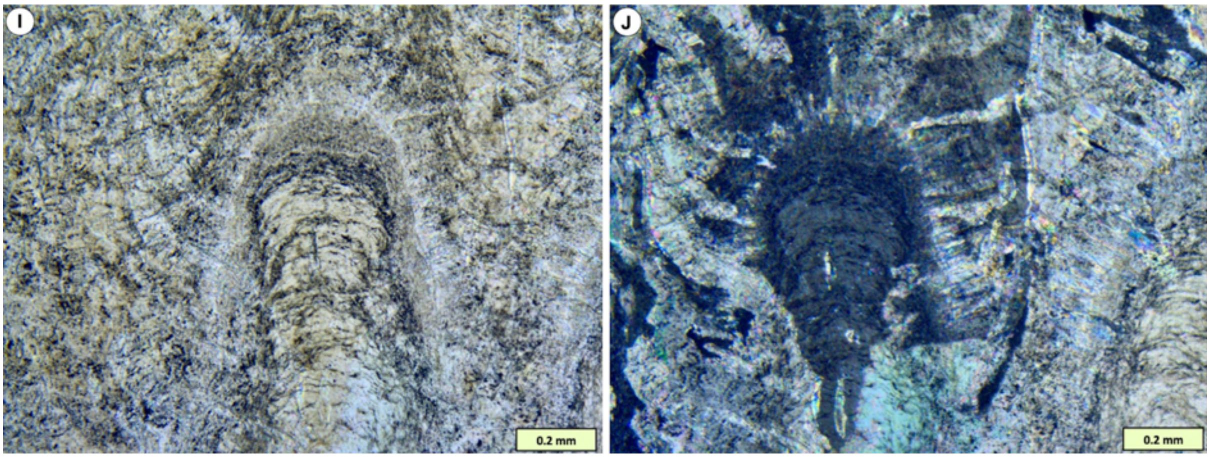


Fig. 6.8-1I-J. Enlargements of the central feature in G & H showing detail of the curved structure in PPL that looks like it is made of curved thin plates (can't really resolve the detail here) and in XPL shows the diagenetic overprinting of 3D crystal fans centred on the peak of the curved areas. Note also in PPL that the plate-like structure is visible only in the central part of the tightly curved area, but not elsewhere in the photo; however, the CL views seen in earlier photos indicates the entire structure

is made of thin irregular plates and irregular crystals. Note this specimen nicely shows the central part is a single crystal, from which the 3D crystal fans radiate. This is the same as other samples in this atlas, but look at Fig. 6.9-6 that shows some evidence the entire central column was previously composed of 3D crystal fans. File: 15-5-Case08-KLoose54-Ls-Diagenesis-Cut

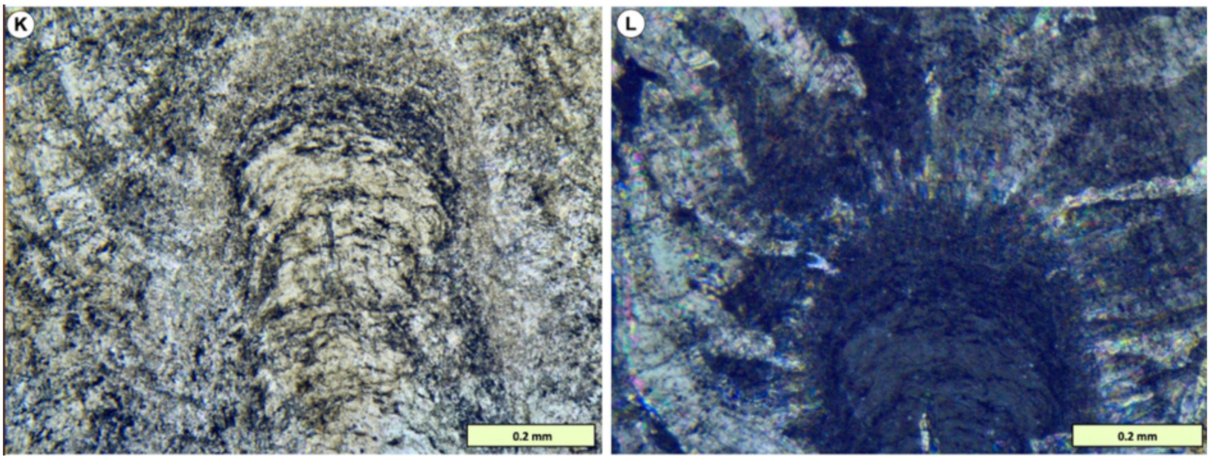


Fig. 6.8-1K-L. High-resolution images of centres of I & J showing more detail of the PPL and XPL views. File: 15-6-Case08-KLoose54-Ls-Diagenesis-Cut

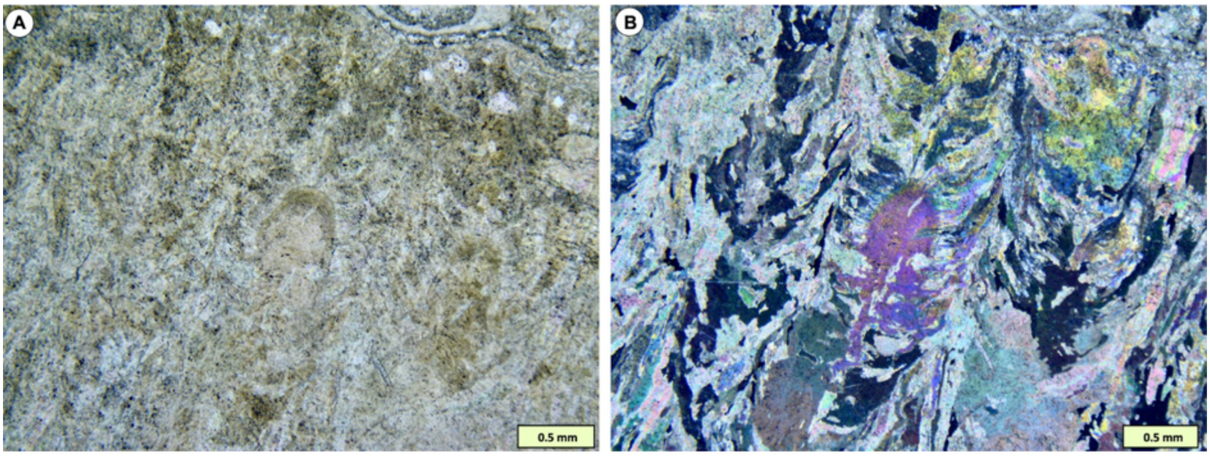


Fig. 6.8-2. PPL and XPL views of another part of the thin section, showing another rather nice image in XPL of the diagenetic overprinting with 3D crystal fans centred on the tight upcurved areas of *Ls* skeleton. File: 15-7-Case08-KLoose54-Ls-Diagenesis-Cut