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Late Palaeozoic Sedimentology of 7120/2-1:
VOLUME 1 Core sedimentology and diagenesis

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1. EXECUTIVE SUMMARY

Just over 200m of core from the Falk and Ørn Formations (Late Carboniferous to Early Permian) of well 7120/2-1 has been logged. Subsequent analysis of 62 thin sections – some of which were available from the NPD, and others specifically sampled for this report – has enabled lithofacies to be described. This has revealed a mixed carbonate-clastic system which is strongly modified by diagenesis, particularly in the carbonate intervals.

The Falk Formation is characterised by both clastic and carbonate lithologies, and 11 facies have been recognised. The clastic lithofacies range from fine mudstones and siltstones, through fine to coarse sandstones, to pebbly sandstones, and stratified conglomerates. Carbonate lithofacies include mud-support dolomites (mudstones-wackestones) through to grain-support dolomites, with a diverse faunal assemblage (packstones and grainstones). The carbonate lithofacies commonly also contain clastic grains, suggesting carbonate and clastic settings where closely associated. Breccias are present in the Falk Formation, but are not common.

The Falk Formation marks the first marine incursion above the alluvial/fluvial clastics of the Ugle Formation, and is characterised by a large scale transgression from base to top. Coarse clastic, marginal marine facies dominate at the base, with the succession becoming increasingly more marine influenced upwards. There is a decrease in siliciclastic content and grain size upwards as the siliciclastic source becomes drowned, and an increase in carbonate content. The overall depositional setting of the Falk Formation is that of a river-dominated deltaic system, but with carbonate environments more prevalent during periods of sea level maxima. Most evidence points to current-dominated sedimentary structures, although there is probable tidal influence as there are key intervals where bi-directional cross beds are recognised.

The Ørn Formation is characterised by carbonate deposition, and its base is marked by the last upwards occurrence of clastics. This results in the transition between the Falk Formation and Ørn Formation being diachronous across the Barents Shelf area. Seven carbonate lithofacies have been observed in the Ørn Formation, ranging from

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Petrographic analysis further confirms the differences between the upper and lower parts of the cored Falk Formation. The similarities include the generally arkosic classification (relatively high feldspar content) and sub-rounded to sub-angular nature of the grains (Figure 3r). Additionally, the sediments also appear to show a degree of compaction and are generally laminated. Sorting, on the other hand, varies quite considerably, with the upper Falk appearing to be better sorted.

Interpretation: Laminated and cross-bedded sandstones were deposited in a high-energy depositional setting. Tabular cross-bedding is formed mainly by migration of large-scale, straight-crested ripples and dunes, and these sedimentary structures are the most common in the Falk Formation. These sedimentary structures also indicate generally unidirectional flow such as currents – there is little evidence for wave-formed sedimentary structures in the Falk Formation.

Where bi-directional cross bedding is present, it may reflect a tidal influence. Climbing ripples represent intervals where there was very high sediment supply and rapid deposition.

Delta mouthbar to upper shoreface depositional settings are interpreted for the majority of these facies (see further discussion in Appendix 2).

3.2.5. Coarse sandstone with scattered pebbles

Description: This is a coarse-grained sandstone which typically contains common, scattered, poorly sorted pebbles which are sub-rounded to very well rounded (Figure 4b, c). The pebbles range from small pebble to cobble size, and are composed predominantly of quartz and lithic pebbles (Figure 4 a, b, c). Whilst the pebbles are often exceptionally well rounded, the sphericity is highly variable, and locally very low. Where pebbles are elongate, they are commonly aligned to bedding (oblate), but do not exhibit any imbrication. The sandstone “matrix” to this lithofacies is typically medium to very coarse sand-grade sandstones, with subangular to subrounded grains.

Bedding can exceed 1.5m in thickness, and typically exhibits a fining upwards profile. The bed contacts are usually erosive or gradational. This lithofacies commonly forms

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3.3. Falk sequences and depositional models

A detailed overview of the Falk Formation is provided in Appendix 2, and should be referred to, along with the core log in Appendix 1, for more detail.

The Falk Formation is characterised from base to top by a broad transgression: marginal marine facies dominate at the base, with the succession becoming increasingly more marine influenced upwards (Figure 2). There is a decrease in siliciclastic content and grain size upwards as the siliciclastic source becomes drowned, but this transgression is overprinted by higher order sequences.

The overall depositional setting of the Falk Formation is that of a river-dominated deltaic system (Figure 6). Most evidence points to current-dominated sedimentary structures, although there is probable tidal influence as there are key intervals where bi-directional cross beds are recognised. Throughout the entire cored interval, there is very little evidence of wave-influence. Carbonates are characteristic of periods of sea-level maxima (MFS; Figure 7).

The base of the Falk is dominated by the more proximal and much coarser facies of this system, whilst in the upper parts of the river delta has become more evolved and coarse clastic components are rare.

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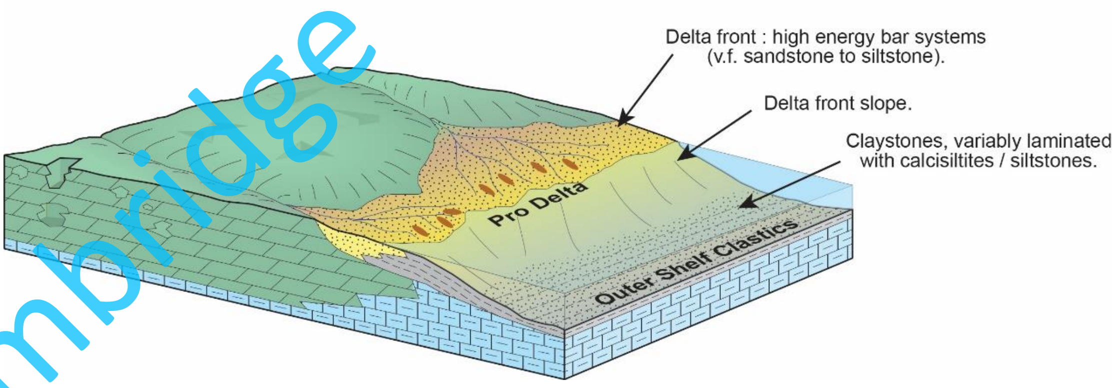

Figure 6 Schematic 3D model highlighting the depositional environments of the Falk Formation during predominantly clastic deposition.

Typically the facies is finely crystalline dolomite in nature (Figure 14I, j), and allochems (where identifiable) are characterised by broken up and comminuted shelly material, common crinoids, scattered monaxon sponge spicules, bivalves, gastropods, fusilinid foraminifera, and other small benthic foraminifera. Locally, bioturbation traces are mimetically preserved – this is particularly well developed between 1980m to 1975m where there is an upwards increase in the diversity and intensity of trace fossils (Figure 14g, h). The majority of the trace fossils are subhorizontal forms which represent living and feeding traces, and include common *Planolites* traces, local *Palaeophycus* traces, *Chondrites* traces and rarely *Asterosoma* traces.

Thin section petrography confirms the fine crystalline, replacive nature of the dolomites. Thin section analysis also confirms the local presence of silica as an intercrystalline cement to the fine dolomite. The silica cement is typically patchy, but there also appears to have been a ?late dissolution phase which has dissolved some of the dolomite crystals, leaving very small moulds. Microporosity is locally well developed (Figure 14j).

Interpretation: The original texture of the fine crystalline dolomite is mudstones and locally wackestones – these mud-supported facies would have been deposited in a low-energy depositional setting below wave-base. It cannot be said with certainty if these facies represent fully open-marine low-energy settings, or deposition within a lagoon – probably both depositional settings are represented within the Ørn succession.

4.2.3. Dolomitised Palaeoaplysina bindstones

Description: This lithofacies only occurs in one interval in the entire cored section, between 2016.9m and 2018m. The interval is approximately 1m in thickness and is characterised by banded dolomites with yellowish-grey and brown-grey coloured bands (Figure 14k). The banding is wavy and discontinuous, and the thickness of the bands range from <1cm to 4cm in thickness. The thickness of the bands appears to increase upwards through the interval. The dolomitisation is pervasive, and as such it is very difficult to determine the exact nature of what the banding represents. Locally

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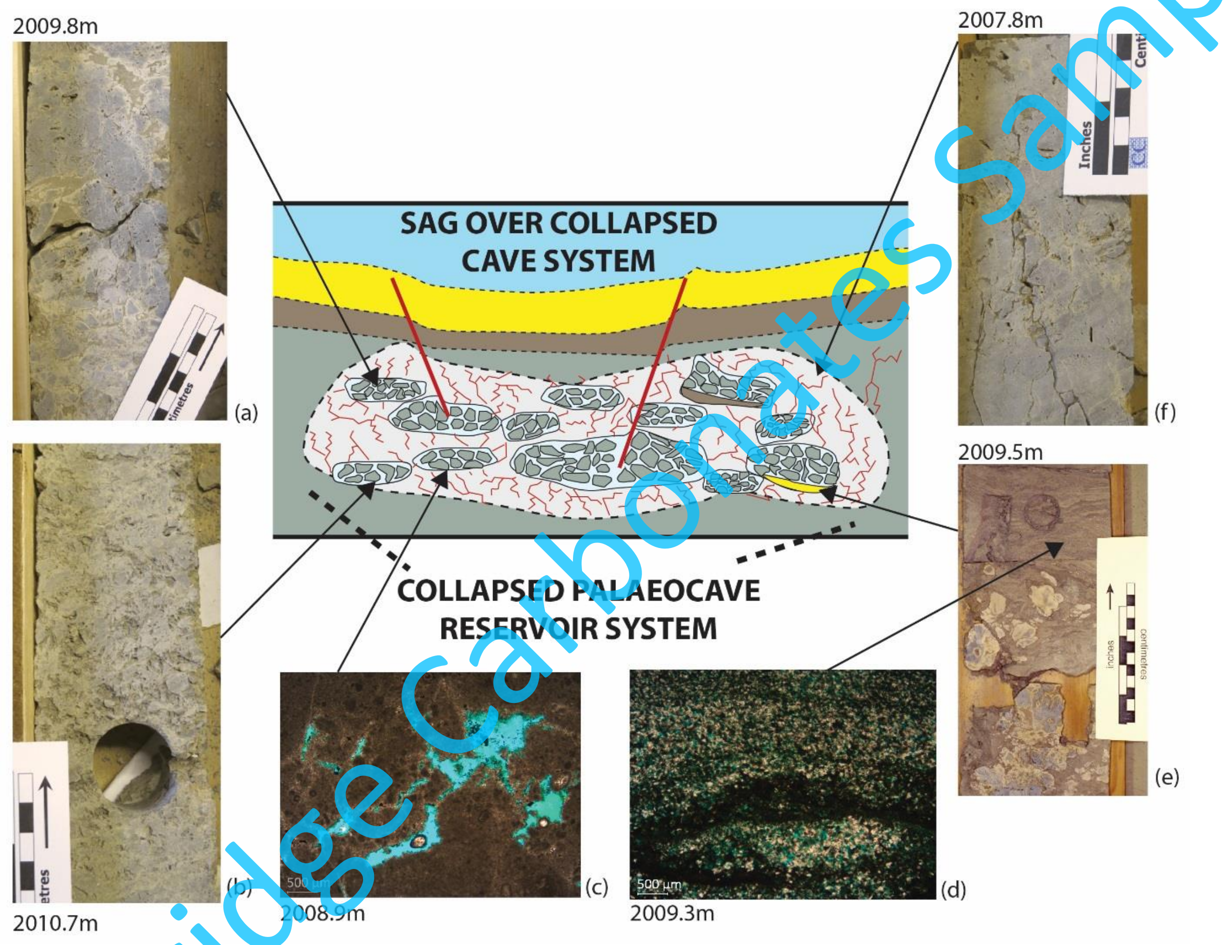

Figure 16 Schematic diagram showing the possible geometry of the breccia body, and examples of the breccia facies. (a) Collapse breccia with minor detrital sediment fill. (b) and (c) collapse breccia. (d) and (e) sediment fill. Note that at the base of photograph e, there is possible speleothem. (f) Crackle breccia at roof of cave.

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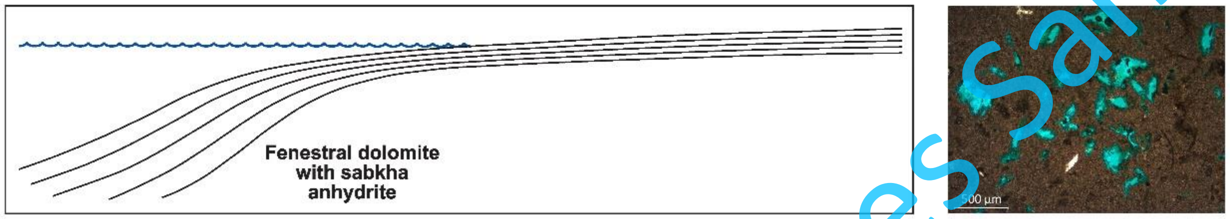
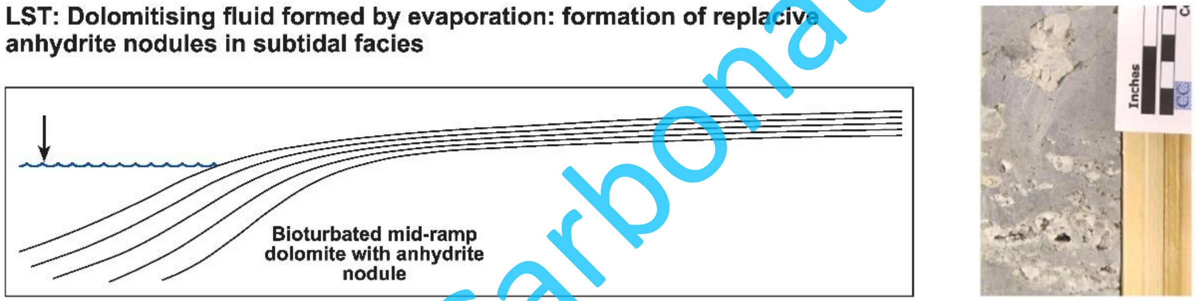
HST: progradation of subtidal to peritidal facies (now dolomite)



LST: Dolomitising fluid formed by evaporation: formation of replacive anhydrite nodules in subtidal facies



TST: flushing of dolomitising fluid through ramp carbonates during transgression

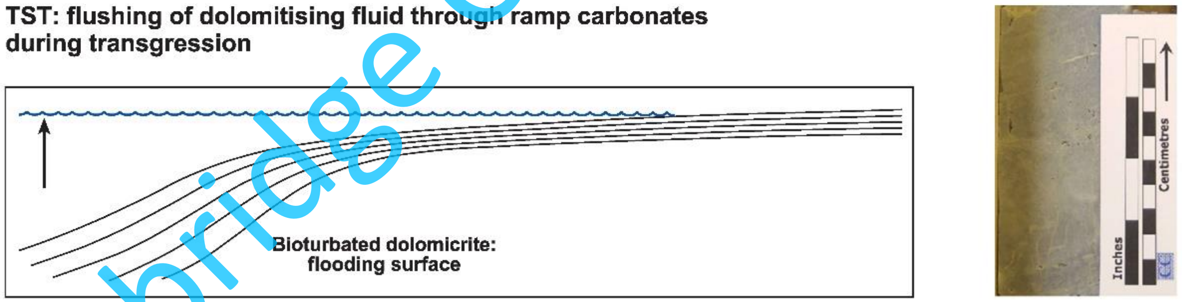


Figure 21 Schematic model for dolomitisation during transgressions.

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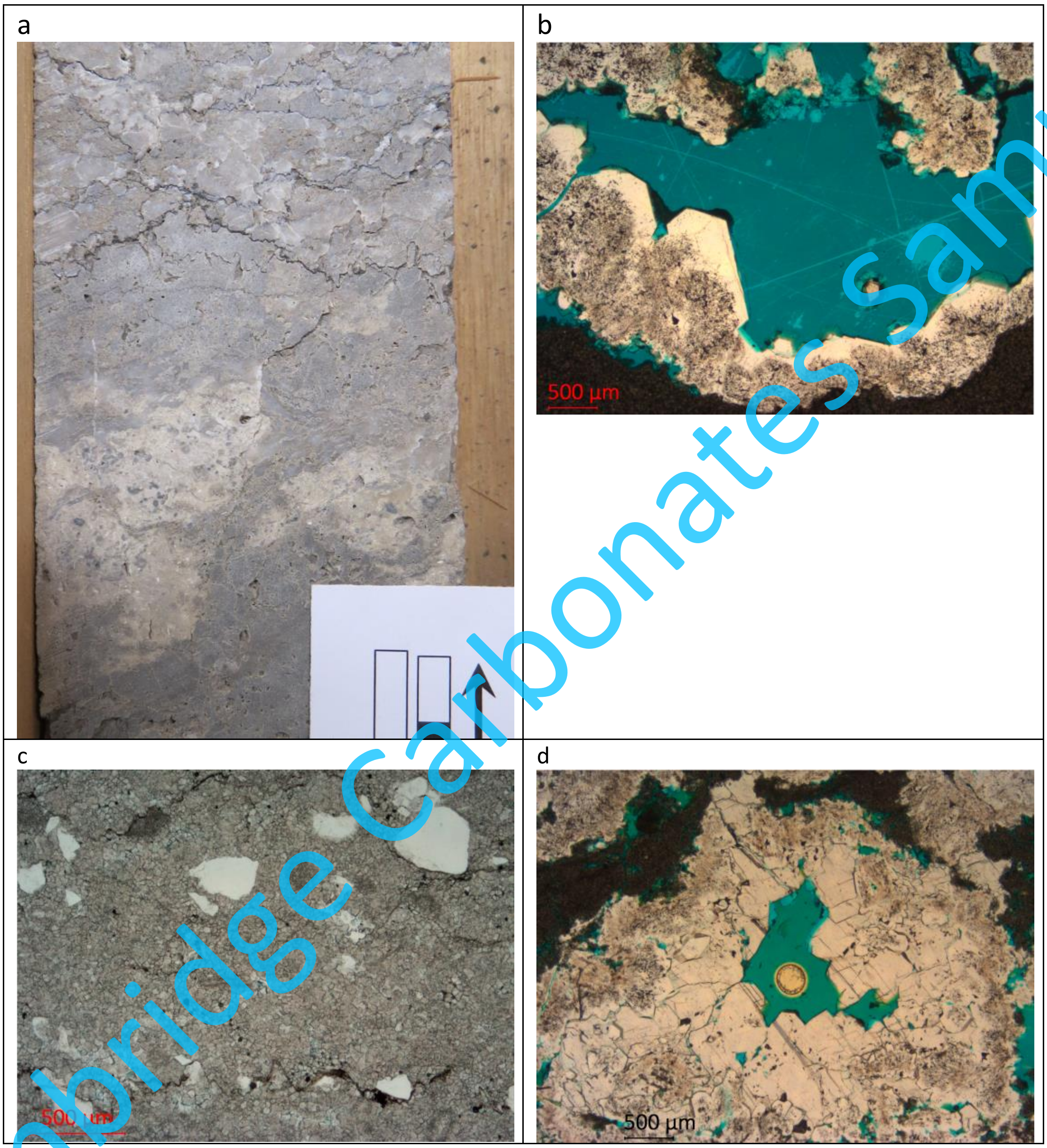
oil was recovered from DST-4 in 7120/2-1 (Figure 27). Published work by Ohm et al. (2008) suggests that these oils have an ETR (extended tricyclic terpane ratio) typical of a Palaeozoic source.



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9. APPENDIX 2 – CORES 17 TO 5 – FALK FORMATION DETAILED DESCRIPTION

9.1. 2224.80m – 2218.2m

The base of the Falk Formation is recorded at 2224.80m and is a key surface signifying the first marine influence in the depositional system above the continental Ugle Formation. This wackestone contains scattered crinoids (Figure 28a) plus either reworked caliche nodules/cemented burrows and exhibits a sharp basal contact. Above this, a 4m thick, coarsening upward trend is observed, passing from bioturbated, bioclastic muddy siltstones into pebbly fine-grained sandstones and medium-grained bioturbated sandstones. These likely represent mouthbar or upper shoreface deposition.

The maximum flooding surface is picked at the transition to a dolomitised carbonate mudstone-wackestone. The fine dolomite has a bioturbated basal surface and contains cemented burrows of *Thalassinoides* and *Planolites* plus dolomitised bioclasts, including fusilinids and crinoid ossicles.

Clasts of the dolomite occur in the sandstone directly above these carbonates and it is inferred that the contact is representative of a hardground. The overlying bioclastic sandstones broadly coarsen upwards and contain a diverse ichnofacies assemblage (*Thalassinoides*, *Planolites*, *Chondrites*, *Asterosoma* plus indeterminable varieties). The bioclastic, bioturbated sandstones eventually pass up into low angle tabular cross-bedded medium-grained sandstones. This succession represents progradation of shoreface to mouth bar deposits during the late HST.

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9.8. 2157.60m-2142.60m

This sequence is relatively thick (15m), and in reality could represent a few stacked sequences. The transgressive systems track is marked by a clear deepening event, with dolomitic grainstones of the underlying highstand being overlain by laminated mudstones and siltstones. The remainder of the TST is characterised by calcareous fine to medium sandstones, or sandy dolomites which are variably laminated or structureless (Figure 4h). Bioturbation is locally present as are thin granule-grade lags which sometimes have a scoured basal surface. There are possible higher-order cycle-tops picked out by fracturing and/or development of incipient epikarst (e.g. at 2154.9m; Figure 31c).

It is difficult to place the maximum flooding surface, as there are few strong candidate surfaces. It has been tentatively placed at around 2151m, marked by a sandy dolomite which contains Chondrites burrow traces.

The highstands system tract is characterised initially dolomitic fine sandstones which are either structureless, or contain well-preserved ichnotraces. The dolomitic sandstones are commonly pale blue green in colour, reflecting the presence of probably illite. A package of medium to coarse pale blue green sandstones occur at 2144.7m, and exhibit evidence of soft sediment slumping and deformation, suggesting rapid deposition and dewatering of the sediments (?due to high sediment load, possible in a prodeltaic setting). A 10cm thick pebble lag overlies the slumped zone, which then fine into dolomitic sandstones and upwards to a 1.4m thick dolomite interval which is fractured and intensely brecciated (Figure 5h). At the top of this unit, the host rock appears to be steeply dipping, but this may represent a large clast. This is underlain by a mosaic breccia where clasts show rotation, but minimal displacement (Figure 31d). There is a complex brecciated interval with sediment-filled pipes that sits below this mosaic breccia. The sediment filled pipes are >80cm in length, containing sub-rounded lithoclasts up to 80mm in diameter. Lithoclasts are poorly sorted coarse dolomitic sandstones, with subangular to subrounded quartz grains cemented by dolomite. Polymict clasts are associated with chaotic breccias, and have a matrix

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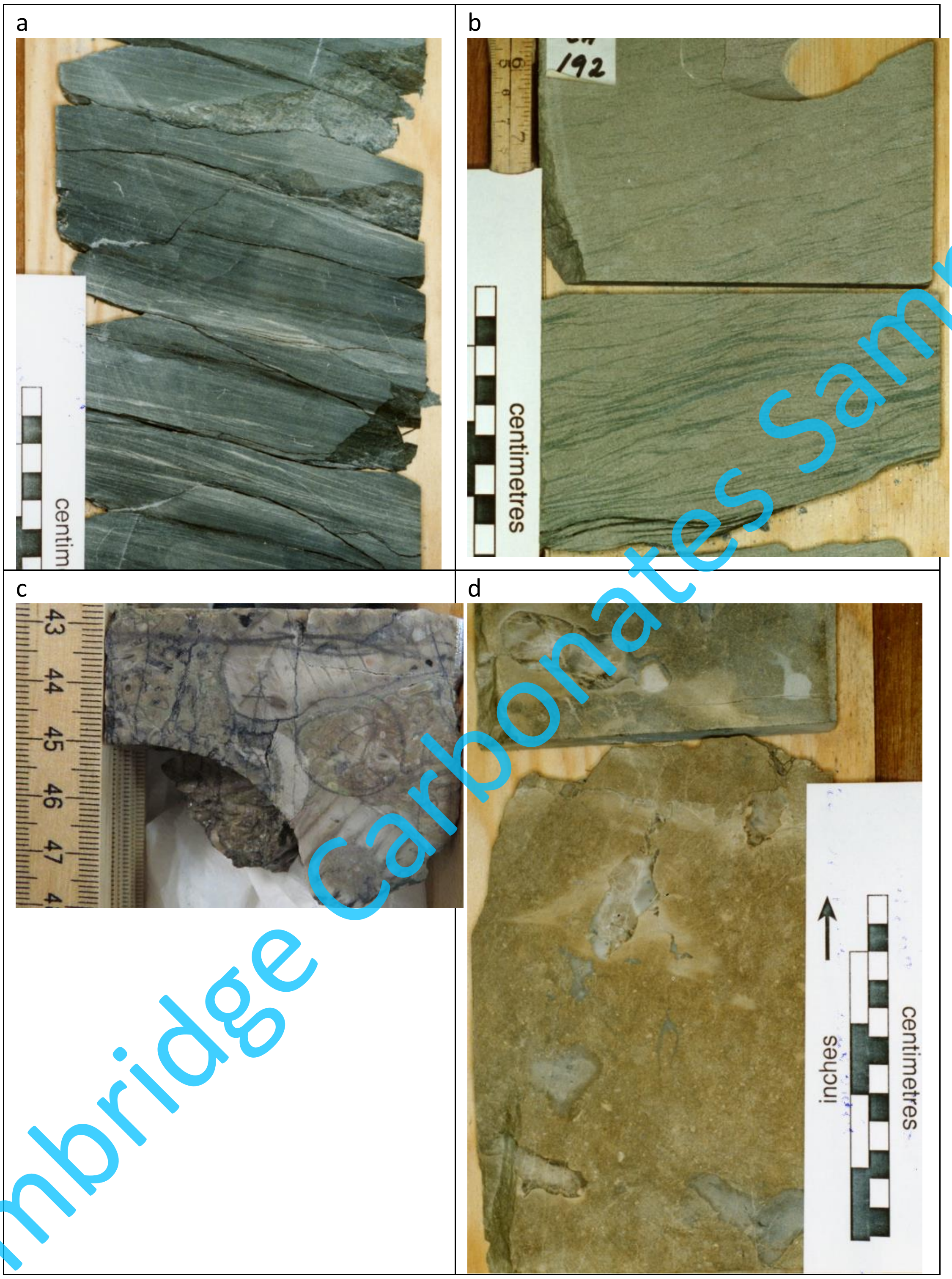

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Figure 34 (a) Laminated shales at 2060.7m. (b) Fine sandstone with climbing ripple laminations. Note the green clay drapes. 2058.40m. (c) Accumulation of large crinoid stems. 2056.44m. (d) Fine crystalline dolomite with silica-cemented vugs. 2051.5m

fill, with the clasts derived from the cave roof and margins of the cave wall. The fine clastic/detrital dolomitic sediment internal fill was clearly sourced external to the cave.

It is not possible to determine the provenance of the clastic cave fill, as there are no samples of the "in-situ" sediment to compare it to. However, the presence of detrital dolomite within the karst fill suggests reworking of pre-existing dolomitic strata.

Since it is most likely that the karst relates to a much later event (Permian uplift), and is not "syn-deposition", the karst in this interval does not actually reflect the top of the depositional cycle.

The base of core 3 is characterised by a 3.5m package of bedded microbial/oncoidal dolomites which is capped by a thin dolomitic breccia at 2000.10m. Core preservation is rather poor in this interval, but the microbial/oncoidal dolomites locally have quite complex digitate forms, with well-preserved laminae, or appear more thrombolitic in nature (Figure 15g). Barites is especially well developed in this interval (Figure 15f, i, k). These sediments are interpreted to have been deposited in an intertidal or shallow protected relatively low-energy setting. A 40cm thick, clast support breccia occurs at 2000.50m. Clasts range from mm to 5cm in size, are monomict, and are angular in nature (Figure 38a). The clasts are fractured. The matrix to the breccia is brownish-grey, and possibly represents mechanically ground-up dolomite. The breccia is interpreted as a karst breccia that formed in response to meteoric dissolution, again most likely relating to the Permian uplift. And therefore not an "in-deposition" cycle top.

Overlying the thin karst at 2000m is an 8m package fine dolomitic mudstones (locally wackestones) that have abundant silica nodules and locally chert bands, and a 3m interval which is highly mouldic in nature. The silica nodules are typically small (1cm), and form a coalesced chicken-wire or enterolithic texture (Figure 15o). The nodules are considered to have been former evaporite nodules have now been dissolved/replaced by silica. The lithofacies is also locally very vuggy, probably representing nodules which have been dissolved (Figure 15n).

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Overlying these high energy grain-supported facies is a 3m thick interval rich in oncoids and cryptalgal laminae. The oncoids are typically up to 3cm in size, and the microbial coating are relatively well preserved, despite the dolomitisation (Figure 15j). The microbial/oncoidal facies forms a very strong association with well-developed laths/needles of barites (Figure 15i). Barites occurs throughout this 3m interval, occurring within the dolomitic matrix (replacive/displacive) and growing into vuggy pore space. The presence of microbial/cyanobacterial communities, forming predominantly as oncoids, is suggestive of shallow waters, possibly protected, but with sufficient energy for movement of the oncoids. The association with vugs and geopetals (interpreted as possible fenestrae) suggests that inner-ramp to intertidal settings seem most likely.

This large-scale shallowing upwards interval is capped by a 10cm thick dolomite breccia, which is interpreted to have formed in response to meteoric exposure – it is difficult to determine with confidence if the breccia is a cycle top breccia or related to the Permian uplift. This is a clast-support breccia, where the clasts are monomict. Vugs/fractures are present, and are locally filled by laminated silt. A sequence boundary has been placed at this surface.

10.7. 1965m-1960.4m

The interval between 1965m to 1960m at the top of the core is a complex interval where dolomitisation and silica diagenesis has made interpretation of the original depositional textures very difficult. The interval is typically bioclast-poor, and probably mostly had a matrix-supported depositional texture (mudstones and wackestones). Petrographic studies confirm the replacive nature of the fine dolomite, but locally bioclasts such as crinoids, sponge spicules, and possible benthic foraminifera can be recognised. What is notable are the common vugs, geopetals and silica nodules (which have potentially pseudomorphed evaporites), and pinprick moulds (which appear to have been former evaporite crystals) suggesting that this interval was in part at least shallow-marine to intertidal/supratidal.

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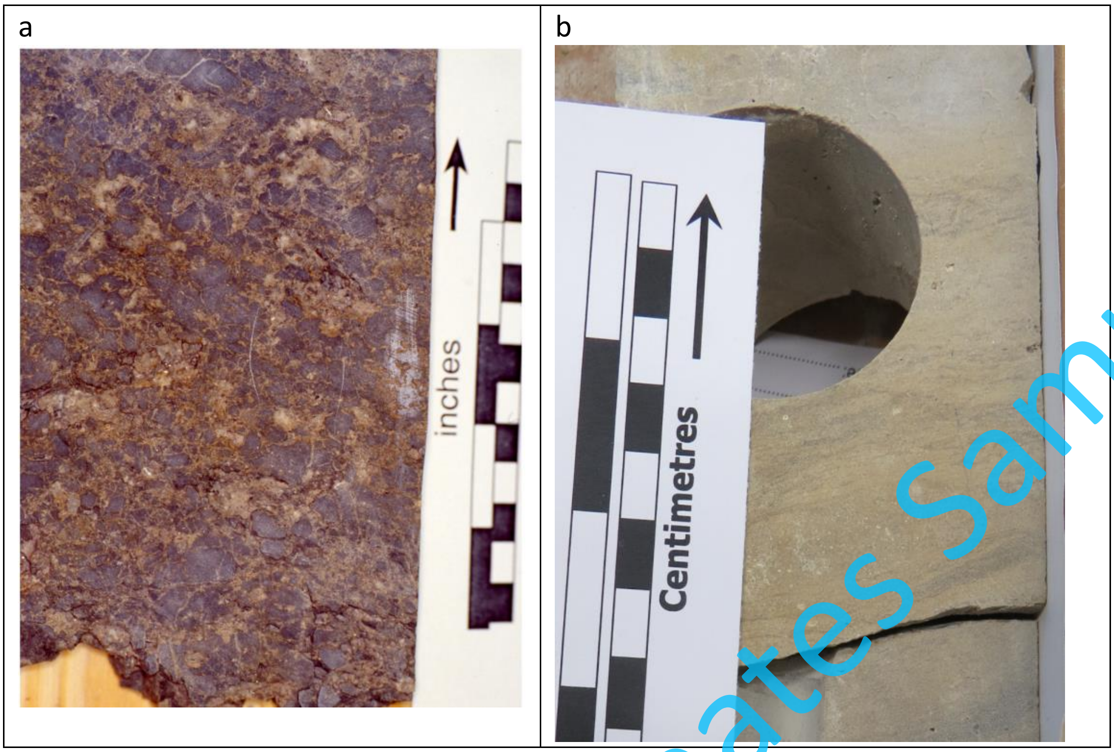

Figure 38 (a) Dolomitic breccia at 2000.1m. (b) microbially laminated dolomites at 1974.5m

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