Facies analysis and diagenetic evolution of the Dinantian carbonates in the Dutch subsurface: data and analyses well UHM-02

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Facies analysis and diagenetic evolution of the Dinantian carbonates in the Dutch subsurface: data and analyses well UHM-02

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1. Table of contents

14. Uithuizermeeden-02 (UHM-02)

14.1 Introduction

This well was also known as Gusher-01, as the well was regarded as tight (tight information-wise). Operations started 2001 and the well was abandoned 2002. This well is the most northerly well to penetrate the Dinantian intervals. This well is drilled within the Uithuizermeeden platform (Figures 14-1 to 14-3 and Table 14-1).

Figure 14-1: Map showing all the wells penetrating the Dinantian carbonates. Location of the UHM-02 well is indicated by a dashed red circle.

Table 14-1: Table summarising the coordinates of the UHM-02 well (from www.nlog.nl).

Co-ordinates (x, y in utm31, ed50 format)	752854, 5929191
Lat/Long (°)	53.44981495, 6.80805075
Supplied co-ordinates	249314.13, 607914.33 (RD)
Depth in meters referred to :	Rotary Table
Total depth (m, along hole) :	5432
Vertical position of Rotary Table :	11.57 meter relative to NAP
Trajectory shape :	Vertical
Deviation in X-direction :	-3.99
Deviation in Y-direction :	-8.96
True vertical depth (TVD) in m :	5430.997

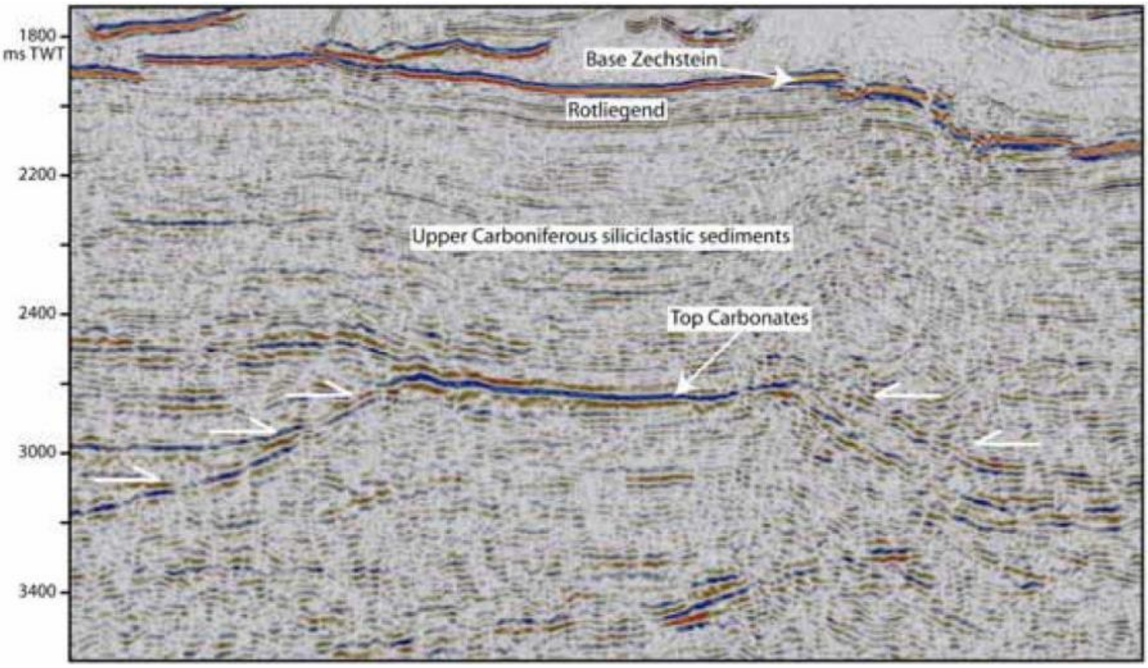


Figure 14-2: Seismic line showing the Uithuizermeeden platform as depicted in Kombrink (2009).

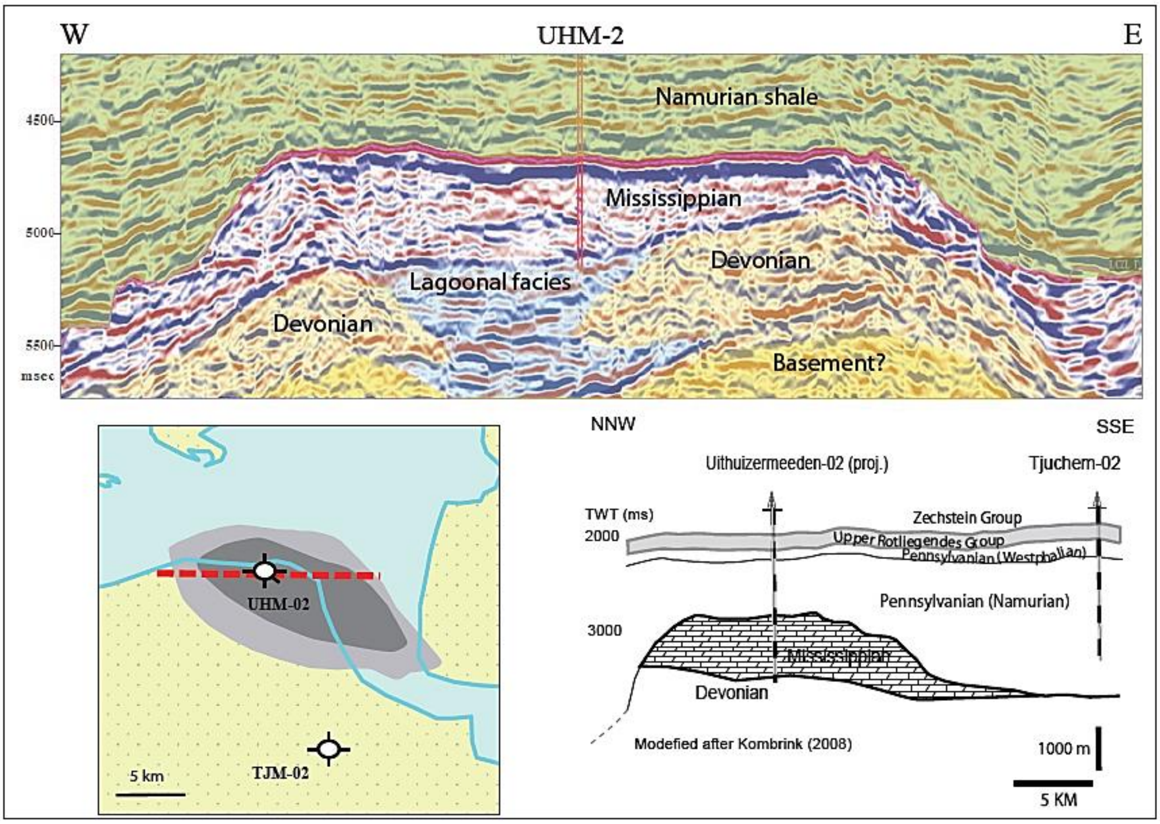


Figure 14-3: Interpretation of the Uithuizermeeden platform by van Hulten (2012).

14.2 Available dataset

Most of the available data and reports on the UHM-02 well are available on "www.nlog.nl" within the following link:

https://www.nlog.nl/nlog/requestData/nlogp/allBor/metaData.jsp?tableName=BorLocation&id=106523395

The most relevant publications discussing and presenting the data obtained from UHM-02 well are as following:

Abbink, O. A., Devuyst, F. X., Grotsch, J., Hance, L., van Hoof, T. B., Kombrink, H., and van Ojik, K. (2009). The Lower Carboniferous of Key-well UHM-02 , Onshore The Netherlands , and Implications for Regional Basin Development. In EAGE 71st Conference and Technical Exhibition (p. 5). Amsterdam. https://doi.org/10.3997/2214-4609.201400469

Bakker, E., and Pruno, S. (2003). Final Report conventional and special core analysis on cores from well Gusher-1. Panterra Report. Warmond.

Bouroullec, R., Nelskamp, R., Kloppenburg, A., Abdul Fattah, R., Foeken, J., Ten Veen, J., Geel, C..R., Debacker,T., and Smit, J. (2019). Burial and Structural Analysis of the Dinantian Carbonates in the Dutch Subsurface. SCAN Report, September 2019, 170 p. Report downloadable from www.nlog.nl/scan.

Carlson, T. (2019). Petrophysical Report of the Dinantian Carbonates in the Dutch Subsurface. SCAN Report, 26 p. Report downloadable from www.nlog.nl/scan.

Chemostrat. (2003). Chemostratigraphy of Carboniferous Sequences, wells TJM-2A and UHM-2, Holland. Llanfyllin.

Church, P. (2001). Uithuizermeeden 2 - Critical Well Review. NAM B.V. Assen.

Collinson, J. D., Jones, C. M., Blackbourn, G. A., Besly, B. M., Archard, G. M. And Mcmahon, A. H. (1993). Carboniferous depositional systems of the Southern North Sea. In: Petroleum Geology of Northwest Europe: Proceedings of the 4th Conference (edited by J. R. Parker). The Geological Society, London, 677-687.

Faugères, J. C., Stow, D. A., Imbert, P., Viana, A. (1999). Seismic features diagnostic of contourite drifts. Marine Geology 162 (1), 1-38.

Gluyas, J., Tang, L., and Jones, S. (2018). Argyll Field: the first oil field to be develop ed on the UK Continental Shelf. In History of the European oil and gas industry. Geological Society of London Special publications, 465, 77-93.

Goldberg, A. T., Millan, I., Lipsey, L., and Nelskamp, S. (2017). Geothermal exploration in deep Dinantian carbonates in the Netherlands. Unpublished TNO Report. Utrecht.

Gutteridge, P. (2002a). Uithuizermeeden-2, Core 1. Summary Report. Cambridge Carbonates Ltd.

Gutteridge, P. (2002b). Microfacies, high resolution sequence stratigraphy, diagenesis and dolomitization, Dinantian carbonates: well UHM-2, onshore NE Netherlands report. Cambridge Carbonates Ltd.

Gutteridge, P. (2002c). Uithuizermeeden-2, Sidewall Core Samples: description and interpretation. Cambridge Carbonates Ltd.

Higgs, R., Reading, H., Xu Li and Eagar, R. M. C. (1990). Upper Carboniferous Lacustrine and Deltaic Sedimentology, S.W. England, Westward Ho! and Bude. Field Guide No. 15, compiled for the 13th International Sedimentological Congress, Nottingham, UK.

Hoornveld, N. (2013). Dinantian carbonate development and related prospectivity of the onshore. Vrije Universiteit Amsterdam.

Jaarsma, B., Brolsma, M. J., Hoetz, G., and Lutgert, J. E. (2013). Exploring Dinantian Carbonates in the SNS - New Data Offering New Insights. In 75th EAGE Conference & Exhibition incorporating SPE EUROPEC 2013, London, 5 p.

Kombrink, H. (2008). The Carboniferous of the Netherlands and Surrounding Areas; a Basin Analysis [PhD Thesis]: Utrecht University, 184 p.

Kombrink, H. (2009). Seismic Interpretation of Dinantian Carbonate Platforms in the Northwest European Carboniferous Basin. In 71st EAGE Conference & Exhibition Amsterdam, 5 p.

Oxtoby, N. H. (2002). 4754.50 m & 4757.02 Dinantian, Well UHM-2, Netherlands. Evidence for petroleum emplacement and the conditions of cementation from fluid inclusions. Esher.

Owens, B., Mclean, D. and Bodman, D. (2004). A revised palynozonation of British Namurian deposits and comparisons with eastern Europe. Micropaleontology, 50, 89-103.

Poty, E. (2016). The Dinantian (Mississippian) succession of southern Belgium and surrounding areas: stratigraphy improvement and inferred climate reconstruction. Geologica Belgica, 19/1-2, 177-200.

Schroot, B. M., V.Bergen, F., Abbink, O. A., David, P., V.Eijs, R., and Veld, H. (2006). Hydrocarbon potential of the Pre-Westphalian in the Netherlands on- and offshore. TNO report.

Staplin, F. L. (1977). Interpretation of thermal history from color of particulate organic matter – a review. Palynology, 1, 9-18.

Switzer, S., Holland, W., Christie, D., Graf, G., Hedinger, A., McAuley, R., Wierzbicki, R., and Packard, J. (1994). Devonian Woodbend-Winterburnstrata of the Western Canada Sedimentary Basin, in: Geological Atlas of the Western Canada Sedimentary Basin, edited by G. D. Mossop and I. Shetsen, Canada Society of Petroleum Geology and Alberta Resource Council, 165-202.

Van Dijk, C. P. J., and Foglietta, M. (2002). Petrography of cuttings and rotary sidewall samples from well Uithuizermeeden-2, Onshore Netherlands. Panterra Report. Warmond.
Van Hulten, F. F. N. (2012). Devono-carboniferous carbonate platform systems of the Netherlands. Geologica Belgica, 15(4), 284-296.

14.2.1 Logs

This well has a complete suite of logs (Figure 14-4) and has been petrophysically evaluated within the scope of the SCAN project (Carlson, 2019).
Spectral gamma ray is available and confirms that the interval directly above the Dinantian is clay-rich. This is in contrast with the two documented SWCs from the Gutteridge (2002) report, which indicates there are some limestones above the top Dinantian pick (see discussion below).

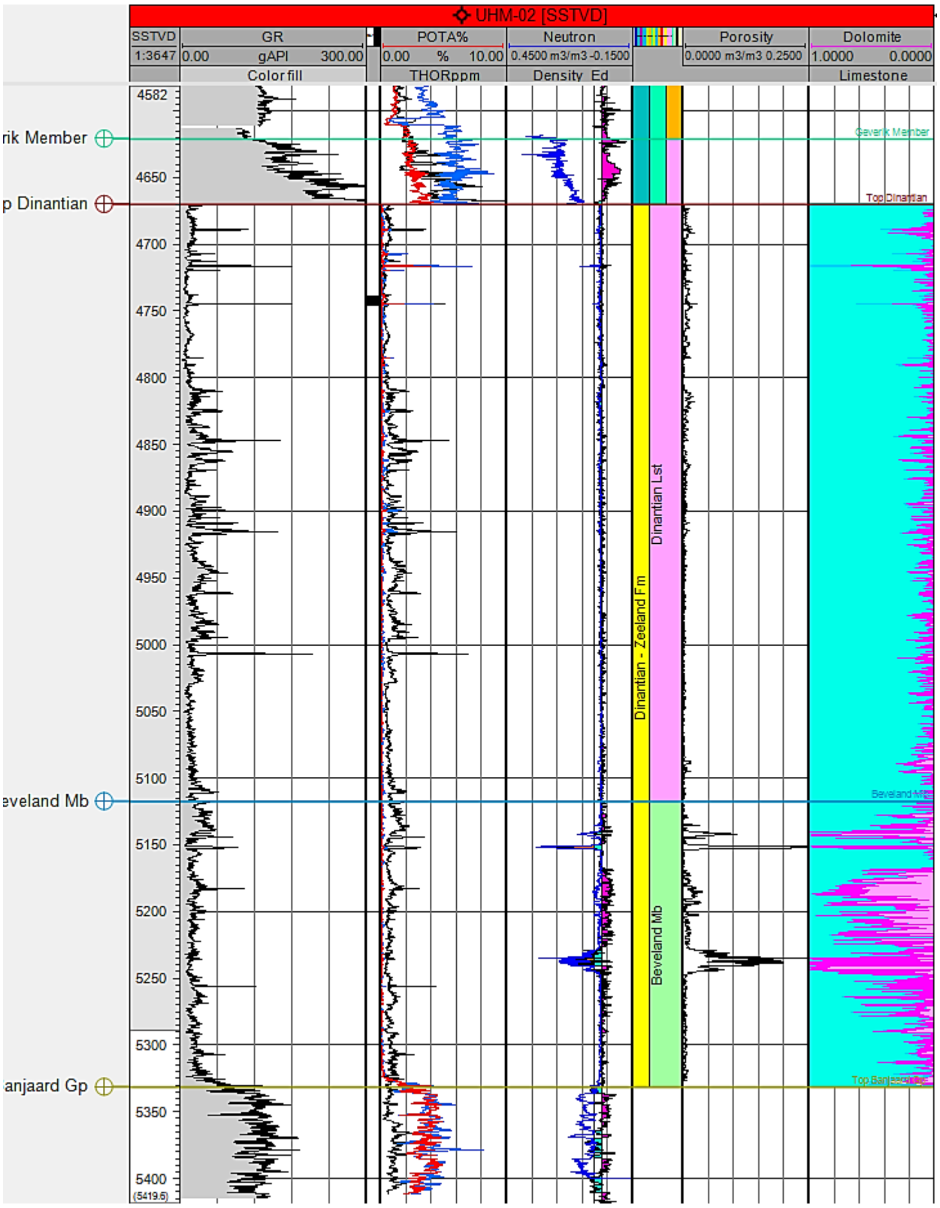


Figure 14-4: Gamma ray, neutron/density, porosity and mineralogical logs in the UHM-02 well.

14.2.2 Cores, sidewall cores and cuttings

The cored interval is between 4751 and 4757.84 m and consists of 6.74 m of limestone overlain by 0.2 m of shale.

Both rotary sidewall cores and shot sidewall cores are available. The rotary sidewall cores were described (hand specimen), and thin sections were made of the shot sidewall cores and described by Gutteridge (2002c). However, there were problems with the shot sidewall cores, and the depths have been labelled incorrectly (at least the uppermost two SWCs). The depth-assignation of the SWCs should be treated with caution.

Cuttings were recovered and described by Gutteridge (2002b) for the entire Dinantian interval, and part of the overlying Namurian, and also the underlying clastics (4650 m - 5422 m). Selected cuttings were photographed at NAM's core storage in Assen.

14.2.3 Petrography and additional analyses

A total number of 19 thin sections are available in this cored interval. These have been described by Gutteridge (2002b), and also have been photographed during this project.

In the previous study by Gutteridge (2002b), CL, stable isotopes (C and O), and fluid inclusion analyses were performed on selected core samples from UHM-02.

The only additional analyses performed in this study (SCAN project) were biostratigraphic studies, XRD and Vitrinite Reflectance studies (Table 14-2). These were all performed on the clastic mudstone at the top of the core at 4751.1 m.

Table 14-2: Available vitrinite reflectance values for wells UHM-01 and 02. Well UHM-01 was drilled extremely close to UHM-02, so the maturity analyses can be used the two wells without any issue.

Well Name	**Depth m MD**	**%Ro**
UHM-01	3178	2.03
UHM-01	3200	2.10
UHM-01	3216	2.08
UHM-02	4751.1	4.68

14.3 Stratigraphy

The succession of the UHM-02 well ranges from the Quaternary to the Devonian intervals, encountering the Cretaceous unconformity at 1946 m MD over the Namurian and the Dinantian at 4682 m MD (Table 14-3).

Table 14-3: Stratigraphy of the UHM-2 well (from www.nlog.nl).

Stratigraphical unit	**Top interval**	**Base interval**
Upper North Sea Gp.	0	374
Middle North Sea Gp.	374	395
Asse Mb.	395	495
Brussels Sand Mb.	495	589
Ieper Mb.	589	867
Basal Dongen Tuffite Mb.	867	880
Landen Clay Mb.	880	887
Ommelanden Fm.	887	1824
Plenus Marl Mb.	1824	1826
Texel Marlstone Mb.	1826	1875
Upper Holland Marl Mb.	1875	1908
Middle Holland Claystone Mb.	1908	1912
Lower Holland Marl Mb.	1912	1915
Vlieland Claystone Fm.	1915	1946
Rogenstein Mb.	1946	1996
Main Claystone Mb.	1996	2176
Lower Buntsandstein Fm.	2176	2193
Z4 Salt Mb.	2193	2245
Z4 Pegmatite Anhydrite Mb.	2245	2247
Red Salt Clay Mb.	2247	2248
Z3 Salt Mb.	2248	2480
Z3 Main Anhydrite Mb.	2480	2534
Z3 Carbonate Mb.	2534	2546
Grey Salt Clay Mb.	2546	2547
Z2 Roof Anhydrite Mb.	2547	2551
Z2 Salt Mb.	2551	2798
Z2 Basal Anhydrite Mb.	2798	2826
Z2 Carbonate Mb.	2826	2834
Z1 Anhydrite Mb.	2834	2875
Z1 Carbonate Mb.	2875	2880
Coppershale Mb.	2880	2881
Ten Boer Mb.	2881	2949
Upper Slochteren Mb.	2949	3043
Ameland Mb.	3043	3061
Lower Slochteren Mb.	3061	3170
Ruurlo Fm.	3170	3455
Baarlo Fm.	3455	3816
Ubachsberg Mb.	3816	3959
Epen Fm.	3959	4633
Geverik Mb.	4633	4682
Zeeland Fm.	4682	5130
Beveland Mb.	5130	5344
Banjaard Gp.	5344	5432

14.3.1 Dinantian interval

The Dinantian interval is present between 4682 and 5344 m MD and was originally interpreted as a generic Zeeland Formation overlying the Beveland Member at 5130 m.

14.4 Biostratigraphy

The biostratigraphy is not covered in any report available on NLOG. Abbink et al. (2009) summarised the results on 86 samples, prepared and analyzed for sporomorph taxa and 59 for foraminifera. Accordingly, Tournaisian is missing, with the early Molinacian (Chadian - Cf4α) sitting on top of ?Late Devonian (Figures 14-5 and 14-6). The topmost Warnantian (Brigantian) is present, although the latter authors indicate an unconformity at the top of the Dinantian. Pendleian overlies on the topmost Warnantian (Brigantian), and thus it cannot be a significant unconformity. Abbink et al. (2009) also reported that part of the Arnsbergian sediments are absent, but do not indicate if the Pendleian is complete. No details on the faunas are indicated by the latter authors.

Van Hulten (2012) suggested that UHM-02 well was terminated in Famennian aged clastics (Figure 14-7), but gave no supporting evidence while indicating Frasnian rather than Famennian in the presented figure. He also suggests that LTG-01 terminated in the same clastics.

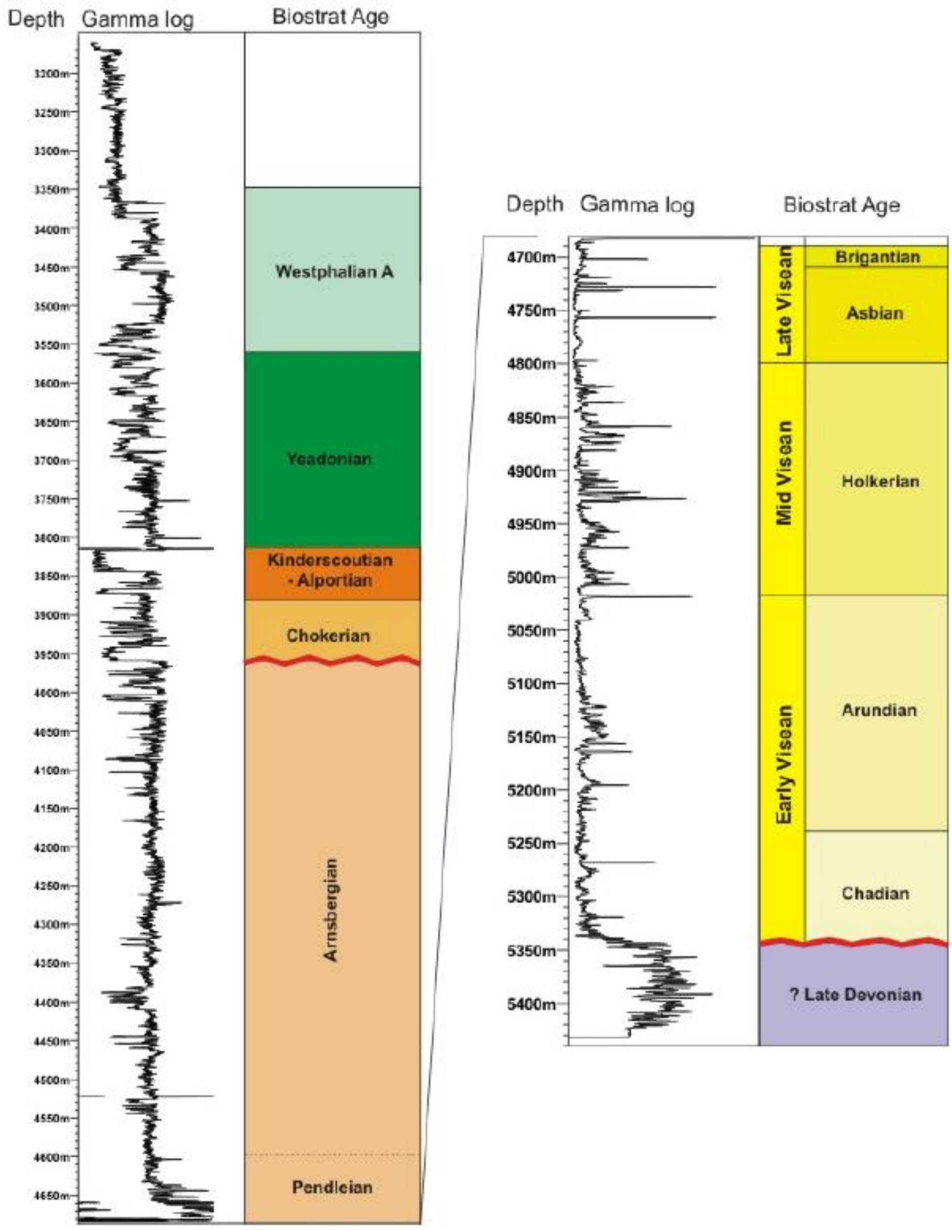


Figure 14-5: Biostratigraphic interpretation of the UHM-02 well, from Abbink et al. (2009).

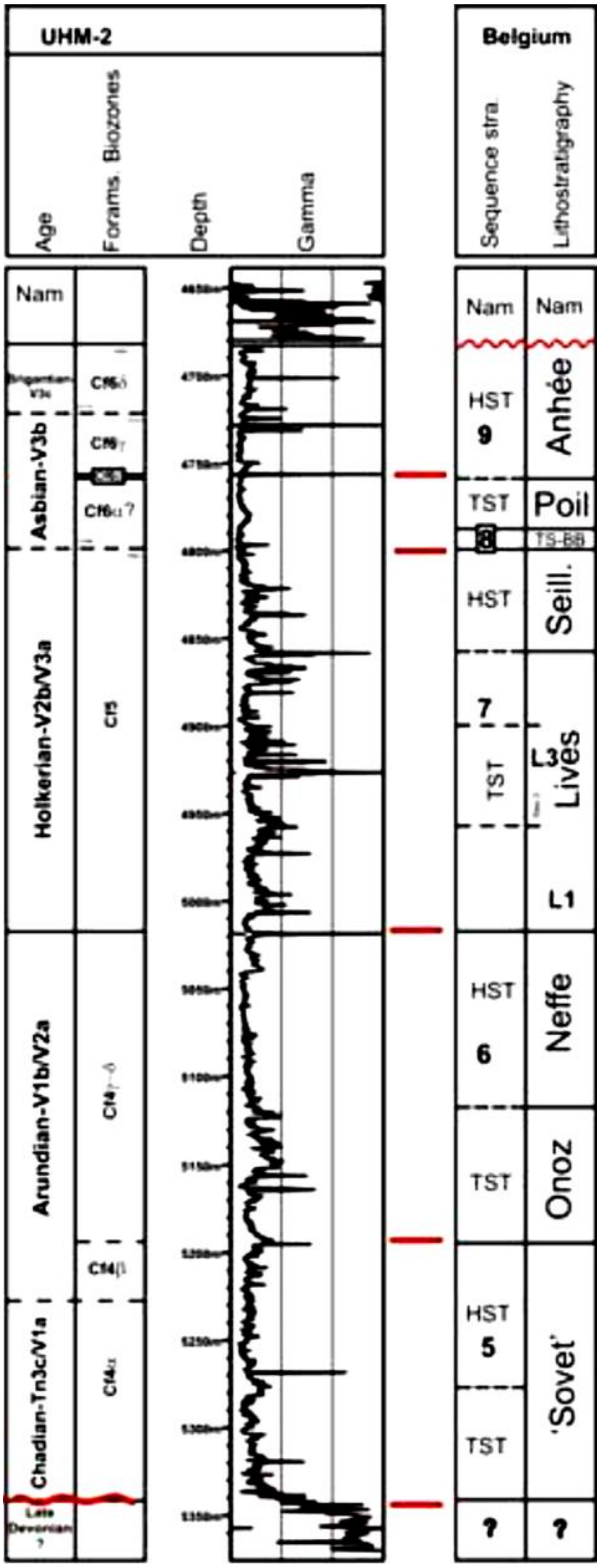


Figure 14-6: Sequence stratigraphic subdivision of the UHM-02 well as interpreted by Abbink et al. (2009). The sequence stratigraphic framework is the one applied in Belgium (e.g. Poty, 2016).

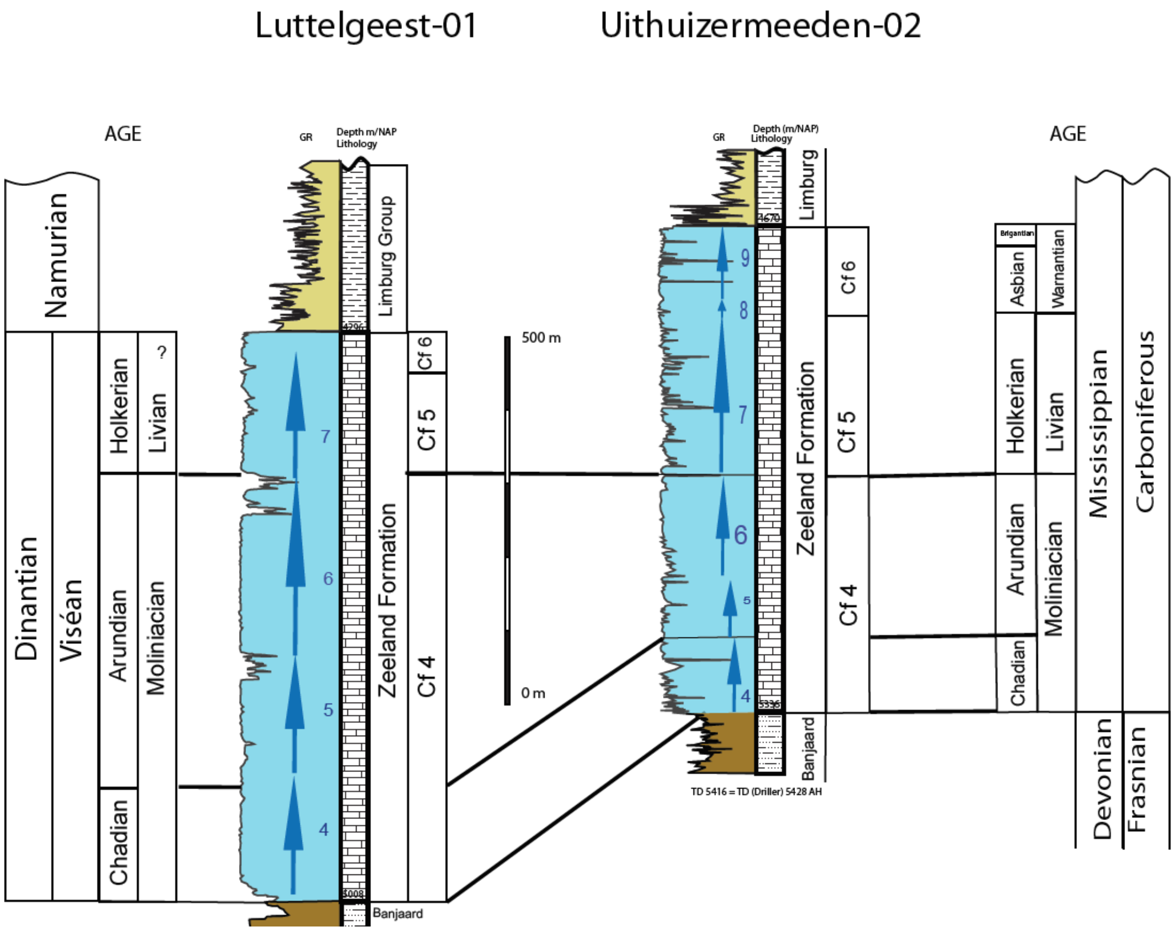


Figure 14-7: Correlation of the LTG-01 to the UHM-02 well by van Hulten (2012).

Chemostratigraphic correlation is presented by Chemostrat (2003). A total number of five-fold chemostratigraphic zonation and correlation scheme was constructed for the Carboniferous successions penetrated by wells TJM-02A and UHM-02 (Figure 14-8). The chemostratigraphic zonation being based on changes in provenance as well as weathering, facies and palaeo-environmental factors.

The studied intervals are subdivided into chemostratigraphic packages, units and subunits. Packages P2 to P5 are recognised in both study wells, with package P1 only recognised in well UHM-02, though P1 may lie below the well TJM-02A study interval. The packages have following principal geochemical characteristics:

- Package P1: high Ca levels
- Package P2: lower Rb/K and Rb*Cs/La values overall than packages P3 to P5
- Package P3: higher Fe/K values than package P4 and lower Zr/Nb values than package P5
- Package P4: lower Fe/K values than package P3 and lower Zr/Nb values than package P5
- Package P5: higher Zr/Nb values than packages P3 and P4

The confidence assigned to the correlation of Packages P2 and P3 is lower than that of Packages 1,4 and 5. The chemostratigraphy appears to support the biostratigraphic interpretation of Abbink et al. (2009) in that there is little or no missing stratigraphy at the Namurian/Dinantian boundary. Based on high U and Mo values, Chemostrat (2003) concluded that Unit P2 was deposited in mainly anoxic conditions. The upper part of the succession was deposited in less anoxic conditions with increased input from subaerial weathering. They did not analyze sandstones because these are litharenites.

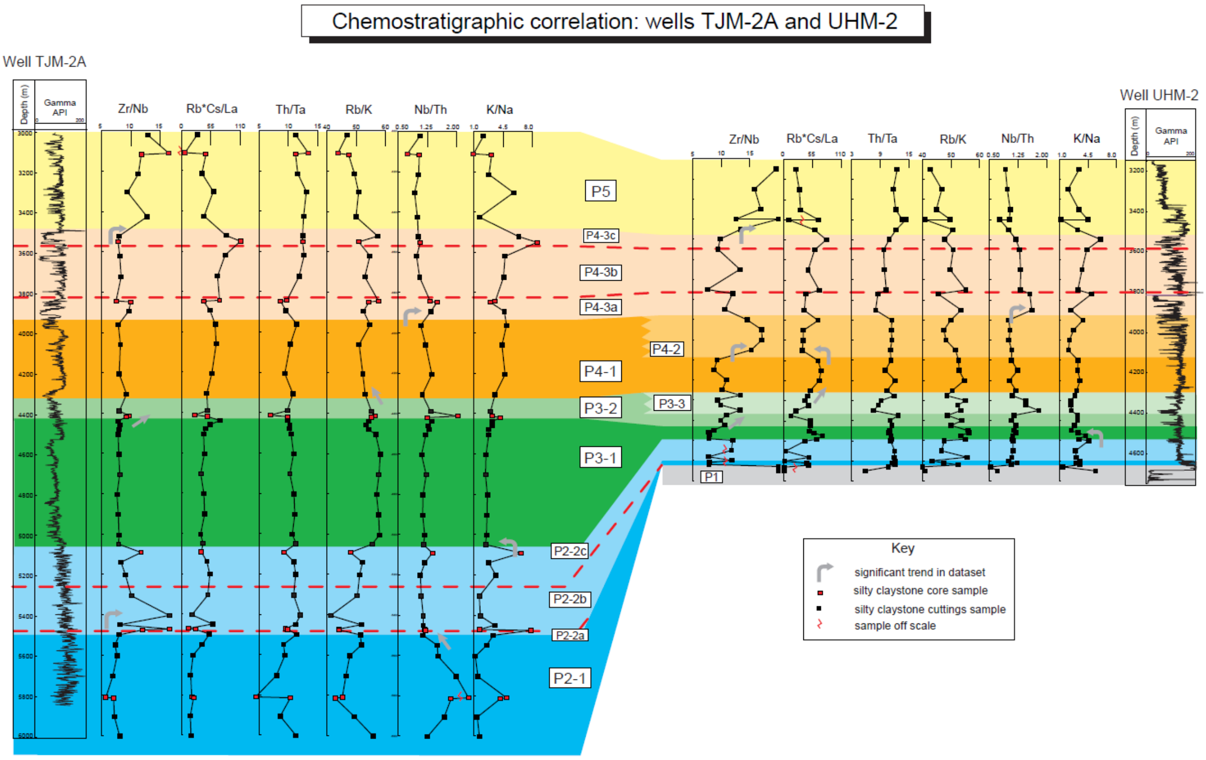


Figure 14-8: Chemostratigraphic correlation between wells TJM-02A and UHM-02 (Chemostrat, 2003).

It is necessary to understand the relationship between TJM-02A and UHM-02 wells, as there are clear geometric relationships from the seismic which suggests that the early Namurian onlaps against the Uithuizermeeden isolated platform. Biostratigraphic data in TJM-02A indicate that the base of the well can be dated by the spore *Crassispora kosankei*. There are conflicting interpretations of the age-assignation for this spore though. A report prepared by the Rijks Geologische Dienst concluded that *Crassispora kosankei* indicates Upper Namurian A to Westphalian D age. Publications by Owens et al. (2004) suggest an Alportian age, broadly supporting conclusions of the Rijks Geologische Dienst. However, publications by Higgs et al. (1990) and Collinson et al. (1993) suggested that the spore can be older (Pendleien age). In general, the First Appearance Datum (FAD) of this spore is usually base Namurian in Northwestern Europe.

Based on the seismic geometries, the base of TJM-02A is older than the top of UHM-02 (i.e. the Alportian age). An assumed Pendleian age as the oldest possible age for the base of TJM-02A is also comparable to the top of UHM-02. This means the sedimentation rates in the basin must have been considerably higher than the platform top. Possible presence of a condensed succession overlaying the top of UHM-02 invokes an almost rapid drowning of the platform, as deep-water shales appear to overly the shallow-water platform facies. Nevertheless, none of the cuttings indicate that the facies are especially condensed (i.e. no hardgrounds, no phosphate mineralisation, no rhodoliths). Based on the seismic signature, one may assume that the lower part of the Namurian succession in UHM-02 was missing (Figure 14-9). However, this is not the case according to Abbink et al. (2009). It should be noted that we do not have any biostratigraphic information to calibrate/confirm their interpretation.

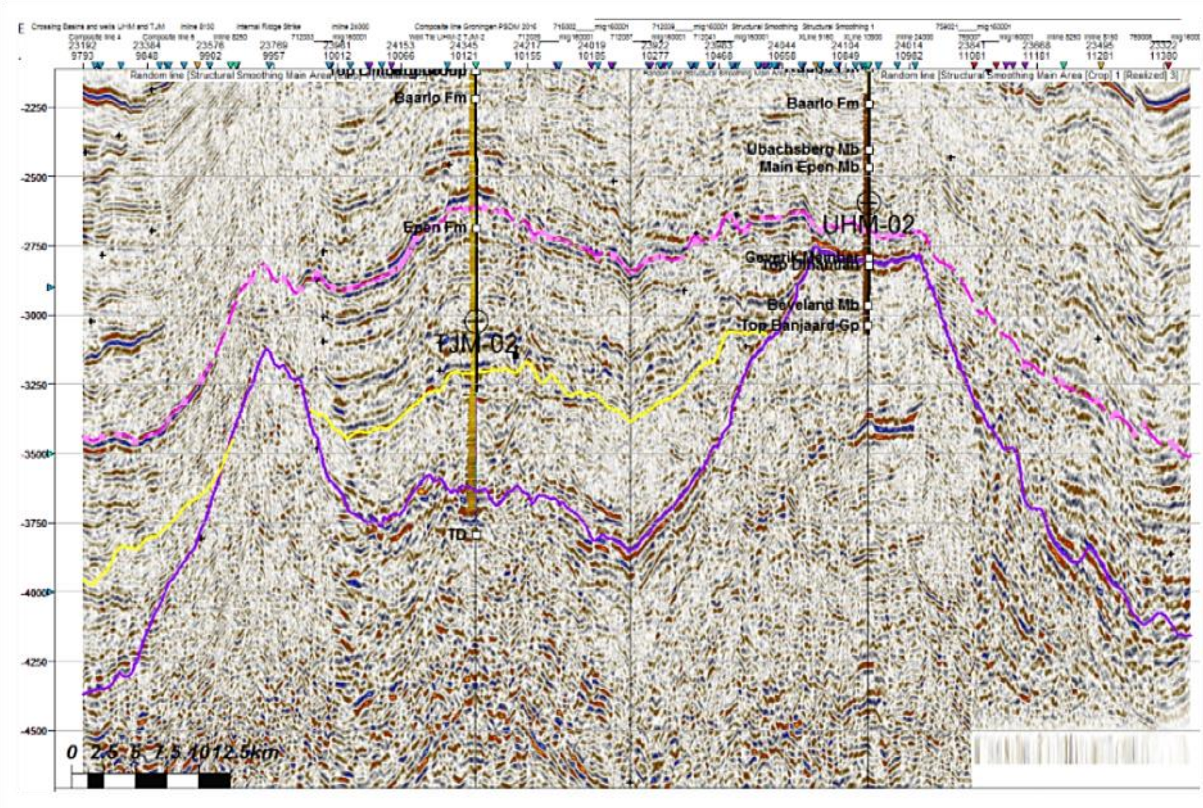


Figure 14-9: Seismic interpretation across the UHM-02 and TJM-02A wells, showing the platform-to-basin relationships.

14.4.1 New Biostratigraphic Dating

A sample from top of the UHM-02 well (4751.10 m) was analyzed for biostratigraphic dating (SCAN project). The obtained data indicated a kerogen residue dominated by black degraded organic material, with rare black wood and miospores. Miospore assemblage includes rare black indeterminate miospores. The common *Lycospora* spp. are black apiculate miospores. Presence of common *Lycospora* spp. suggests an age of not older than Visean, but *Lycospora* spp. are often the dominant components of miospore assemblages from the Visean and throughout the Late Carboniferous. The spore colouration is black, spore colour index 4, (Staplin, 1977).

14.5 Sequence stratigraphy

The biostratigraphy of the UHM-02 well shows that the lower part of the Dinantian succession is incomplete and dates to early Moliniacian (Chadian). The basal Dinantian sedimentary sequences recognised in the SW Netherlands are missing here. Available microfacies information (Gutteridge, 2002b) of cuttings has been incorporated in to the present study. The following depositional sequences have been tentatively recognised in the well (Figure 14-10):

Cycle 1c: This depositional cycle represents the initial onlap of the basement high and is probably incomplete. The depositional setting was probably in a marginal mixed clastic-carbonate environment.

Cycle 1d: This depositional cycle represents carbonate mudstone/wackestone deposited during the TST followed by low gamma-ray HST interpreted as a high energy platform interior depositional setting with bioclast and peloid packstone/grainstone.

Cycle 2a: This depositional cycle is interpreted as carbonate mudstone/wackestone deposited during the TST followed by low gamma-ray HST indicating a high energy platform interior

depositional setting with bioclast and peloid packstone/grainstone. Some gamma-ray spikes may represent soils development at the high order sequence boundaries.
Cycle 2b: This depositional cycle represents carbonate mudstone/wackestone deposited during the TST followed by low gamma-ray HST interpreted as a high energy platform interior depositional setting with bioclast and peloid packstone/grainstone.
Cycle 2c: This depositional cycle is interpreted as carbonate mudstone/wackestone deposited during the TST followed by low gamma-ray HST pointing to a high energy platform interior depositional setting with bioclast and peloid packstone/grainstone.
Cycle 2d: This depositional cycle is interpreted as a carbonate shelf deposit in a platform interior setting. At least one flooding event may be present and the gamma-ray spikes may represent soils developed at high order sequence boundaries.
Cycle 3a: This depositional cycle is interpreted as a carbonate shelf deposit in a platform interior setting. At least one flooding event may be present and the gamma-ray spikes may represent soils developed at high order sequence boundaries.
Cycle 3b: This depositional cycle generally has a low gamma-ray signature with thin spikes interpreted as soils developed at high order sequence boundaries. Core from the depositional cycle shows that the carbonates were deposited in a high energy shelf setting above normal wave base.

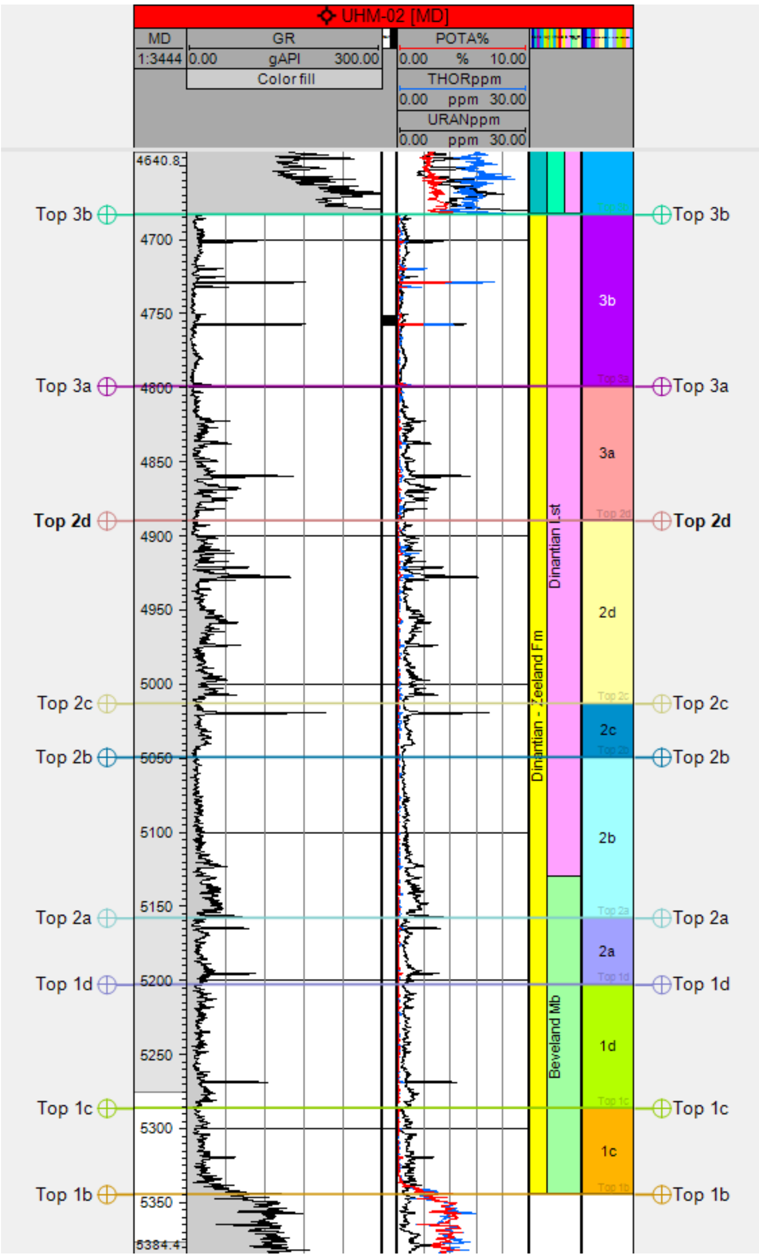


Figure 14-10: Depositional cycles recognised in the UHM-02 well.

14.6 Sedimentology

14.6.1 Namurian

Cuttings and rotary side wall core (SWC) descriptions indicated the Namurian section which are directly overlying the Dinantian carbonates are shales, locally laminated, argillaceous with rarer arkosic sands. These have a very high gamma ray signature and are also clay-rich according to the spectral gamma ray tools. There are also two "shot" SWCs within the overlying high gamma ray interval, however, these are composed of shallow marine carbonates. According to Carlson (2019) there were problems with the shot SWC, and this data must be disregarded as it cannot be representative of the Namurian section, and the depths must have been labelled incorrectly.

14.6.2 Dinantian

Nearly 7 m of core has been taken from the upper parts of the UHN-02 well. Core 1 comprises 6.74 m of limestone overlain by 0.2 m of shale (Figure 14-11). The limestone consists mainly of sorted grainstone/packstone (Figures 14-12 and 14-13) with some wackestone/packstone beds. No sedimentary structures are present; bedding is poorly defined and marked by subtle changes in colour, sorting and mottling, occasionally emphasised by the presence of stylolites. The majority of bioclasts are disarticulated, fragmented and rounded and include endothyrid, earlandid and archaeodiscid foraminifera, beresellid algae, Koninckopora, calcispheres, echinoderms, bivalves and brachiopods. Occasional large fragments of solitary rugose corals, brachiopod valves and an in situ Syringopora colony can be seen in the core. Bioclasts have been micritised and peloids are locally common. Some allochems also have a partial coating of micrite. Intervals of bioclast wackestone/packstone with bioturbation mottling are also present. There is no evidence of emergence through the limestone and no evidence of depositional cyclicity over the thickness of the core.

The majority of the cored section was deposited in a moderate to high-energy well reworked subtidal environment just above normal wave base. The diverse bioclast assemblage indicates deposition in open marine conditions and the presence of micritisation and coating of allochems indicates episodes of relatively slow sedimentation. The overall depositional setting was part of a carbonate shoal complex associated either with a carbonate shelf margin of on the inner part of a carbonate ramp. The intervals of bioturbated wackestone were deposited in a moderate to low energy subtidal environment just below normal wave base or in a sheltered subtidal setting within the carbonate sand body.

Cuttings samples suggest that the succession comprises cyclic subtidal carbonates deposited on a carbonate shelf. Carbonate cycles are dominated by low to moderate energy subtidal carbonates that shallow-up into higher energy subtidal and occasional peritidal conditions. Since the core shows no evidence of cyclicity, the scale of cyclicity is thought to be larger than the core (i.e. on the order of at least 10 m).

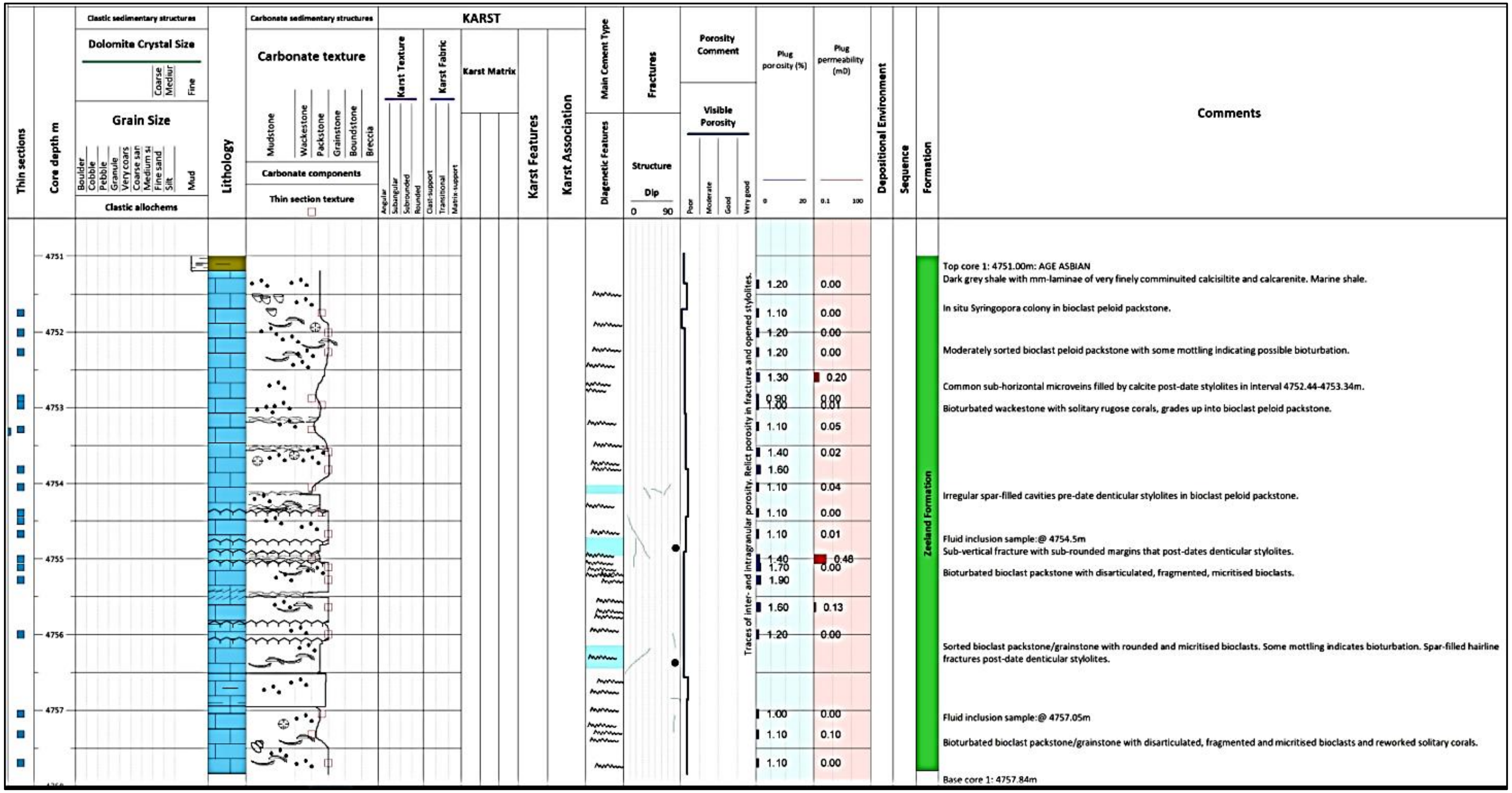


Figure 14-11: Overview of the sedimentological log constructed for Core 1, well UHM-02 (an image of higher resolution is available as a supplementary document).

Figure 14-12: Left, well sorted fine grainstone/packstone with calcite vein. Right, shale bed at top of core 4751.0 m.

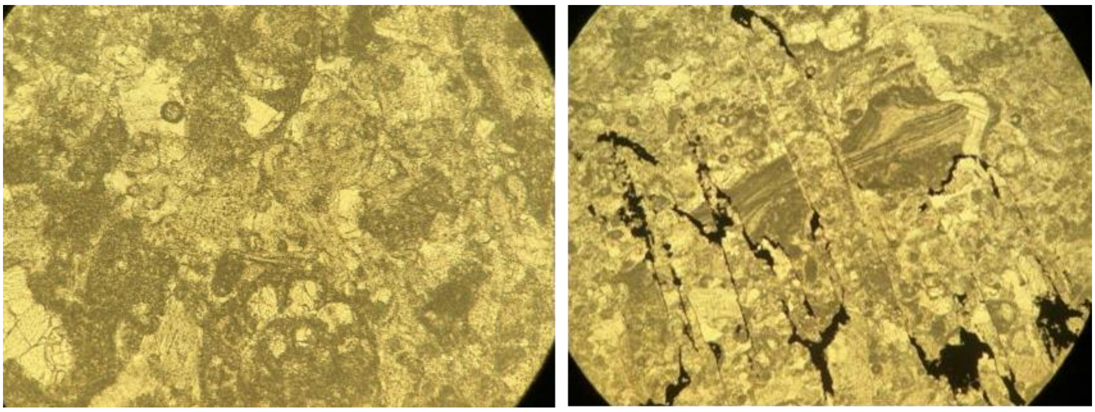
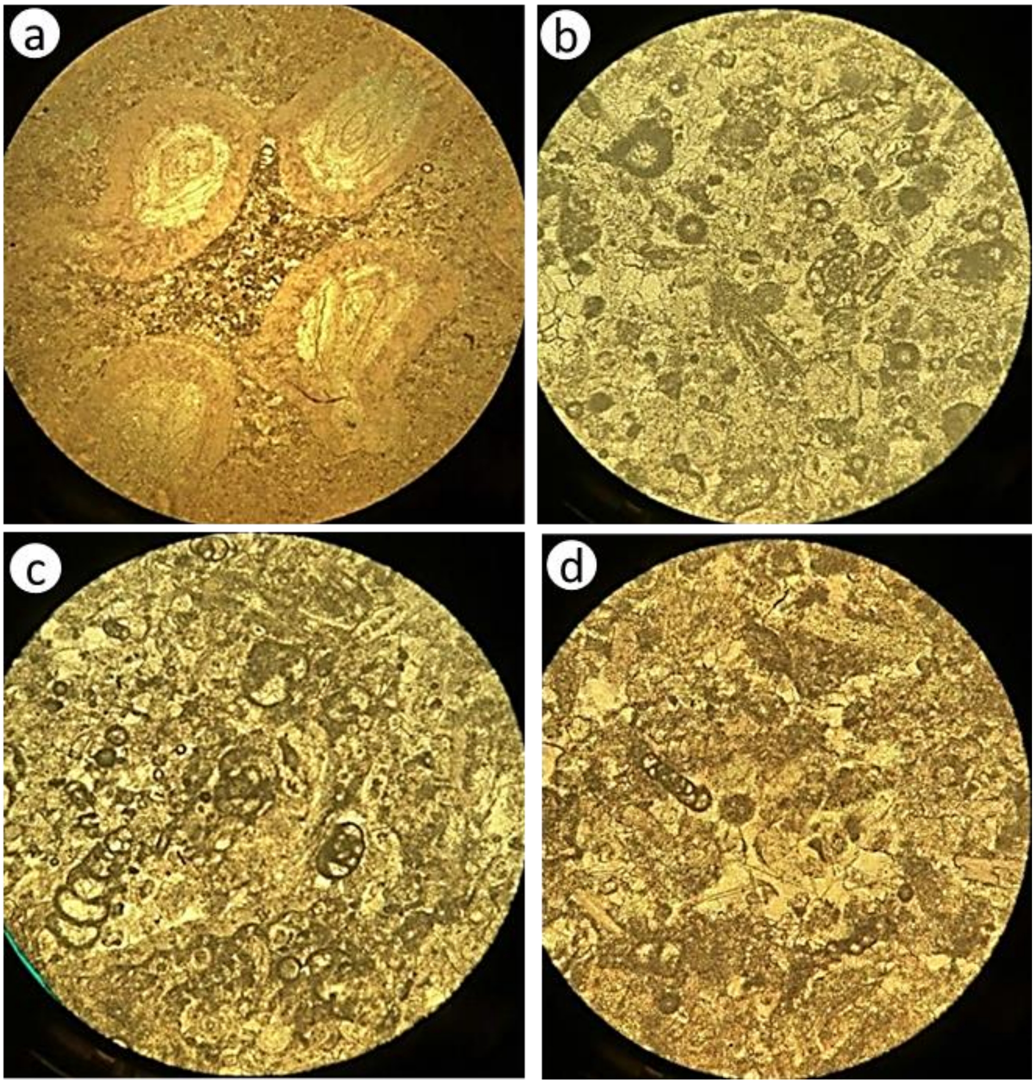


Figure 14-13: Left, well sorted fine grainstone with micritised peloids, crinoids and foraminifera (4752.88 m, FOV= 3.5 mm). Right, well sorted fine grainstone with micritised peloids, brachiopods and foraminifera affected by stylolite (4752.88 m, FOV=3.5 mm).

The depositional setting of Core 1 is interpreted as a high energy carbonate platform interior, above normal wave base. The shale at the top of the core is poorly laminated. It is noon-calcareous with very fine layer laminations and compacted lenses of silt. The shale is in sharp contact with the underlying limestone; but there is no clear evidence in the topmost limestone showing the possible nature of this contact (e.g. erosional). XRD analysis of the shale indicates indicated minerals such as illite-chlorite-smectite (61.6%), quartz (12.3%), alkali feldspar (9.3%), anatase (Titanium Oxide, 1.1%) and pyrite: 14.8%. The shale is tentatively interpreted as a modified soil of possible volcanic origin. Representative microfacies photomicrographs are shown in Figure 14-14.



14-14: a) Syringopora (4751.75 m, FOV=8 mm). b) Bioclastic pack- to grainstone (4753.25 m, FOV=2 mm). c) Bioclastic pack- to grainstone with common forams (4754.05 m, FOV=2 mm). d) Bioclastic pack- to grainstone with common forams (4755.28 m, FOV=2 mm).

The rest of the Dinantian interval is evaluated through cuttings and sidewall cores. The facies is characterised by various microfacies associations, indicated in Table 14-4.

Table 14-4: Microfacies associations of the UHM-02 well.

Microfacies associations					
Siliciclastic	**Mixed clastic/ carbonate**	**Carbonate**	**Diagenetic**	**Macroporosity indicators**	**Long distance cavings**
Laminated argillaceous mudstone	Terrigenous wackestone	Bioclast grainstone	Replacive dolomite	Cement crystals	Pelagic carbonate mudstone
Structureless argillaceous mudstone	Terrigenous packstone/ grainstone	Peloid grainstone	Mesocrystalline dolomite	Type 1 fractures	Glauconitic sandstone
Argillaceous siltstone		Peloid coated grain packstone	Coarsely crystalline dolomite	Type 2 fractures	
Arkosic sandstone		Bioclastic calcisiltite/ calcarenite		Fracture/vug	
		Wackestone		Lost circulation material	
		Argillaceous calcarenite			
		Peloidal wackestone			

Siliciclastic microfacies are present in the Visean but are thought to be caved. However, there is also one SWC at 5019.5 m which is siliciclastic and is described as a fine to medium grained arkose. If this is in position (i.e. the depth is not labelled incorrectly, as in the ones in the Namurian), the only way to explain clastics being part of an isolated carbonate platform is that part of the basement was still exposed and could shed the clastic material.

14.6.4 ?Devonian

The base of UHM-02 encountered >80 m of fine clastics (mudstones to sandstones), as described from the sidewall cores. The sandstones are generally fine to medium grained and are both texturally and mineralogically immature. None of the thin sections contain fossils. In the original sidewall core description report, the lack of fossils was taken as an indicator of continental sedimentation. This may be supported by paleogeography reconstructions suggesting a clastic coastline to the north of UHM-02, and indeed in the Argyll field in the UK, some 450 m of continental Upper Devonian clastics are present (Gluyas et al., 2018).

The sidewall core thin sections were not available at NAM's core storage in Assen to photograph (missing). It cannot be certain that these are Devonian clastics - an alternative is that these are Tournaisian in age – there is no age dating.

Seismic indicates that an interval of Devonian carbonates could sit underneath the drilled section in UHM-02. If a Givetian to Frasnian aged isolated carbonate platform existed at the UHM-02 locality, it is necessary to explain the presence of intervening clastics. Theoretically, it is difficult to deposit sandstones on an isolated carbonate platform, as the platform is detached from a clastic source. However, there are examples of such scenarios, such as the Devonian of the Western Canada Basin shown in Figure 14-15.

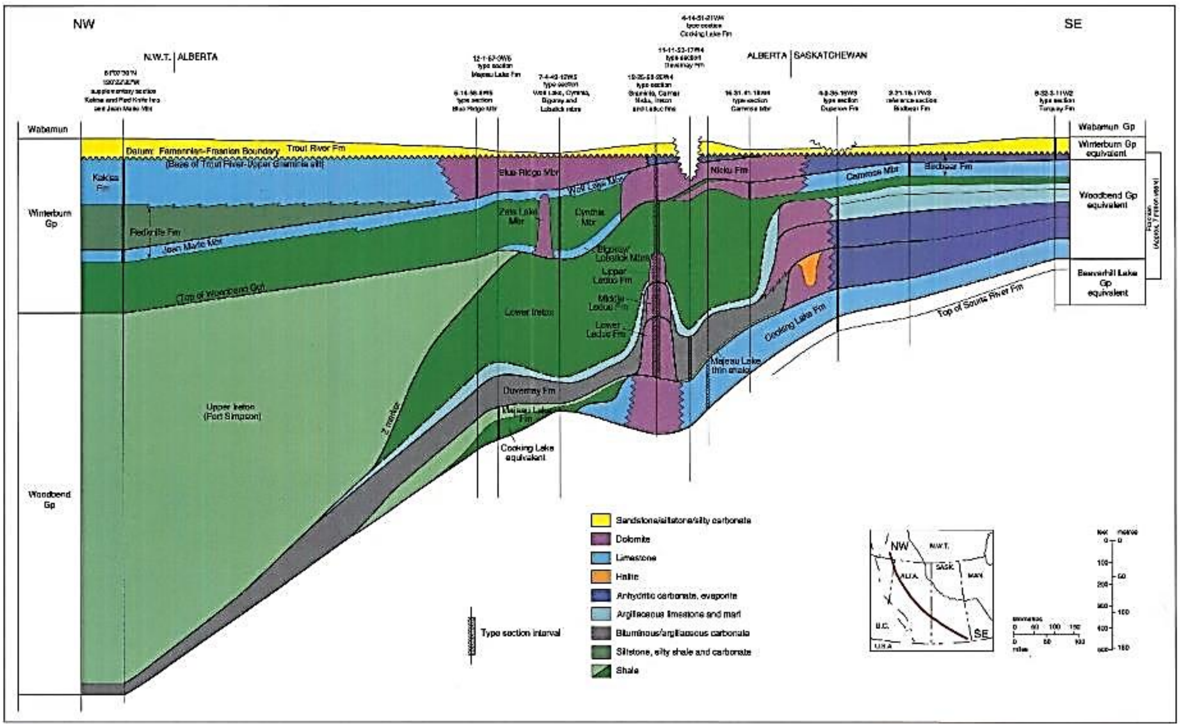


Figure 14-15: Example of Devonian pinnacle reefs in Canada, with clastics overlying the carbonates (Switzer et al., 1994).

In Western Canada, stacked shallow-water carbonate platforms are separated by shales (not sandstones, as in UHM-02). Of note, in well Munsterland-1 in Germany, a ?Famennian-aged clastic interval sits above Givetian-Frasnian carbonates. However, this well is located considerably further south compared to UHM-02. The Famennian clastics are widespread but in many places these are represented by fine clastics (i.e. shales; Rheinische Schiefergebirge area outcrops). The source of the clastics at UHM-02 may be from the Fenno-Scandian or Ringkøbing-Fyn High to the North. The distribution of Devonian platforms is shown in Figure 14-16.

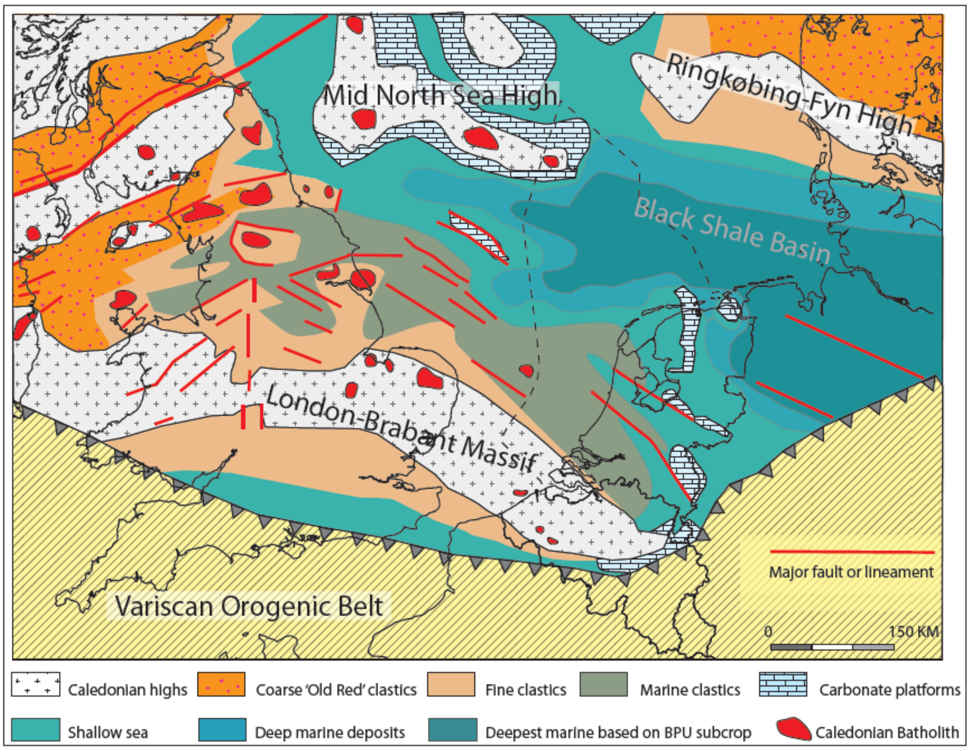


Figure 14-16: Paleogeography during Devonian (Givetian-Frasnian) (from Van Hulten, 2012).

14.7 Evolution of the UHM Platform

The Uithuizermeeden platform is the most prominent carbonate feature visible in the northern Netherlands and has been drilled by the well UHM-02. It sits directly underneath the Groningen Gas Field.

The measured thickness of the shallow water carbonates in UHM-02 well is 662 m and was drilled roughly in the centre of the platform. The edges of the platform are slightly elevated (shown in Ten Veen *et al.*, 2019), and the surrounding slopes have a dip of about 12° (Figure 14-16), with an increase in the upper slope up to 30°. The area of the platform-top (the projected area) is more than 130 km^2.

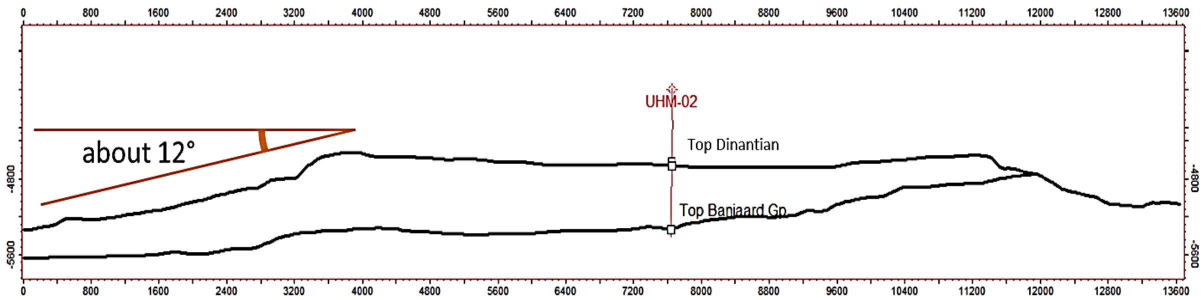


Figure 14-16: E-W profile crossing the UHM-02 well, showing the geometry of the Uithuizermeeden platform without vertical exaggeration.

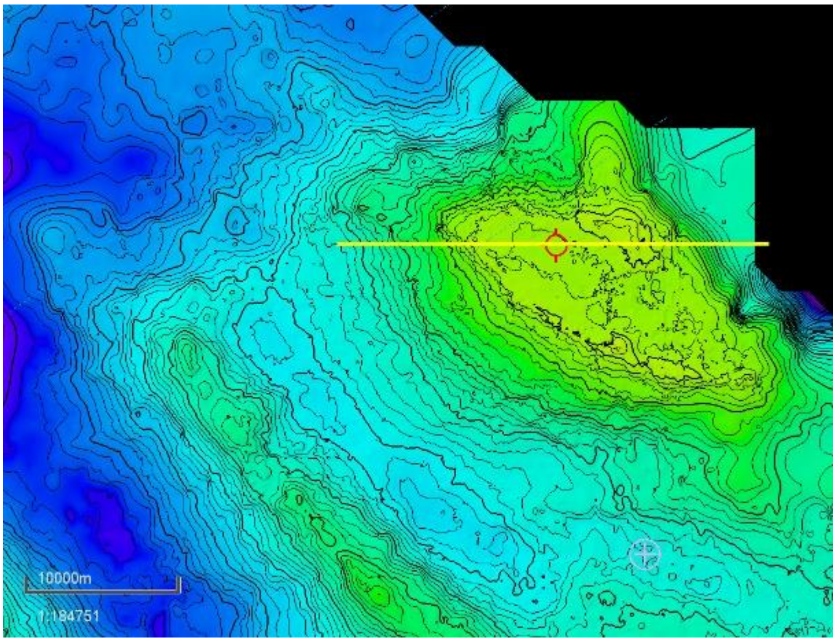


Figure 14-17: Map of the top of Dinantian with the visible feature of the UHM Platform. The yellow line indicates the seismic section shown in Figure 14-18.

The evolution of this platform is shown in Figure 14-18 and can be summarised as follows:

1. Tilted Devonian fault block during Early Carboniferous (earliest Tournaisian). This may have had as much as 1 km vertical height with respect to surrounding sea floor. Strong erosion is expected from this structural high, with the development of a thick wedge of clastics in Tournaisian basins; in the North Sea, well E06-1 encountered 700 m of Tournaisian clastics that could be related to this erosional phase in the region. Well Munsterland-1 shows an extreme condensation of the coeval basins, explained with the temporary shutdown of carbonate production.
2. Carbonate deposition onlapped the structural high from the west – this early phase of deposition may be latest Tournaisian in age but was not necessarily encountered in the well. The eastern part of the high may have been exposed and could have shed clastics onto the high and into the basin. Mounded seismic geometries may represent isolated buildups that later coalesced into a more widespread carbonate platform.
3. Early Visean – carbonate deposition is well established, but considerably thicker to the west compared to the east. The fault-block high may still have been exposed (i.e. not covered by carbonates) at this stage, so the high may have still been shedding clastics. Sidewall cores suggest that the base of the UHM-02 carbonate interval was a mixed carbonate clastic interval. It is possible at this stage that a rimmed margin is established, although reflectors in the platform "interior" still remain chaotic, perhaps due to the patchy development of these carbonates or karstification related to high order depostional cycles.
4. Expansion of carbonate platform and deposition on top of structural highs. Development of more parallel reflectors suggests the platform interior setting is better established.
5. At the end of the Visean, the carbonate platform developed a thickness of more than 600 m and a topographic relief of some 2 km above the surrounding basin. The isolated platform may have developed a rimmed margin with parallel reflectors in the platform interior.

6. Onlap of the Namurian onto the slope of the older carbonate isolated platform and death of the carbonate platform as it is suffocated by clastics derived from the north.

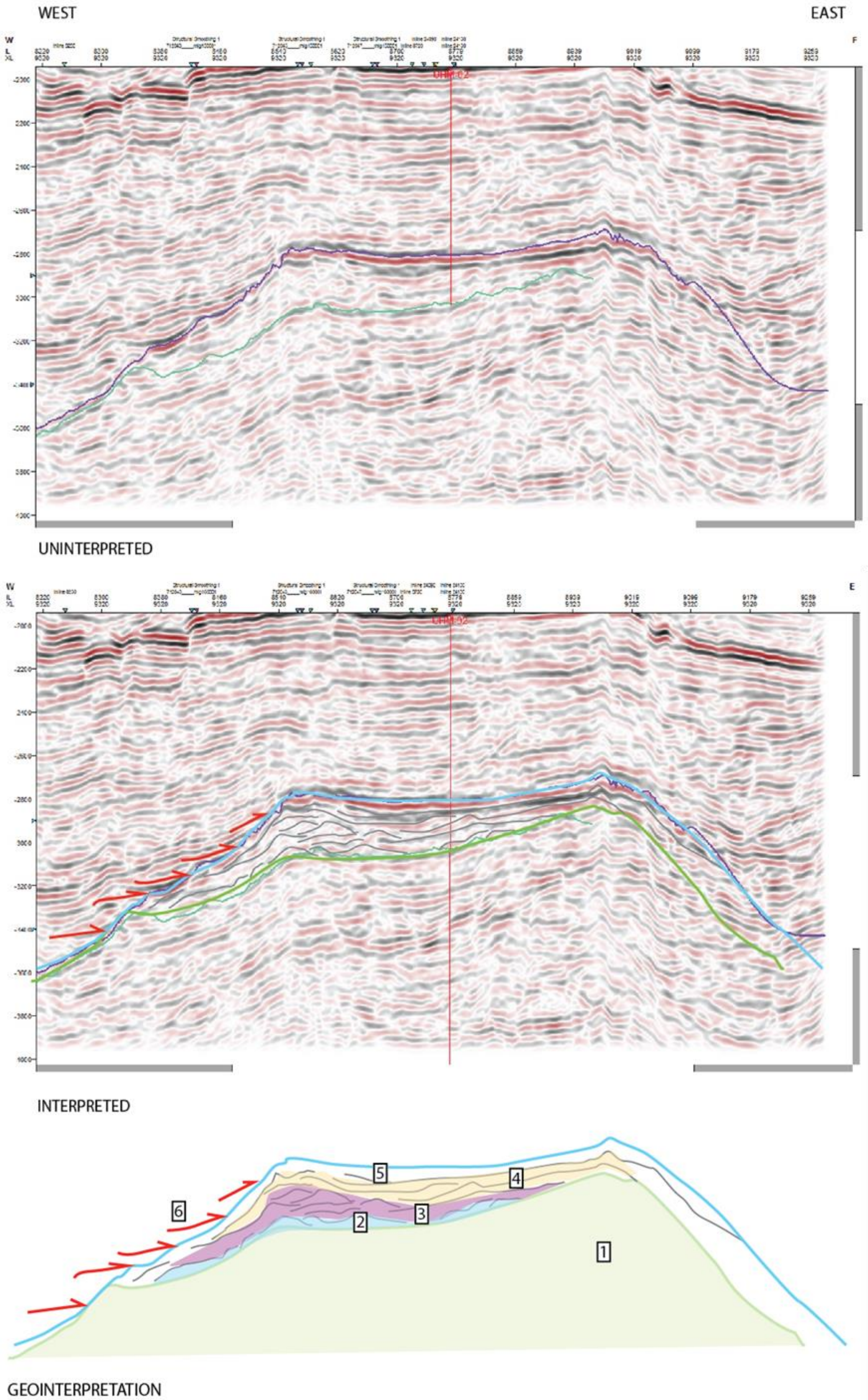


Figure 14-18: Uninterpreted, interpreted and geointerpreted west-east section through UHM platform.

It is not always clear how the eastern margin of the platform has developed. A relatively localised “apron” is developed at the base of the platform, which could be explained by a number of scenarios:

a. A depositional apron composed of reworked probable clastic material derived from the tilted fault block.
b. A carbonate apron derived from reefal material deposited on the high, but no longer present there.
c. No clear features indicating moat or channels (shown by Faugères et al., 1999) can be pinpointed but the geometry could tentatively indicate a possible contourite deposit.
d. A shallow-water carbonate platform nucleated around the northern margin of the UHM high, deposited during the early stages of shallow water carbonate production around the southern margin of the high. The carbonate platform around the northern margin may not have developed subsequently as a result of steep depositional topography of the northern margin of the exposed basement.

A strong reflector is present within the tilted fault block. This has been mapped as Base Devonian, but it cannot be excluded that some of the reflectivity was caused by multiples from the overlying salt.

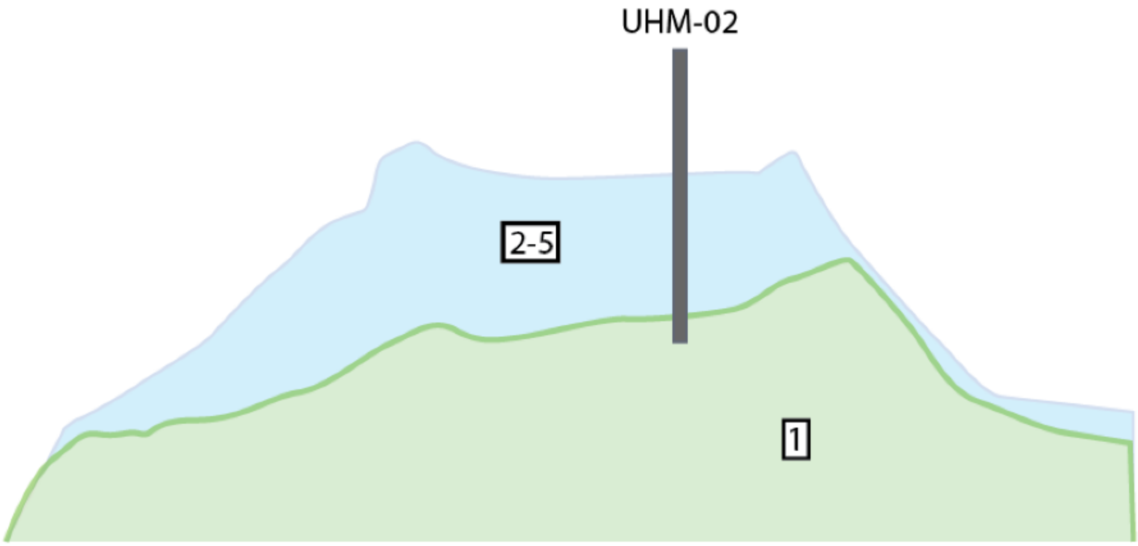


Figure 14-19: Simplified interpretation of west-east section through UHM platform shown in Figure 14-18.

14.8 Sequence stratigraphy

Details of the depositional cyclicity is discussed in Gutteridge (2002b). The cyclicity of the succession was analysed by means of a Fischer Plot that shows increasing and decreasing trends in cycle thickness that can be interpreted in terms of changing accommodation space as follows:

- Upward increase in the thickness of higher order (in this case 4th order) cycles is interpreted as an increase in accommodation space attributed to a lower order (in this case 3rd order) sea level rise.
- Upward decrease in the thickness of 4th or 5th order cycles is interpreted as a decrease in accommodation space attributed to 3rd order sea level fall.

The succession has been divided into five groups of cycles that were deposited at different stages of 3rd order sea level cycle. In some cases, the influence of 4th order sea level variations have been detected.

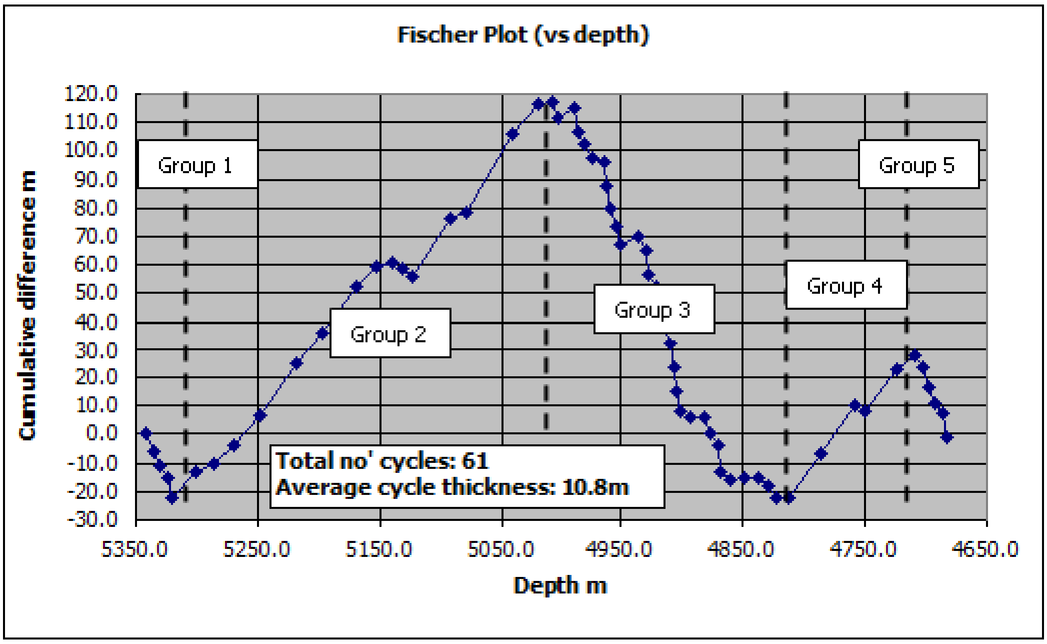


Figure 14-19: Fischer plot computed for the UHM-02 well.

14.9 Diagenesis

Macroscopic observations note that stylolitisation is pervasive in the cored interval. Stylolites frequently had a very high amplitude and density, with a vertical spacing in the order of 6 stylolites/meter.

Two generations of calcite vein, pre- and postdating these stylolites occurred in the studied cores (Figure 14-20).

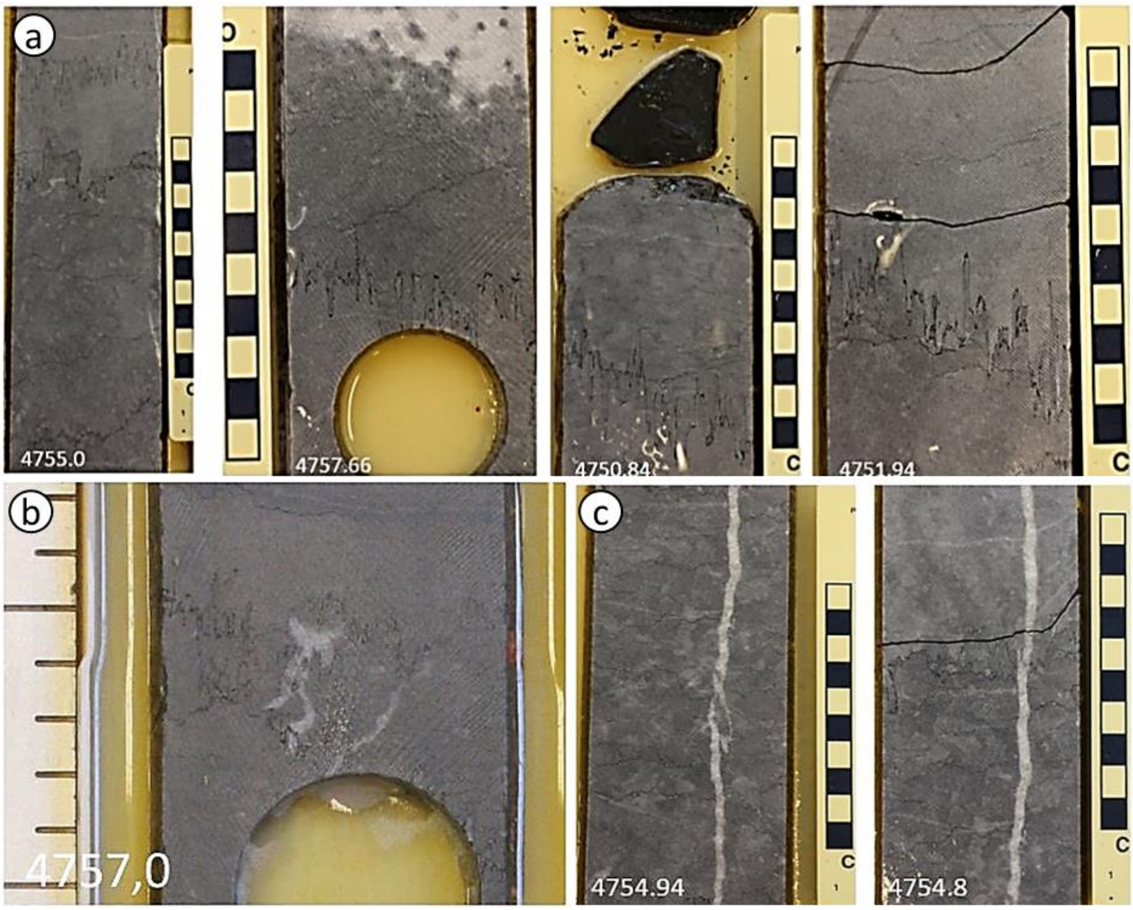


Figure 14-20: a) Common observed stylolites. b) Calcite vein pre-dating stylolites. c) Calcite veins postdating stylolites in the UHM-02 well.

14.9.1 Paragenetic sequence

Diagenetic studies were carried out by Gutteridge et al. (2002b), and have subsequently been refined during this study. The major diagenetic phases include:

1. Early burial with some meteoric cementation.
2. Early fracturing and dissolution of possible karstic origin.
3. Progressive pressure dissolution (stylolite formation) supplying carbonate for cementation.
4. Fractures postdating stylolites.
5. Matrix and cement dolomitisation.

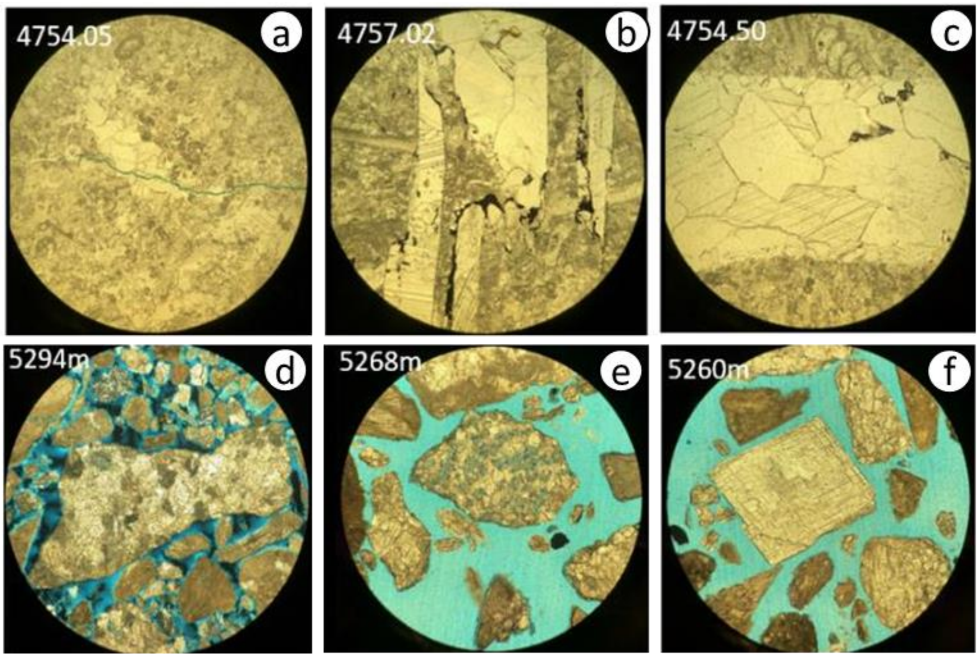


Figure 14-21: a) Calcite cemented small ?early vug (FOV=4 mm). b) Calcite vein pre-dating stylolites (FOV=4 mm). c) Calcite vein postdating stylolites (FOV=4 mm). d) Medium-coarse crystalline dolomite from cuttings samples (FOV=2 mm). e) Fine crystalline dolomite from cuttings sample with minor porosity (FOV=2 mm). f) Coarse single dolomite crystals from cuttings sample (FOV=2 mm).

A study of fluid inclusions is reported in Gutteridge et al. (2002b). Fluid inclusions in the pre-stylolite veins cement have the following characteristics:

Three types of inclusions are present:

- Two phase H_2O liquid and vapour inclusions with homogenisation temperatures in the range of 165-256 °C (mode 190-200 °C).
- Two phase CO_2 liquid and vapour inclusions with homogenisation temperatures in the range of 26-27 °C.
- Three phase CO_2 and H_2O liquids plus vapour inclusions with homogenisation temperatures of 300-350 °C (however, this may not be accurate since the inclusions decrepitated during heating run).
- There are no fluorescent inclusions in the fracture-filling cement or the wall rock indicating the presence of alive oil.

The inclusions contain co-existing CO_2, water and calcite. The CO_2 has a relatively high density of 0.22-0.26 g/cc that shows it was trapped at pressure and is not therefore of near surface origin. Freezing temperatures indicate salinities of 24-25% NaCl equivalent (however, hydrates are present that may introduce errors into the salinity measurement).

Fluid inclusions in the post-stylolite veins have the following characteristics:

- Only two phase liquid and vapour H_2O inclusions are present with homogenisation temperature in the range of 166-269 °C (mode 180 °C).
- No fluorescent inclusions in fracture or wall rock.
- Freezing temperatures indicate salinities of 25-28% NaCl equivalent (however, hydrates are present that may introduce errors into the salinity measurement).

The stable $\delta^{13}C$ and $\delta^{18}O$ isotopes of pre-stylolite and post-stylolite veins and the bulk matrix limestone were analysed (Figure 14-22).
Samples obtained from the fracture filling calcite cements appear to be relatively pure because they are coarsely crystalline with a uniform cathodoluminescence texture and plot in tight clusters on the $\delta^{13}C$ - $\delta^{18}O$ cross plot.

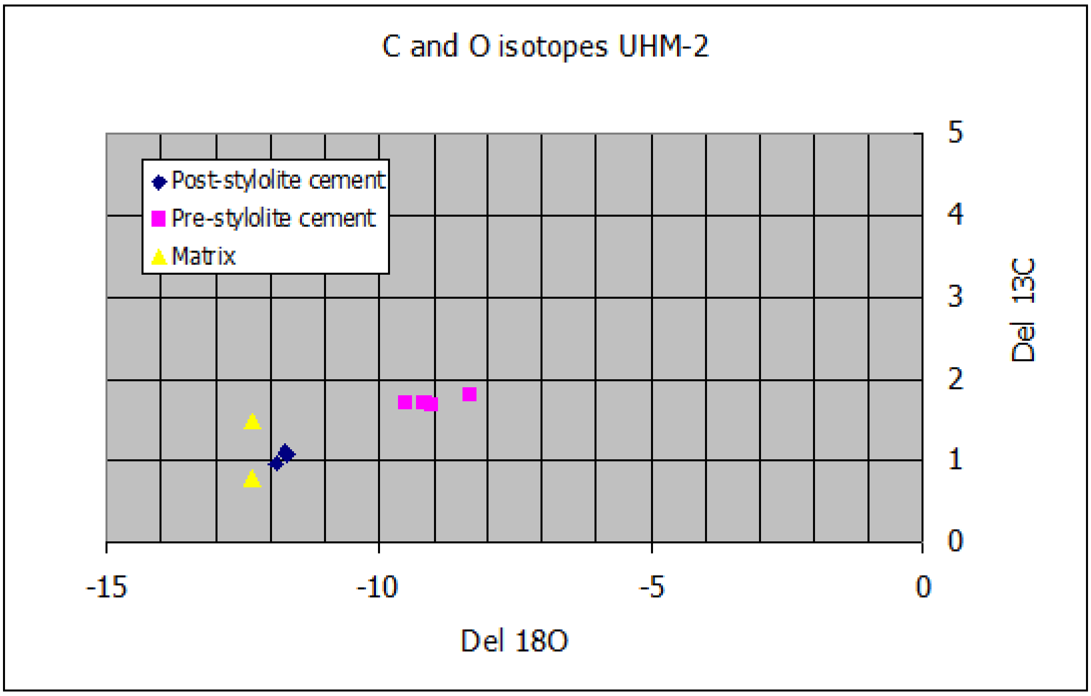


Figure 14-22: $\delta^{13}C$ - $\delta^{18}O$ cross plot of the carbonate samples from well UHM-02.

Dolomitisation has been observed in the cutting samples, but not the core. Dolomites occur primarily in the lower parts of UHM-02. The dolomites are generally meso to coarse crystalline and are unlikely to be syn-sedimentary in origin. In CL the dolomites have a dull luminescent core surrounded by non-luminescent dolomite. Locally, a finer-crystalline replacement dolomite occurs which has a bright CL character. There have been no further geochemical analyses on the dolomites to date.
New vitrinite reflectance data was obtained during this study. A Vr of 4.683 (±0.312%) was calculated from the shale located at the top of the core at 4751.1m. Spore colouration from this shale was black with a colour index of 4. The thermal evolutionary model developed by Bouroullec et al. (2019) suggests a heat-flow peak at the Early Permian and Late Jurassic, similar to that seen in LTG-01, with short-lived heat flow events/spikes relating to uplift and erosion in the Early Permian and Late Jurassic. The high measured homogenisation temperatures may indicate hydrothermal circulation of fluids during those thermal events.

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