Facies analysis and diagenetic evolution of the Dinantian carbonates in the Dutch subsurface: data and analyses wells CAL-GT-01, 02, 03

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Facies analysis and diagenetic evolution of the Dinantian carbonates in the Dutch subsurface: data and analyses wells CAL-GT-01, 02, 03

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2. Californië wells (Cal-GT-01, 02, 03)

2.1 Introduction

The Californië wells are located in the eastern Netherlands (Figure 2-1, Table 2-1) and were drilled for geothermal purposes between 2012 and 2013.

Figure 2-1: Map showing all the wells penetrating the Dinantian carbonates. Location of the Californië wells is indicated by dashed red circle.

Table 2-1: Coordinates and depth of main Californië wells.

Code	CAL-GT-01	CAL-GT-01-S1	CAL-GT-02	CAL-GT-03
Co-ordinates (x, y in utm31, ed50 format)	714934, 5701428	See parent well	714937, 5701435	714940, 5701442
Lat/Long (°)	51.42218805, 6.09139302	See parent well	51.42225071, 6.09143712	51.42231336, 6.09148122
Supplied co-ordinates	203895, 381599 (RD)		203898, 381606 (RD)	203901, 381613 (RD)
Depth in meters referred to	Rotary Table	Rotary Table	Rotary Table	Rotary Table
Total depth (m, along hole)	2082	2730	1694	2977
Vertical position of Rotary Table	33 meter relative to NAP	33 meter relative to NAP	32 meter relative to NAP	33 meter relative to NAP
Trajectory shape	Deviated	Deviated	Deviated	Deviated
Deviation in X-direction	-364.82	-399.16	340.18	166.87
Deviation in Y-direction	-681.92	-753.86	624.2	-1667.85
True vertical depth (TVD) in m	1856.643	2510.172	1481.682	2255.767

2.2 Available dataset

The Californië wells were drilled for geothermal purposes between 2012 and 2013. Two other wells, CAL-GT-04 and CAL-GT-05, were drilled later but their data will be confidential until mid-2021.

Most of the available data and the ones used in this report are available on www.nlog.nl with the following links:

https://www.nlog.nl/nlog/requestData/nlogp/allBor/metaData.jsp?tableName=BorLocation&id=949495773

https://www.nlog.nl/nlog/requestData/nlogp/allBor/metaData.jsp?tableName=BorLocation&id=949495778

https://www.nlog.nl/nlog/requestData/nlogp/allBor/metaData.jsp?tableName=BorLocation&id=1119729899

The most relevant publications discussing and presenting the data obtained from the Californië wells are:

Boxem, T. A. P., Veldkamp, J. G., and Van Wees, J. D. A. M. (2016). Ultra-diepe geothermie: Overzicht, inzicht and to-do ondergrond. TNO 2016 R10803 Eindrapport, 53, 1-53.

Broothaers, M. (2013). Het geothermieproject Nieuw Erf/Californie (Horst a/d Maas, NL); Geologische rapportage voor de SDE en SEI garantieregeling. VITO.

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Duchesne, J. (2006). Geologica Belgica. Royal Belgian Institute of Natural Sciences, 122 pp.

Geluk, M. (2007). Permian. Geological development. In: Wong, T. E., Batjes, D. A. J., and de Jager, J. (eds), Geology of the Netherlands. Royal Netherlands Academy of Arts and Sciences, 63-83 pp.

Geluk, M., Duin, E., Dusar, M., Rijkers, R., Berg, M. V., and Rooijen, P. V. (1994). Stratigraphy and tectonics of the Roer Valley Graben. Geologie en Mijnbouw, 129-141.

Geluk, M., Dusar, M., and de Vos, W. (2007). Pre-Silesian. Geological development. In: Wong, T. E., Batjes, D. A. J., and de Jager, J. (eds), Geology of the Netherlands. Royal Netherlands Academy of Arts and Sciences, 27-42 pp.

Harings, M. J. (2014). CAL-GT-01 - Implications for the Distribution of the Early Namurian Geverik Member in the Netherlands. In 76th EAGE Conference and Exhibition (p. 5). Amsterdam.

Houtgast, R., Van Balen, R., Bouwer, L., Brand, G., and Brijker, J. (2002). Late Quaternary activity of the Feldbiss Fault Zone Roer Valley Rift System, The Netherlands, based on displaced fluvial terrace fragments. Elsevier Tectonophysics, 295-315.

Kombrink, H., (2008). The Carboniferous of the Netherlands and surrounding areas; a basin analysis, Geologica Ultraiectina. 294, Ph.D. thesis University of Utrecht, 184 pp.

Kombrink, H., Doornenbal, J., Duin, E., Den Dulk, M., Gessel, S., Ten Veen, J., and Witmans, N. (2012). New insights into the geological structure of the Netherlands; Results of a detailed mapping project. Netherlands Journal of Geosciences, 419-446.

Panterra (2012). Analysis Report Water/Gas Samples CAL-GT-01 - Grubbenvorst Californie Wijnen. Leiderdorp.

Poty, E. (2014). Report on cuttings from the CAL-GT-01S borehole. Unpublished report EBN BV.

Reijmer, J. J., Johan, H., Jaarsma, B., and Boots, R. (2017). Seismic stratigraphy of Dinantian carbonates in the southern Netherlands and northern Belgium. Netherlands Journal of Geosciences, 96, 353-379.

Reith, D. F. H. (2018). Dynamic simulation of a geothermal reservoir, Case study of the Dinantian carbonates in the Californië geothermal wells, Limburg, NL. Master thesis, 103 pp.

Ter Borgh, M. (2017). Internal reporting EBN B.V.

Van Adrichem Boogaert, H. A. and Kouwe, W. F. P. (1994). Stratigraphic nomenclature of the Netherlands; revision and update by RGD and NOGEPA, Section B, Devonian and Dinantian, Mededelingen Rijks Geologische Dienst, 50 pp.

Van Hulten, F., and Poty, E. (2008). Geological factors controlling Early Carboniferous carbonate platform development in the Netherlands. Geological Journal. 43, 175-196.

Wijnen, P. (2013). End of Well Report CAL-GT-01.

2.2.1 Logs

The log dataset for the Californië wells is quite sparse, as wireline log acquisition was not as complete as in the other wells. The most complete dataset has been obtained from the CAL-GT-01 well and its side tracks.

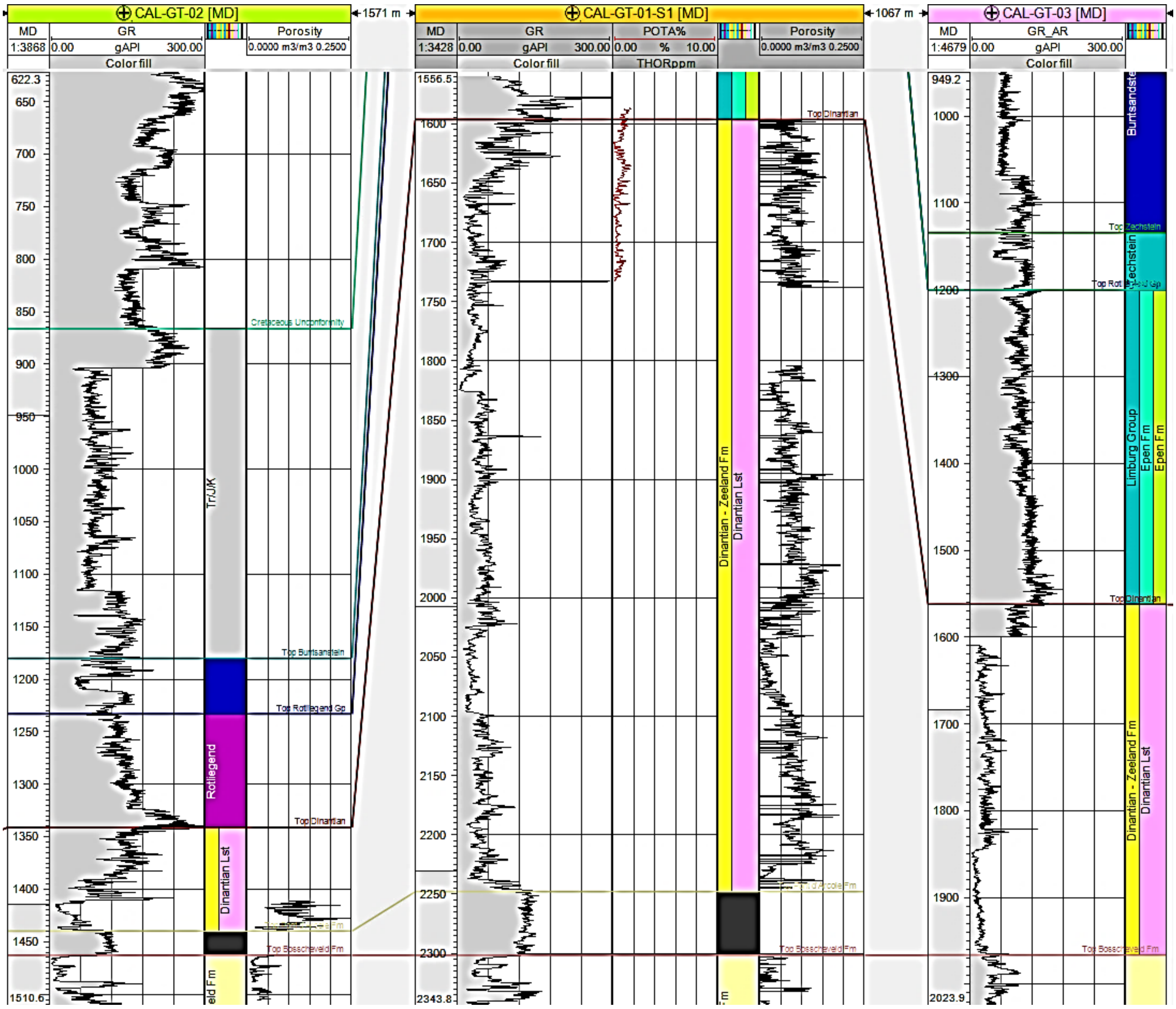

Figure 2-2: Main logs available for the public Californië wells. The order of the wells in the image is from north to south.

2.2.2 Cores, sidewall cores and cuttings

No cores are available for these wells. Most of the studies are based on cuttings.

2.2.3 Petrography and additional analyses

The petrography analysis was performed on thin sections prepared from cuttings. Further analyses was halted by the limited amount of the available material.

CAL-GT-01

A detailed microfacies study on the available cuttings from CAL-GT-01 was performed by Poty (2014).

This well encountered some 750 m of Dinantian carbonates, underlain by Devonian quartzite and dolomite. The well encountered a large karst feature between 1737 and 1758 m depth, resulting in total losses of drilling fluids. No core was taken in this well. Sample description and microscopic analysis were reported in two unpublished documents, PanTerra (2012) and Poty (2014).

The presence of fossiliferous grainstone and packstone cuttings in the samples taken at the top of the karst zone indicates deposition in shallow water, possibly still in situ or reworked after deposition. Chert is present and probably derived from silicified carbonate, possibly related to bioturbated layers. The carbonates are mostly tight, except for some intercrystalline porosity in partly dolomitised carbonate and dissolution porosity in chert, which is attributed to the chertification, not the karstification. SEM analysis indicates the presence of some microporosity (PanTerra, 2012).

Severe diagenesis below the karst zone hampered microfacies interpretation, and very little biostratigraphic dating could be performed. The upper section of the Dinantian carbonates (between 1605 and 1980 m) could be attributed to the Middle and Late Visean, and the lower section (between 1980 and 2350 m) to the Early Visean and the Tournaisian. The recognised microfacies is mainly grainstone and wackestone, suggesting a platform or ramp setting for the entire section, but not a reef. This suggests that the (present-day) high could be due to block faulting (Poty, 2014). The entire section below the karst are diagenetically altered, with the Visean section silicified and the supposedly Tournaisian-age section dolomitised and de-dolomitised. The quartz veins, sparry calcite and (de)dolomite suggest that diagenesis is related to hydrothermal waters rich in silica and in calcium sulphate (the latter causing (de)dolomitisation) (Poty, 2014). According to the personal communications with the latter author, the harsh diagenetic modifications could take place in zone of 10's of meters around the faults. Geochemical analysis could not be executed due to the too small sample size.

CAL-GT-02

Thin sections available for this well were described within the frame of current study (SCAN project):

Zeeland Formation 1341-1440 m: cuttings microfacies include dolomitised grainstone, minor argillaceous wackestone and common replacive sucrosic dolomite with fabric-destroying texture. Occasional limestone cuttings of fine bioclastic grainstone/packstone including endothyrids, ealandids, calcispheres, echinoderms, beresellid algae, bivalve and brachiopod fragments, Koninckopora. Probable high energy platform interior or margin setting.

Pont d'Arcole Formation 1440-1463 m: is poorly represented in cuttings samples, this consists of a chertified argillaceous limestone.

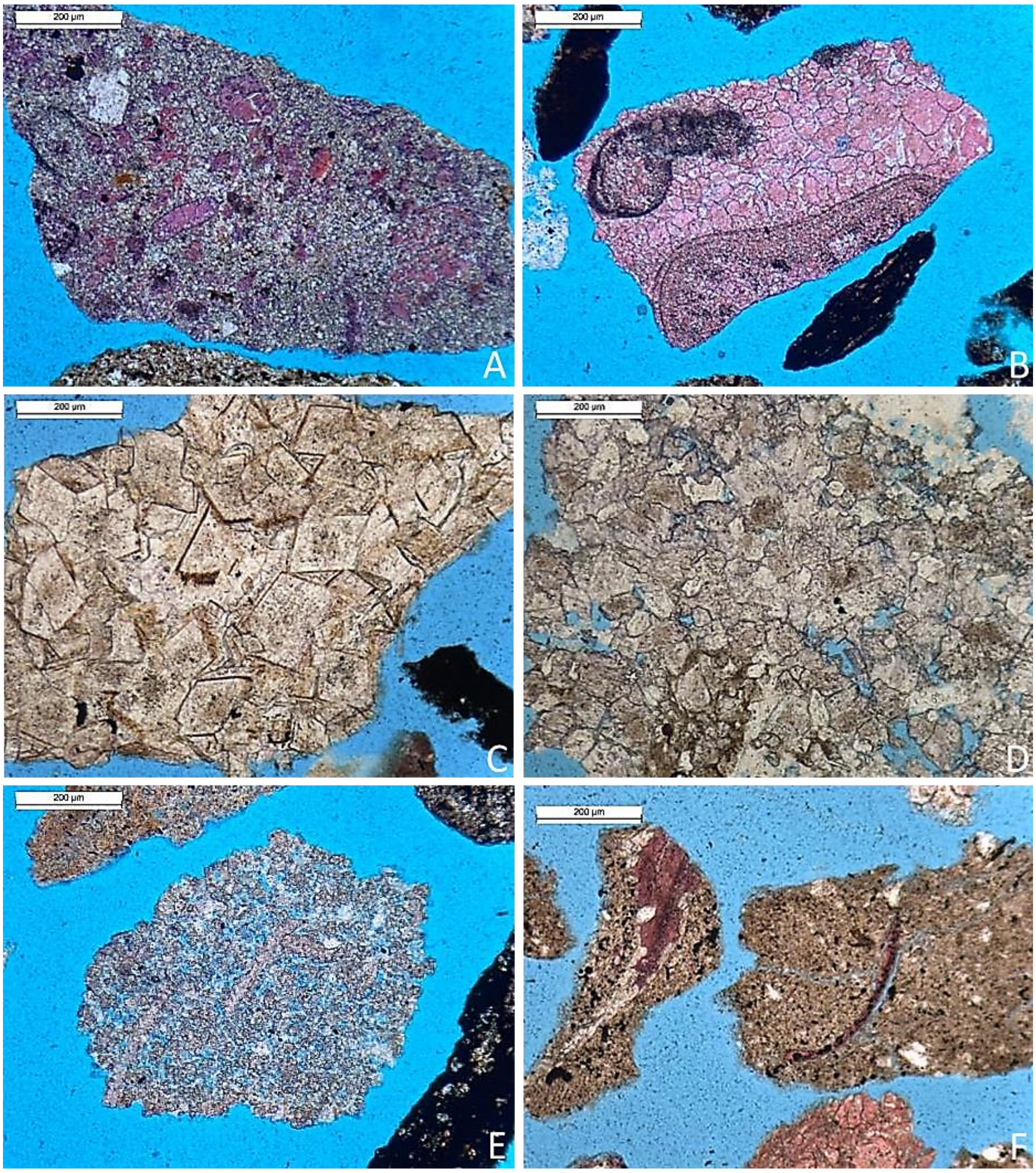

Figure 2-3: A) Zeeland Formation, dolomitised grainstone/packstone 1370-1420 m. B) Zeeland Formation, coated grain bioclastic grainstone 1370-1420 m. C) Zeeland Formation, subhedral dolomite 1420 m. D) Zeeland Formation, subhedral dolomite with intercrystal porosity 1420 m. E) Zeeland Formation, dolomitised packstone with intercrystal and intergranular pores 1420 m. F) Pont d'Arcole Formation, chertified limestone 1450 m.

CAL-GT-03

No information.

2.3 Stratigraphy

The available stratigraphy has been modified to include the Pont d'Arcole Formation, clearly identified in two wells (CAL-GT-01 and CAL-GT-02). The stratigraphy of the Californië wells is summarised in Table 2-2. These wells span from Quaternary until Devonian. The Cretaceous unconformity was found at about 818 m in CAL-GT-01, then a very pronounced

Saalian unconformity is present at 1150 m in CAL-GT-01, even eroding the Dinantian carbonates in CAL-GT-02.

Table 2-2: Stratigraphy of the Californië wells (modified from NLOG website). The modified well tops are marked by *.

Stratigraphic unit	**Formation Tops (m MD)**			
	CAL-GT-01	**CAL-GT-01-S1**	**CAL-GT-02**	**CAL-GT-03**
UNKNOWN	0		0	0
Kieseloolite Fm.	24		26	26
Breda Fm.	56		56	60
Veldhoven Fm.	336		340	336
Rupel Clay Mb.	526		530	530
Vessem Mb.	644		670	650
Landen Clay Mb.	666		700	664
Gelinden Mb.	682		746	700
Heers Mb.	724		760	724
Swalmen Mb.	740		776	740
Houthem Fm.	760		806	760
Maastricht Fm.	790		836	790
Nederweert Sandstone Mb.	818		868	824
Zechstein Upper Claystone Fm.	1094		1180	1134
Z3 (Leine) Fm.	1110		1196	1152
Z2 (Stassfurt) Fm.	1122		1210	1166
Rotliegend Fm.			1233*	
Epen Fm.	1150*			1200*
Zeeland Fm.	1596	1596	1341	1562
Pont d'Arcole Fm.		2248*	1440*	
Bosscheveld Fm.		2301*	1463*	1966*
Banjaard Gp.		2436*	1574*	?
TD	2082	2730	1694	2977

Correlation among the public Californië wells is shown by Figure 2-3.
CAL-GT-01-ST: Dinantian is faulted, causing repeated lithology. A karst feature is present between 1737-1758 m.
CAL-GT-02: There may be an element of stratigraphic thinning. This thinning has been observed on seismic data. The base Dinantian is faulted with the upper part of the Pont d'Arcole present in a fault-bounded slice and at least two faults may be present in the Dinantian. The top Dinantian is not represented.
CAL-GT-03: Dinantian is incomplete as a result of faulting with a total of approximately 200 m of section. The basal section of the Dinantian including the Pont d'Arcole Formation is not represented because it is faulted out. The Dinantian is in faulted contact with the underlying Bosscheveld Formation.

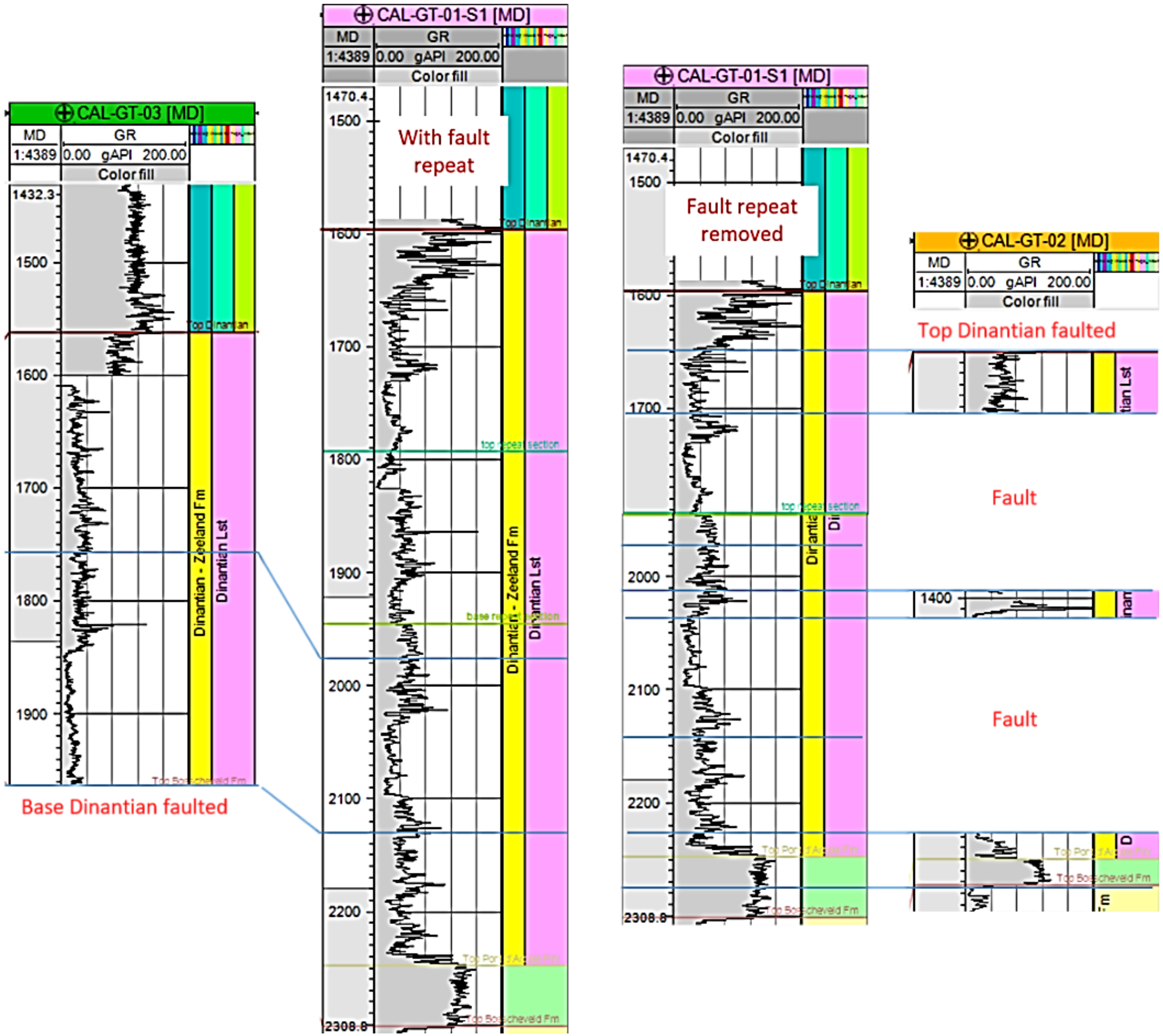

Figure 2-4: Proposed correlation of Californië wells; depths are MD.

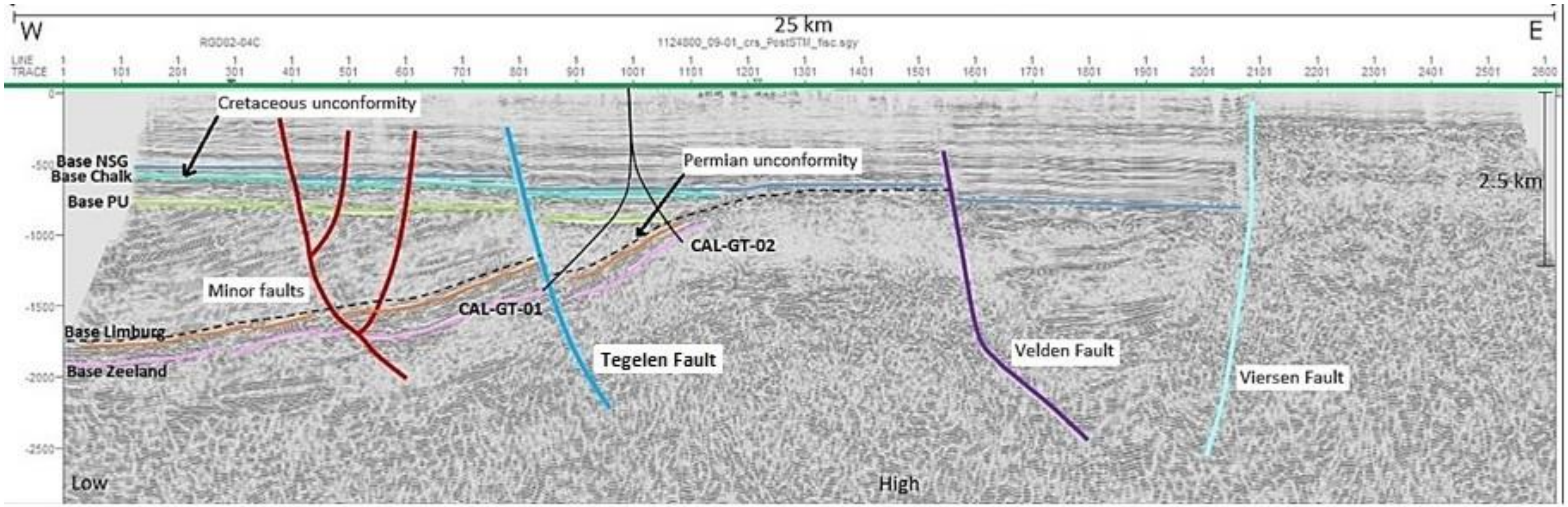

Figure 2-5: Seismic context of Californië wells (Modified from Reith, 2018).

2.4 Biostratigraphy

No detailed Biostratigraphic data are available for the Californië wells: only a very rough attribution is present in Poty (2014).

2.5 Sedimentology

Details of the depositional environment and reservoir quality are based on a microfacies study of cuttings samples from the CAL-GT-02 well; unfortunately, of the three wells studied, this has the shortest Dinantian section having been cut by faults.

Bosscheveld Formation: (6 cuttings thin sections) this is a mixed clastic-carbonate succession with bioclastic grainstone with minor terrigenous grains deposited in conditions ranging from low to high energy above normal wave base. This may represent a cyclic carbonate platform attached to a source of siliciclastic sediments.

Zeeland Formation: (3 cuttings thin sections) Most of the Zeeland Formation appears to be replaced by a medium to coarsely crystalline dolomite. The dolomite mainly obliterates the depositional textures and some intercrystal porosity is present. Some bioclastic coated grain limestone and partly dolomitised limestone are also present. There is minor replacement by microcrystalline chert, sometimes with porosity. The overall depositional setting may be a shallow water carbonate platform. A possible basic intrusive may be present. This consists of coarsely crystalline feldspar with possible pyroxene and mica altered to chlorite.

2.6 Sequence stratigraphy

A sequence stratigraphic interpretation of the three Californië wells has not been attempted because of the high degree of both repetition and attenuation of the succession by repeated faulting.

2.7 Diagenesis

2.7.1 Paragenetic sequence

Ferket et al. (2009) undertook a comparative diagenetic study of the Dinantian carbonates from the Krefeld High and the Campine Basin with the aim of predicting the likely pore types and controls on reservoir quality prior to drilling the Californië wells. They concluded that reservoir quality is most likely to be related to dolomitisation with intercrystalline pores and fractures and brecciation associated with faulting and some indications of de-dolomitisation were also noted. No detailed diagenetic work has been carried out on the Californië wells, however, an outline paragenetic sequence was constructed from cuttings from CAL-GT-02 during the current study. This shows that the main event responsible for the generation of matrix porosity is replacement of the limestone by dolomite. In grain-supported limestone, the dolomite initially replaces the matrix with the preservation of inherited intergranular and new intercrystalline pores.

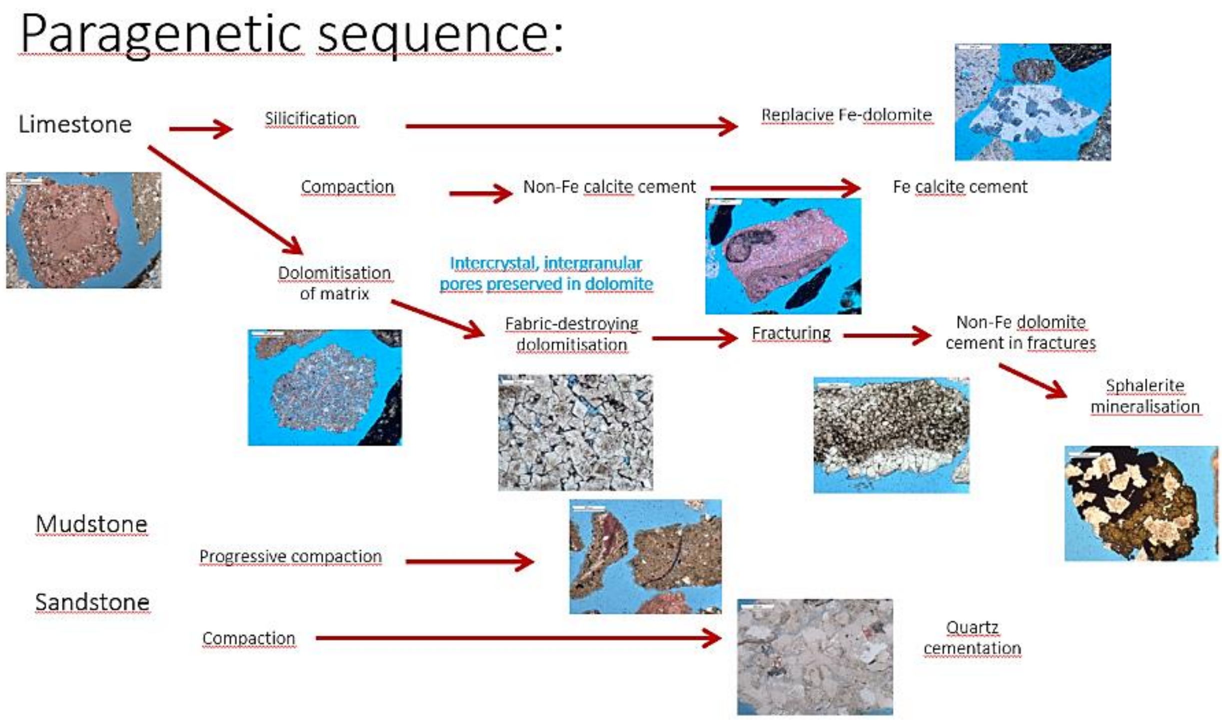

Figure 2-6: Paragenetic sequence based on cuttings from CAL-GT-02.

The fabric-replacive dolomite also locally contains intercrystalline porosity. Further fracturing events have the potential to generate more porosity, however, fractures observed in cuttings were cemented by dolomite that display euhedral fracture terminations suggesting that relict porosity may be present in some factures. There was a subsequent phase of mineralisation.

2.8 Reservoir quality

Reservoir quality in CAL-GT-01 and -02 wells is relatively good when compared with the rest of the wells drilled in the Dinantian carbonates in the Netherlands, with porosity values up to more than 20%. Matrix permeability measurements are not available.

2.9 Other information

During the drilling of the CAL-GT-01 well a karst zone was encountered between 1737 and 1758 m MD. Production tests flowed water of 60 °C at a rate of 300 m^3/h. A second high permeability zone flowing 80 °C water was encountered at 2400 m of depth. The high permeability is interpreted as the result of high fracture density of the Tegelen Fault zone (Figures 2-5 and 2-7).

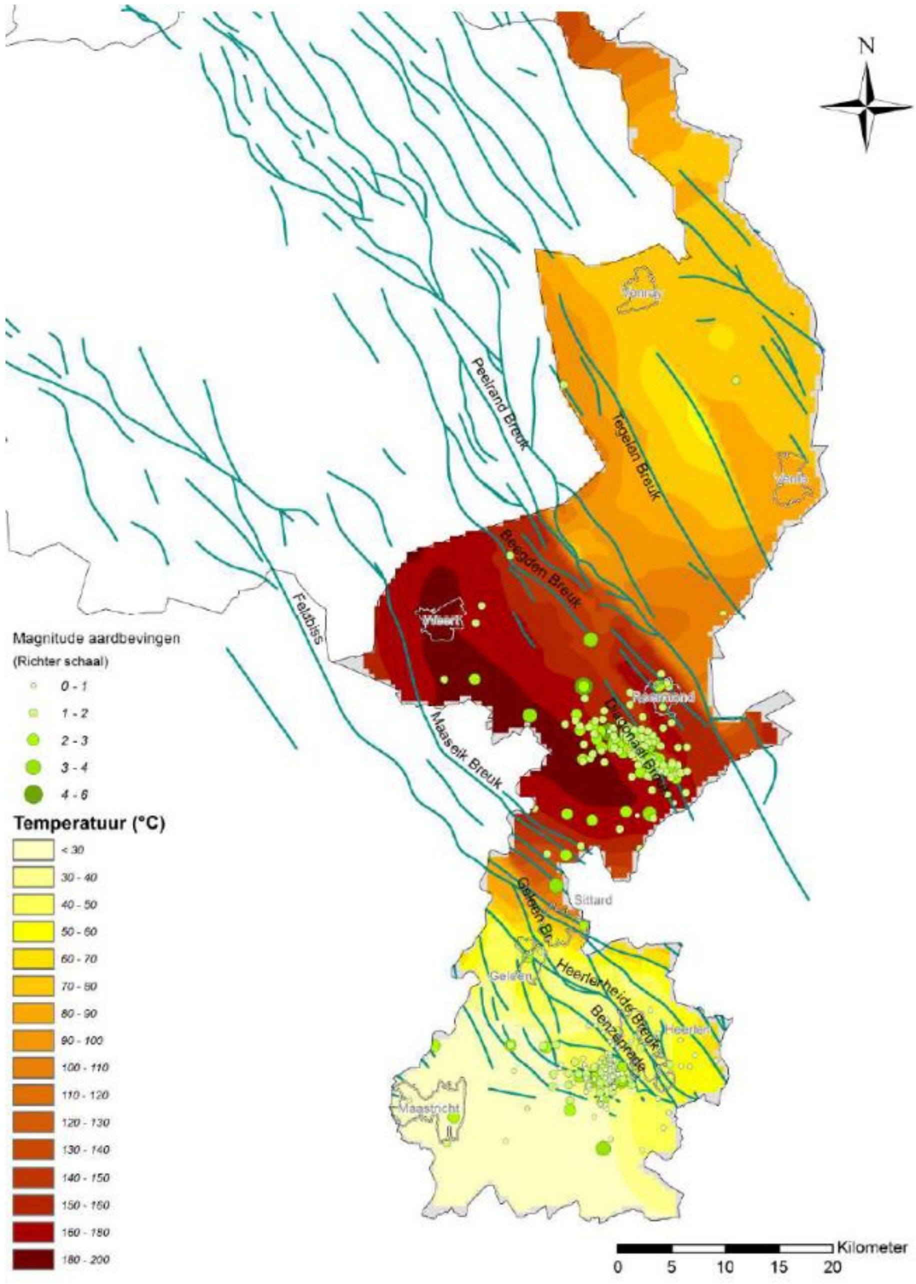

Figure 2-7: Map of the Dinantian carbonates temperature, faults and earthquakes (KNMI.nl).

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