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Database with the Thermal, Hydrological, Mechanical, Chemical (THMC) properties of rock salt

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Database with the Thermal, Hydrological, Mechanical, Chemical (THMC) properties of rock salt

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Contents

1 Introduction

COVRA aims to set up a long-term rock salt properties database programme to support radioactive waste disposal operations, expected to start in 2130[1]. This database and associated website is intended to be made publicly available, and will contain a set of Thermal, Hydrological, Mechanical and Chemical (THMC) data from different types of salt formations (bedded salt and domal salt), obtained from various sources (e.g., directly from cores or from literature), with an initial focus on the Dutch Zechstein and Röt salt formations.

TNO was asked to provide a data collection (including data structuring, meta-data, QC, validation), specifically of THMC properties from salt occurrences in the Dutch subsurface. The data is derived from currently available sources, such as literature, existing databases and industry reports. The project was then extended with an inventory of similar data available from international origin, focussing on the Southern Permian Basin area[2] (UK-The Netherlands-Germany-Poland) and equivalents worldwide.

In this report, a brief description of the results of the data collection for both the Dutch and international datasets is given. An overview of the Dutch data inventory and resultant dataset is presented in Chapter 2. The international data inventory and resultant dataset is summarized in Chapter 3. Both datasets are included as MS Excel (.xlsx) files in the appendices.

[1] Ministry of infrastructure and the Environment, 2016. The national programme for the management of radioactive waste and spent fuel, p. 61.
[2] Doornenbal, H., & Stevenson, A. (2010). *Petroleum geological atlas of the Southern Permian Basin area*. EAGE.

2 Data inventory NL

2.1 Overview of Dutch rock salt occurrences

In the Netherlands, various salt deposits are present within the sedimentary layers of Permian and Triassic age[3]. The salts deposits in the Zechstein (Permian) are especially widespread, and reach up to 1000 m in thickness in the northern part of the country (Figure 2.1). The Röt salts (Triassic) are significantly less abundant, both in terms of lateral extent and thickness (Figure 2.2). Salt from both stratigraphic intervals is produced by solution mining in the Netherlands[4]. Besides the Zechstein and Röt formations, no other salt occurrences are sufficiently thick for potential waste disposal purposes (i.e. minimum thickness of approximately 100 m).
Exploration for salt mining as well as hydrocarbon exploration activities resulted in numerous boreholes penetrating salt occurrences in the subsurface, both onshore and offshore. An inventory was made of all boreholes with cores retrieved from Röt and Zechstein salt occurrences. The inventory was restricted to onshore boreholes. This resulted in a total selection of 115 boreholes (Table A.1).
The selected boreholes were queried for availability of measurements and/or analysis reports on core samples. This yielded a total of 22 boreholes from which data is available for inclusion in the Salt Property Database NL (Table 2.1), all from Zechstein salt. Figure 2.1 shows the spatial distribution of the data that is available from these 22 boreholes.

Of the total 115 boreholes from which salt cores have been retrieved, a representative part (i.e. entire core sections, or else half or quarter sections) of all retrieved cores is available in the core store of the Geological Survey of the Netherlands. These core samples are publicly available for further analysis.

Table 2.1: Number of cored boreholes with Röt and Zechstein salt present (all onshore)

	Röt salt	Zechstein salt
Total cored boreholes	16	99
Total cores	36	235
Total boreholes with core measurements	0	22

[3] De Jager, J., Geluk, M. C., Wong, T. E., Batjes, D. A. J., & de Jager, J. (2007). Geology of the Netherlands. *Petroleum Geology. Royal Netherlands Academy of Arts and Sciences, Amsterdam, The Netherlands*, *241*, 264.
[4] Staatstoezicht op de Mijnen (2018). Staat van de sector zout. Staat van de sector zout | Publicatie | Staatstoezicht op de Mijnen (sodm.nl)

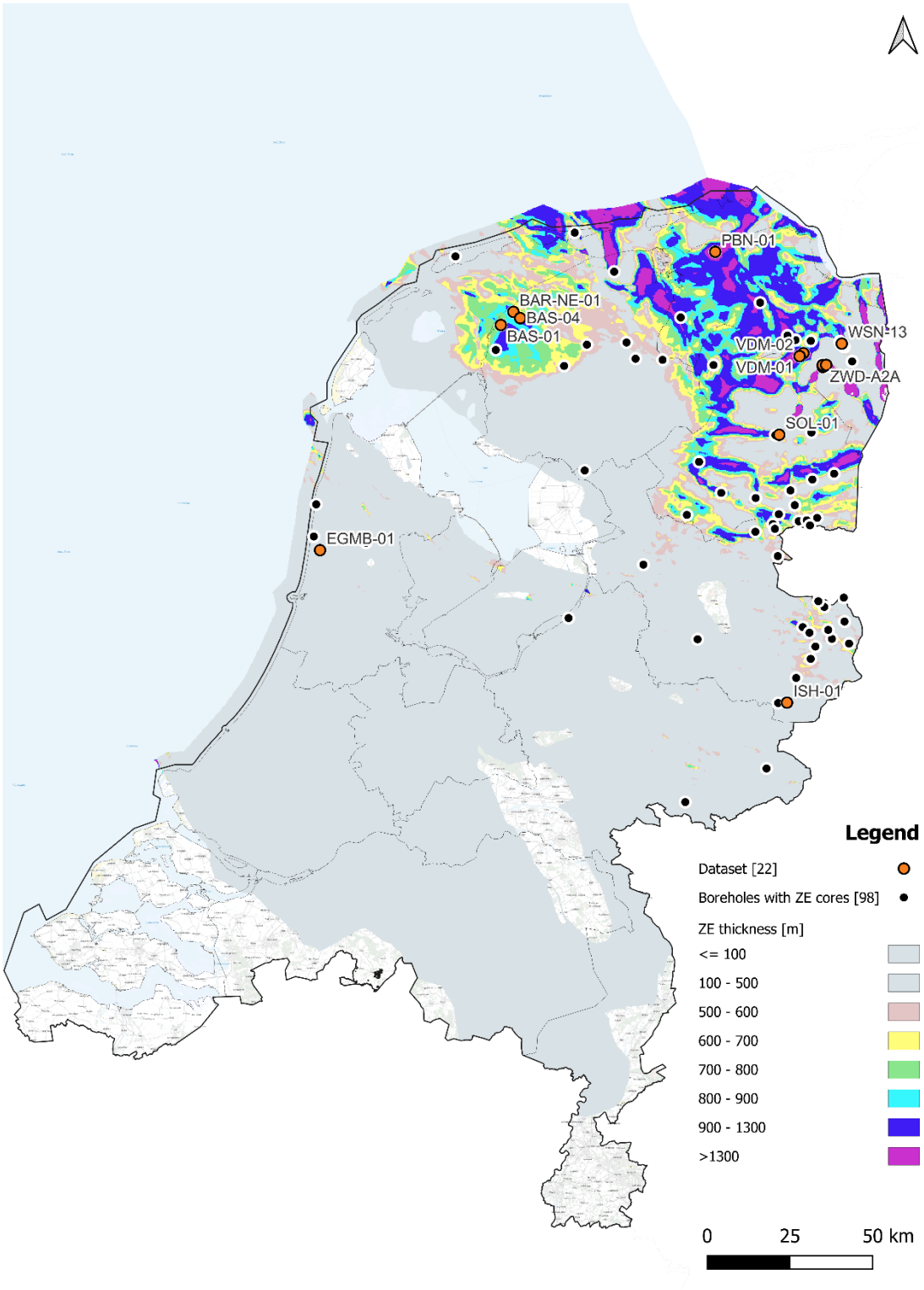

Figure 2.1: Overview of onshore borehole locations with cores retrieved from Permian Zechstein salt (black dots). Orange markers indicate location of Zechstein cores with core analysis included in the dataset for the Salt Property Database NL. The background map indicates the total thickness of the Zechstein formation.

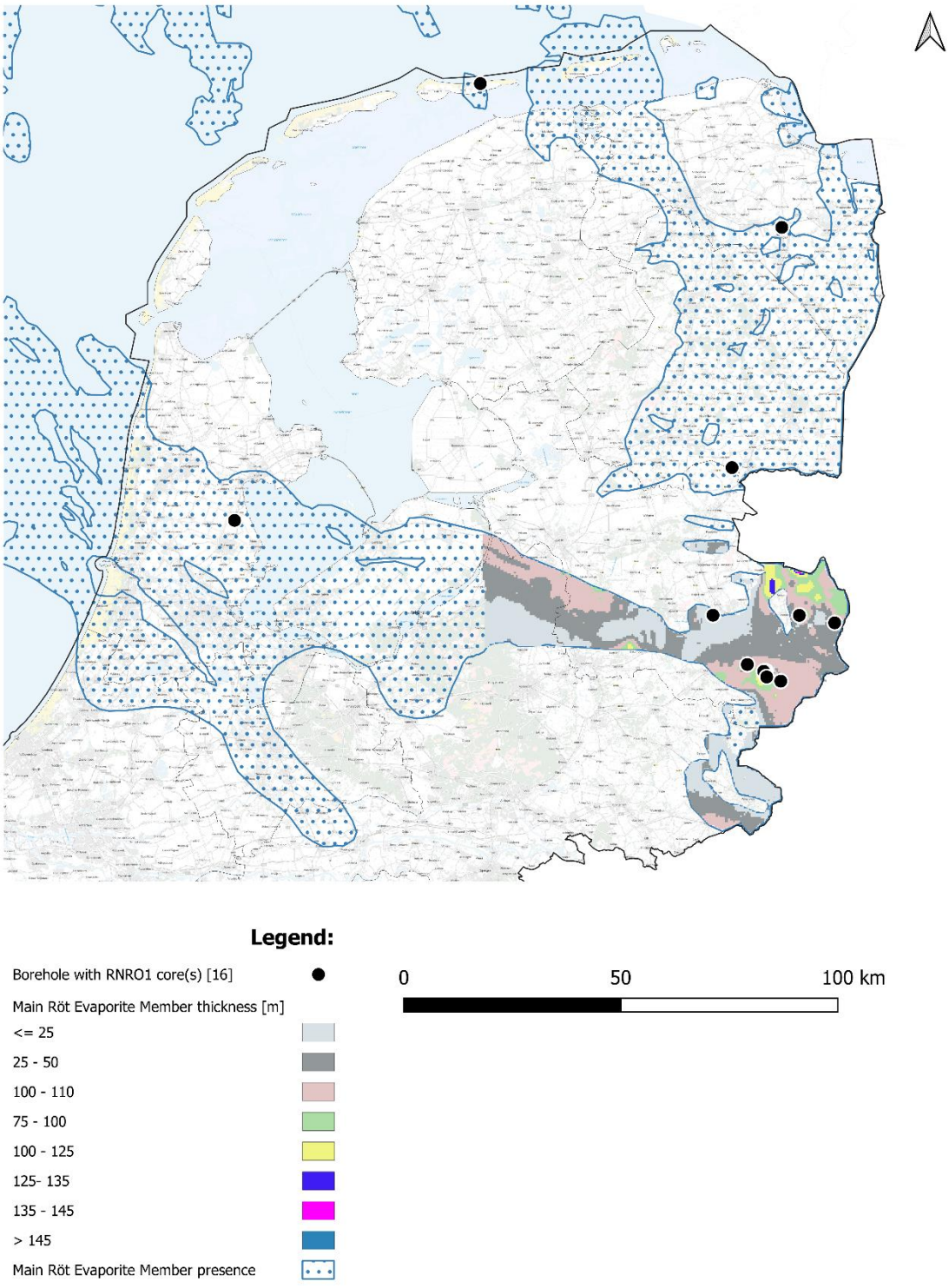

Figure 2.2: Overview of onshore borehole locations with cores retrieved from Main Röt Evaporite (black dots). The background map indicates the thickness of the Main Röt Evaporite Member. If no detailed thickness information is present, the distribution of the Main Röt Evaporite Member is indicated with a dotted hatch.

2.2 Overview of data inventory

Table 2.2 lists the number of measurements per data type. Analysis of salt mineral composition of 8 boreholes resulted in a total number of 1138 sample measurements. Results of mechanical analysis was available for 9 boreholes. Mechanical properties were derived from 285 samples. Core photographs were available for 13 boreholes. A bromide profile is present for 4 boreholes.

Table 2.2: Number of measurements per cored borehole for each data type

Location	Mineral samples	Mechanical analysis	Core photo	Bromide profile
BAR-NE-01	397			
BAR-NE-02-B	4			
BAS-01	56	24		
BAS-02		19		
BAS-04		20		
EGMB-01			x	
ISH-01	38	62	x	x
PBN-01	5			
SOL-01	160			
TCI-09	178	13	x	
VDM-01	300			
VDM-02			x	
VDM-03			x	
VDM-04			x	
WSN-13			x	
ZWD-A2A		17	x	
ZWD-A2B		21	x	
ZWD-A3A			x	
ZWD-A4A			x	x
ZWD-A4B			x	x
ZWD-A6A		68	x	x
ZWD-KNZ-08		41		
Total	1138	285	13	4

The mineral composition dataset contains results of determination of soluble and insoluble fractions, as well as x-ray diffraction (XRD), x-ray fluorescence(XRF) and ion chromatography (IC) analysis.
The mechanical analysis comprises a varying range of uniaxial/triaxial compaction tests, extension tests, creep tests and permeability test, mainly performed by the *Institut für Gebirgsmechanik GmbH* (IfG).
The database is presented in Appendix B and contains the extracted dataset as well as the original source documents from the complete data inventory NL.

Database structure

The extracted dataset is structured in a way that it can be incorporated or transferred into a relational database. The dataset contains six tables; two tables with metadata (*Location* & *Analysis source*), tree tables with measurement and analysis data (*Mineral composition*, *Mechanical* & *Additional documents*) and one reference table (*Mechanical test type*). Table 2.3 gives an overview of the tables and database fields. Note that this overview does not give the full list of *Mineral composition* and *Mechanical* analysis and test result fields. These database field names are self-explanatory.

Table 2.3: Structure and database field description. Database fields marked with 'Key' can be used to relate the various tables

Table	Database field	Key	Description
Location	SHORT_NM	*	Borehole acronym
	BOREHOLE_NM		Borehole full name
	FIELD_NM		Field name or license area
	COUNTRY		Country code
	DRILLING_END_DATE		Date of borehole drilling completion
	SHAPE		Borehole shape
	X_RD		Surface x-coordinate (RD)
	Y_RD		Surface y-coordinate (RD)
	LAT_WGS84		Surface longitude-coordinate (WGS84)
	LON_WGS84		Surface latitude-coordinate (WGS84)
Analysis source	Database field	Key	Description
	ANALYSIS_ID	*	ID number of source document
	DATE		Document date
	TITLE		Document title
	AUTHOR		Document author
	COMPANY		Document company
	SOURCE_DOC		filename of source document
Mineral composition	LOCATION_ID	*	Borehole acronym
	ANALYSIS_ID	*	ID number of source document
	DEPTH		Depth of sample (along borehole)
	LAB		Laboratory
	SAMPLE_NM		Sample name
	Na (weight %)		Sodium weight % of analysed sample
	K (weight %)		Potassium weight % of analysed sample
	..various analysis results		...depending of analysis type
Mechanical	LOCATION_ID	*	Borehole acronym
	ANALYSIS_ID	*	ID number of source document
	TYPE	*	Mechanical test type

Table	Database field	Key	Description
	SAMPLE_NM		Sample name
	DEPTH		Depth of sample (along borehole)
	TEMP		Analysis temperature
	sample_diameter		Diameter of sample
	sample_height		Height of sample
	mass		Mass of sample
	density		Density of sample
	density_calc		Calculated density of sample
	Vp-axial		Compressional wave velocity measured in axial direction
	Vp-horizontal		Compressional wave velocity measured in horizontal direction (perpendicular to long axis of the sample)
	Vs-axial		Shear wave velocity measured in axial direction
	v_calc-dynamic		Calculated Poisson's ratio (dynamic)
	E_calc-dynamic		Calculated Young's modulus (dynamic)
	K_calc-dynamic		Calculated Bulk modulus (dynamic)
	v-static		Poisson's ratio (static)
	E-static		Young's modulus (static)
	K-static		Bulk modulus (static)
	Additional_data		Description of additional reported data
	sample_photo		Photo of sample reported
	..various test results		...depending of test type
Mechanical test type	TYPE	*	Mechanical test type
	DESCRIPTION		Description of mechanical type
Additional documents	ANALYSIS_ID	*	ID number of source document
	LOCATION_ID	*	Borehole acronym
	DATA_TYPE		Description of datatype
	SOURCE_DOC		filename of source document

Data quality control

Note that in all cases, the data included in Appendix B has been copied directly from the source documents, without exclusion or modification of values which appear to contain slight errors (e.g. negative values; mineral fraction data that does not amount to 100% in total). Only in one case has part of the data been omitted – ultrasonic wave velocity measurements and derived dynamic elastic properties from Zuidwending core material reported in IfG 2007 'Rock mechanical investigations Zuidwending', which show unrealistic values without any traceable systematic error that can be readily corrected.

3 International inventory

3.1 Criteria international data inventory

The focus of the international data inventory was on **thermal**, **hydrological** and **mechanical** properties of **natural salt**, rather than chemical/mineralogical/petrophysical data or measurements on synthetic salt, since the latter are less relevant for future modelling and characterisation of potential radioactive waste disposal sites specifically in the Netherlands. Given the practical constraints of this project, the scope of the international inventory was further limited to:

- Papers published in the proceedings of the 10 conferences on the mechanical behaviour of salt (held between 1984 and 2022);
- Papers/reports available from the Solution Mining Research Institute (SMRI) library;
- Papers/reports referenced to in the above, obtained via links in Google Scholar.

Furthermore, in cases where (part of) the same dataset is presented in several reports or publications, only the most recent version is included, to avoid duplication. Within these constraints, 51 documents were selected and included in the data inventory.

3.2 Overview of international data inventory and extracted data

A detailed overview of the selected papers/reports and the data extracted is presented in Appendix C.1. This overview includes detailed information on the following: document details (e.g. authors, year, availability); sample details (e.g. sample location/origin, salt type, stratigraphic interval/formation, sample depth); data type (Rock Mechanical Properties, Thermal Properties, and Hydrologic/Transport Properties); measurement details (e.g. test type, pressure and temperature conditions); test description; notes; reference to the source document.

Most of the papers/reports within the inventory are available in digital form. However, in 5 cases, the original document is not available, but (part of) the dataset is presented in one of the other papers/reports, from which it was extracted with reference to the original source.

The data in this inventory is derived from 41 different salt occurrences/localities around the world – see Figure 3.1. The majority of the data is derived from Permian salt deposits (e.g. bedded salt from the Salado Formation at WIPP, New Mexico and the Zechstein Formation in the Southern Permian Basin area), and Mid-Jurassic Louan Salt in the US (e.g. the Gulf Coast salt domes in Louisiana and Texas). The Rock Mechanical Properties dataset, derived from 41 papers/reports, is the largest, with 1412 samples analysed. The Thermal Properties dataset is derived from 10 papers/reports and counts 455 analysed samples. The smallest dataset, Hydrological/Transport Properties data, comprises 4 documents and 26 samples analysed. Table 3.1 lists several key aspects of the international data inventory.

Figure 3.1: Geographic sample location (41 sample locations in total, in 9 countries).

Table 3.1.1: Brief overview of the international data inventory

	Rock mechanical properties	Thermal properties	Hydrological / transport properties	Total*
Nr. of documents	41	10	4	51
Nr. of sample locations (countries)	37 (9)	7 (2)	8 (3)	41 (9)
Nr. of samples analysed**	1412	455	26	1893
Depth range sampled***	0 – 1430 m	280 – 835 m	297 – 609 m	0 – 1430 m

* Note that several documents / sample locations contain more than one type of data, therefore the totals are not necessarily equal to the sum of the numbers for rock mechanical, thermal, and hydrologic/transport properties columns.

** Only tabulated data are counted (i.e. excluding data available in figures only – refer Appendix C.1)

*** Sample depth is not known in all cases – refer Appendix C.1

The data extracted from the selected documents (i.e. measured values at specific test conditions) are compiled in three separate Excel spreadsheets (Appendices C.2-C.4), grouped per data type (Rock Mechanical Properties, Thermal Properties, and Hydrologic/Transport Properties – see columns L-N in Appendix C.1). Note that several documents report data that fall in more than one category – these are incorporated in just one of the Excel spreadsheets, to avoid data duplicity (refer columns L-N in Appendix C.1). Note as well that in the case of 8 reports/papers, the relevant data is available in figures/graphs only – this is indicated in Appendix C.1 as well as the individual data spreadsheets, where appropriate. The data within these figures/graphs cannot readily be extracted or digitized in table form, and are therefore not included in Appendices C.2-C.4. Including these data as figures/graphs in the intended online database may not be feasible, given copy rights limitations.

In addition to the international inventory and datasets described above, several documents with data/information that is unsuitable for inclusion in the above datasets, but is potentially relevant for future users of the intended online database. This includes the 1981 NIST

‘Physical Properties Data for Rock Salt’, which contains 6 chapters with additional THMC properties data, as well as geophysical, optical and electrical data, on a variety of natural rock salt samples as well as synthetic salt. The scans from this volume are not of sufficient quality for automated data extraction, and therefore no digitization of tables and figures was performed.

Signature

TNO Advisory group for Economic Affairs Utrecht, 16 May 2023

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p.p. J.H.J. Ebbing
Research manager a.i.

Appendix A

List of rock salt containing borehole cores (NL)

Table A.1: Number of core intervals within a stratigraphic interval (Table A.2) Data included in this report is indicated green

	RNRO1	ZE,ZESA,ZESAL	ZEZ1H	ZEZ1H,ZEZ2H	ZEZ1H,ZEZ2H,ZEZ3H	ZEZ2	ZEZ2,ZEZ3	ZEZ2H	ZEZ2H,ZEZ3H	ZEZ2H,ZEZ3H,ZEZ4H	ZEZ3	ZEZ3H	ZEZ4H
AML-02	1												
BAR-NE-01								1					
BAR-NE-02-B								1					
BAS-01								8				1	
BAS-02								3					
BAS-04								2					
BHM-04								1					
BHM-05-S2								1					
BUR-01								1					
COV-02	1									1			
COV-03								1					
COV-04								1	1			2	
COV-09								1					
COV-10								1					
DAL-01								1					
DED-02	1												
DEN-01								1					
DEW-03		1											
DEW-04			1					2					
DSP-01								1					
DWL-02								1					
EGMB-01												1	
EMM-09								1					

	RNRO1	ZE,ZESA,ZESAL	ZEZ1H	ZEZ1H,ZEZ2H	ZEZ1H,ZEZ2H,ZEZ3H	ZEZ2	ZEZ2,ZEZ3	ZEZ2H	ZEZ2H,ZEZ3H	ZEZ2H,ZEZ3H,ZEZ4H	ZEZ3	ZEZ3H	ZEZ4H
EMM-14								1					
EXO-02-S2								2					
FLN-01			1										
GRT-02												1	
GSB-01								1					
HEN-01			1		1								
HKS-01			1					1					
HLE-01									1				
HRL-01								2					
HTM-01								1					
ISH-01			1										
LEW-02								2					
LEW-04								1					
LNH-01			1										
LTV-02				1									
LUT-04-S5	1												
LUT-05								1				1	
MID-101	1												
NOR-23										1			
OSH-02								1					
PBN-01									1				
RAM-02								1					
RAW-01								1					
ROW-01	4												
ROW-02								1					
ROW-05								1					
RST-01												1	
RUI-02								1					
SAP-06-S1												1	
SCH-313								1					
SCH-447								1					
SCH-449								4					
SEB-01										1			
SLB-01		1											

	RNRO1	ZE,ZESA,ZESAL	ZEZ1H	ZEZ1H,ZEZ2H	ZEZ1H,ZEZ2H,ZEZ3H	ZEZ2	ZEZ2,ZEZ3	ZEZ2H	ZEZ2H,ZEZ3H	ZEZ2H,ZEZ3H,ZEZ4H	ZEZ3	ZEZ3H	ZEZ4H
SLO-01								2					
SNK-01								1					
SOL-01		1											
SOL-02		1											
TBR-01								1					
TCI-09												2	
TER-01								1					
TUB-04								1					1
TUB-05			1					1					
TUB-07								1					
TUS-06	1							4				2	
TWR-098	1												
TWR-134	9												
TWR-135	1												
TWR-136	5												
TWR-138	5												
TWR-159A	1												
TWR-182	1												
TWR-480	1												
URE-01												2	
VDM-01												1	
VDM-02												1	
VDM-03												2	
VDM-04												1	
WIM-01												1	
WIR-01	2												
WLO-01		15											
WRG-01								1					
WSN-01		1											
WSN-02		1											
WSN-03		1											
WSN-04		5											
WSN-05		5											
WSN-06		5											

	RNRO1	ZE,ZESA,ZESAL	ZEZ1H	ZEZ1H,ZEZ2H	ZEZ1H,ZEZ2H,ZEZ3H	ZEZ2	ZEZ2,ZEZ3	ZEZ2H	ZEZ2H,ZEZ3H	ZEZ2H,ZEZ3H,ZEZ4H	ZEZ3	ZEZ3H	ZEZ4H
WSN-12		5											
WSN-13		2											
WSN-14		2											
WYK-06								1					
ZED-01								2					
ZWD-A1A		6											
ZWD-A2A		9											
ZWD-A2B						3							
ZWD-A3A		6											
ZWD-A4A		10											
ZWD-A4B						1							
ZWD-A5A						7					2		
ZWD-A5A-S1							1						
ZWD-A6A						6							
ZWD-A7A						7							
ZWD-A7B						2							
ZWD-A8A						4					4		
ZWD-KNZ-02		7											
ZWD-KNZ-03		3											
ZWD-KNZ-05		2											
ZWD-KNZ-06		2											
ZWD-KNZ-07		2											

Table A.2: Stratigraphic names

Strat code	Name
RNRO1	Main Röt Evaporite Member
ZE	Zechstein Group
ZESA	Zechstein salt
ZESAL	Lower Zechstein salt
ZEZ1H	Zechstein Z1 Salt Member
ZEZ2	Zechstein Z2 (Stassfurt) Formation
ZEZ2H	Zechstein Z2 Salt Member
ZEZ3	Zechstein Z3 (Leine) Formation
ZEZ3H	Zechstein Z3 Salt Member
ZEZ4H	Zechstein Z4 Salt Member

Appendix B

Salt property database NL

B.1 The Netherlands Database

Electronic appendix:
<TNO_2023_R10585_Appendix_B1_Salt_property_database_NL.xlsx>

B.2 Database source documents

Electronic appendix:
<TNO_2023_R10585_Appendix_B2_Source_documents.zip>

Appendix C

International salt property database

C.1 Overview International dataset

Electronic appendix:
<TNO_2023_R10585_Appendix_C1_International _Inventarisation.xlsx>

C.2 Rock Mechanical properties

Electronic appendix:
<TNO_2023_R10585_Appendix_C2_Mechanical_properties_extracted.xlsx>

C.3 Thermal Properties

Electronic appendix:
<TNO_2023_R10585_Appendix_C3_ Thermal_properties_extracted.xlsx>

C.4 Hydrologic/Transport Properties

Electronic appendix:
<TNO_2023_R10585_Appendix_C4_Transport_properties_extracted.xlsx>

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