Radioactive Waste Management ISBN 92-64-01067-X

Clay Club Catalogue of Characteristics of Argillaceous Rocks

Compiled by J.-Y. Boisson (IRSN, France)
with the help of the Working Group on the Characterisation,
the Understanding and the Performance of Argillaceous Rocks
as Repository Host Formations (the "Clay Club")

NEA No. 4436

NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

FOREWORD

A wide spectrum of argillaceous media are being (or were) considered in NEA member countries as potential host rocks for deep geological disposal of radioactive waste, i.e. from plastic, soft, poorly indurated clays to brittle, hard mudstones or shales.

Among the favourable characteristics that are generally considered for argillaceous media are:

- thickness and continuity;
- low permeability and low hydraulic gradients;
- chemical buffering capacity;
- propensity for plastic deformation and self-sealing of fractures;
- geochemical characteristics that favour low solubility of radionuclides; and
- high capacity to retard the migration of radionuclides towards the accessible environment, e.g. through sorption capacity and due to a diffusion-dominated transport.

For evaluating performance of deep geological formations, a site characterisation programme helps to provide the required and specific data such as the hydromechanical characteristics *vis-à-vis* underground excavation works and operation, or hydrogeochemical characteristics with respect to the ability of the formation to limit the potential migration of radionuclides to the environment.

In that context, the OECD/NEA Working Group on the Characterisation, the Understanding and the Performance of Argillaceous Rocks as Repository Host Formations, namely the “Clay Club” examines the various argillaceous rocks that are being considered for the deep geological disposal of radioactive waste. The Clay Club promotes:

- a continuing inter-comparison of the properties of different argillaceous media;
- an exchange of technical and scientific information on clay properties and behaviour and on testing being carried out in underground research facilities; and
- a detailed review of the available and most promising investigation techniques for site characterisation.

Considering its overall objectives, one of the first initiatives of the Clay Club was to gather in a structured way the key geoscientific characteristics of the various argillaceous formations that are – or were – studied in NEA member countries with regard to radioactive waste disposal. The effort resulted in an internal catalogue of characteristics in the beginning of the 1990s. After several internal updates (1995 and 1998) and restructuring resulting from end-users’ feedback, the NEA Clay Club considered it necessary and timely to prepare an open version of the catalogue. The present publication represents the outcomes of this Clay Club initiative.

Other past and current Clay Club activities cover the following topics:

- hydraulic and hydrochemical characterisation of argillaceous rocks (see Ref. 1);

- understanding of the basic concepts and mechanisms which control the movement of water, transport of solute and gas across a whole spectrum of argillaceous media being considered for radioactive waste disposal (see Ref. 2);
- evaluation of the occurrence of fluid flow through faults and fractures in argillaceous settings (see Ref. 3);
- assessment of the available pore water extraction methods and their respective advantages and limitations (see Ref. 4 & 5);
- description and assessment of current knowledge and relevance regarding the self-healing of argillaceous rocks under repository conditions (see Ref. 6);
- compilation of relevant “features, events and processes” specific to the disposal of long-lived waste in argillaceous formations and their current relevance for system understanding, namely “FEPCAT” (see Ref. 7);
- establishment of a list of relevant scientific references dealing with argillaceous media (see Ref. 8).

Acknowledgements

The catalogue has been compiled by Jean-Yves Boisson (IRSN, France) with the help of the Clay Club members, the NEA scientific Secretariat and all the following contributors:

Belgium	L. Wouters, P. Manfroy and P. Lalieux (ONDRAF/NIRAS), M. De Craen, L. Wang, I. Wemaere, N. Maes, X. Sillen, F. Bernier, P. De Cannière, G. Volckaert and B. Neerdael (SCK•CEN), D. De Smet and W. De Breuck (RUG)
Canada	OPG
France	J-F. Aranyossy and A. Trouiller (ANDRA), J.-Y. Boisson (IRSN) and C. Beaucaire (IRSN now at CEA)
Germany	GRS and J. Gerardi (BGR)
Hungary	L. Kovács (KÚTFEJ Ltd), G. Hámos, Z. Máthé, J. Csicsák, G. Földing and Zs. Berta (MECSEKÉRC Environmental Co.)
Japan	K. Hama (JNC HORONOBE UNDERGROUND RESEARCH CENTER) and JNC TONO GEOSCIENCE CENTER
Spain	J-C. Major (ENRESA)
Switzerland	A. Gautschi, P. Blumling and P. Bläser (NAGRA/CEDRA), P. Bossart (G. I. MONT TERRI CONSORTIUM), M. Mazurek (UNIVERSITY OF BERN)
United Kingdom	S. Horseman* (BGS)
United States	R.E. Lewis (USGS)

The NEA Secretariat and the Clay Club would like to express their gratitude to IRSN for having supported the work and to Jean-Yves Boisson for having carried it out.

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* Recently deceased.

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OBJECTIVES OF THE CATALOGUE

The present Catalogue gathers in a structured way a series of data sets relating to key geoscientific characteristics for various argillaceous formations that are being or were studied by NEA members countries.

The primary aims of the Catalogue are to:

- provide, for each considered argillaceous formation, an overview of key data across the various geoscientific disciplines that are involved in clay characterisation and performance assessments (e.g. geology, mineralogy, geochemistry, petrophysics, hydrogeology, solute transport, rock mechanics);
- help in understanding the commonalties and differences between formations;
- help in assessing the possibilities of transferring gained knowledge and/or characterisation methodologies from one formation to another (or from one site to another);
- illustrate the wide spectrum of characteristics corresponding to “clays as host formation”.

The Catalogue focuses on argillaceous formations that are (or were) considered as potential disposal host formations. It does not consider the various argillaceous formations that have been studied for instance as natural analogues of disposal systems.

The Catalogue considers data that have been acquired from both surface-based investigations (boreholes with subsequent logging and core analysis, seismic surveys, etc.) and underground research laboratories (URL). In addition to the measured data, a quantitative best-estimate value is also given per each characteristic. However, the Catalogue cannot be utilised in the following situations:

- as a detailed description of a particular geological formation, or as a judgmental tool for assessing the qualities of a geological formation *vis-à-vis* its ability to host a radioactive waste disposal facility or as a comparison of respective performances of the various formations at hand;
- as a direct quantitative input to assessments without any consideration of the origin of data and the related terms of their measurements and without any additional quality and reliability checking work; or
- as a guarantee of the applicability of a given value to a specific location, depth, litho-stratigraphic interval within the formation, etc., without further checking with related specialists.

Each organisation is responsible for the content of its argillaceous formation-specific text and data. Neither the NEA nor the participating national organisations can be held responsible for the use which might be made of the information considered in the catalogue.

This document is open and freely available. Beside the Clay Club members, the Catalogue targets radioactive waste disposal experts and external geoscientific experts as main audiences.

The present Catalogue cancels and replaces all previous internal versions. It consists of a brochure and of a CD-ROM where all data can be found under MS Excel and MS PDF formats.

DESCRIPTION OF THE CATALOGUE AND GUIDELINES FOR ITS UTILISATION

For each considered argillaceous formation, the catalogue consists of a series of forms (MS-WORD format) that were filled in by participating organisation(s). All quantitative data are recorded in tabulated form (MS. EXCEL format).

The following points are detailed hereafter:

- the information that introduces each formation;
- the list of parameters together with the corresponding guidelines that were set up to help participating organisations to fill in the forms;
- the limitations of the catalogue, and its associated caveats; and
- the list of argillaceous formations that are described in the catalogue.

Context for the presented formations

This section consists of a relatively short and introductive presentation for each argillaceous formation in order to state the limitations/caveats that are linked with the gathered information and its utilisation. It also describes the national context in which all the data were gathered:

- indication on the geological environment;
- extension of the studied formation illustrated with map(s) and cross-sections;
- nature of the acquisition means, i.e. geophysical survey, outcrops, boreholes/drillings, existence of an Underground Research Laboratory (URL); and
- scope and status of the organisation research and development programme.

A priori, all parameters or ranges of parameters refer to potential deep repository conditions (depth, geological conditions, etc.). In that respect, a distinction is made to whether data are formation-specific or site-specific (for instance: data on Opalinus Clay at Mont Terri URL are distinguished in terms of presentation from those on Opalinus Clay in the Zürcher Weinland).

Parameters considered in the Catalogue

For each argillaceous formation, the presented parameters are grouped in the following main categories:

- General information.
- Geological Parameters.
- Mineralogy.
- Rock Chemistry.

- Porewater chemistry (including concentration of water components).
- Petrophysical parameters.
- Flow and solute transport parameters.
- Geomechanical parameters.

For each category, a detailed list of parameters is presented. The Excel data sheet within the CD-ROM contains a supplementary column entitled "Remarks and comments" that aims to help in clarifying which kind of information is required for each parameter. These remarks and comments are underscored in Table 1. After Table 1, a series of general guidelines that were distributed is presented in order to help organisations to fill in and then read the catalogue.

Table 1 **Parameters considered in the catalogue and requested type of information**

Parameters	*Remarks and comments (cf. guide lines).*
Argillaceous rock formation	*Clay formation official name.*
Country:	*Country name.*
GENERAL INFORMATION	
Potential Repository Areas:	*Location and geologic setting/tectonic unit.*
Potential Host Rock for:	*Waste type.*
Potential Disposal Depth [m]:	
Underground Research Laboratory:	*Short information on existing or planned rock laboratories.*
GEOLOGICAL PARAMETERS	
Stratigraphic Unit [name]:	
Stratigraphic Age [name]:	
Lithological Description:	*Should include a remark on the degree of induration/compaction.*
Depositional Environment:	
Absolute Age [Ma]:	
Burial Depth Present day Top formation [m]:	*In the potential repository area(s).*
Burial Depth Present day Bottom formation [m]:	*In the potential repository area(s).*
Thickness [m]:	
Burial Depth maximum [m]:	*During geological history.*
Burial Additional in the Past[m] i.e. Maximum minus Present Day Burial Depth:	*During geological history.*

MINERALOGY	
Clay Minerals-Sum of all [% total dry weight]:	*Total clay-mineral content.*
Clay Minerals-Sum of all < 2µm [% total dry weight]:	*Total clay-mineral < 2µm content.*
Clay Minerals-Illite [% total dry weight]:	*Content of individual clay-mineral should be given in absolute values (not % of the total clay-mineral content).*
Clay Minerals-Smectite [% total dry weight]:	*idem*
Clay Minerals-Chlorite [% total dry weight]:	*idem*
Clay Minerals-Kaolinite [% total dry weight]:	*idem*
Clay Minerals-Illite/Smectite ML [% total dry weight]:	*idem*
Clay Minerals-Chlorite/Smectite ML [% total dry weight]:	*idem*
Clay Minerals-Others [% total dry weight]:	*idem*
Quartz [% total dry weight]:	*Content of individual mineral should be given in absolute values.*
Feldspars [% total dry weight]:	*idem*
Feldspars-K [% total dry weight]:	*idem*
Feldspars-Albite [% total dry weight]:	*idem*
Carbonates [% total dry weight]:	*idem*
Calcite [% total dry weight]:	*idem*
Dolomite [% total dry weight]:	*idem*
Ankerite [% total dry weight]:	*idem*
Dolomite + Ankerite [% total dry weight]:	*idem*
Siderite [% total dry weight]:	*idem*
Carbonates Others [% total dry weight]:	*idem*
Pyrite [% total dry weight]:	*idem*
Gypsum [% total dry weight]:	*idem*
Minor Mineral Species [% total dry weight]:	*Content of individual minerals should be given in absolute values. One line per each specie.*
Accessory Minerals [% total dry weight]:	
Accessories Minerals Others [-]:	
Carbon Organic [%]:	
Vitrinite reflectance [%]:	

ROCH CHEMISTRY	
CEC [meq/100g of rock]:	*Cation exchange capacity (define method, clay fraction and ion selectivity).*
CEC < 2µm [meq/100g of rock]:	*idem*
Exchangeable Na [meq/100g of rock]:	*idem*
Exchangeable K [meq/100g of rock]:	*idem*
Exchangeable Ca [meq/100g of rock]:	*idem*
Exchangeable Mg [meq/100g of rock]:	*idem*
Exchangeable Sr [meq/100g of rock]:	*idem*
Exchangeable Cations Sum of [meq/100g of rock]:	*idem*
Total Rock Redox Capacity [meq/g]:	

POREWATER CHEMISTRY	
Pore Water Type:	
TDS Mineralisation [mg/L]:	*Total dissolved solid.*
Ionic strength [M]:	*Indicate tests conditions: lab. or in situ field testing.*
pH [-log H$^+$]:	*idem*
pCO$_2$ tot. diss. [log bar]:	*idem*
Eh [mV]:	*idem*
Electric Conductivity [µS/cm]:	*idem*
Temperature Water Sample [°C°]:	*idem*
Alkalinity [mmol/L]:	*idem*
TIC [mg/L]:	*Total inorganic carbon.*
TOC [mg/L]:	*Total organic carbon.*
^{14}C dating [a]:	
^{14}C [PMC]:	
^{40}Ar/^{36}Ar [-]:	
δ^{37}Cl [$^{0}/_{00}$ vs SMOC]:	
$\delta\,^{18}$O [$^{0}/_{00}$ vs SMOW]:	
$\delta\,^{2}$H [$^{0}/_{00}$ vs SMOW]:	
He [Nml/g]:	
^{34}S/^{32}S [-]:	

^{37}Cl/^{35}Cl [-]:
Tritium [TU]:

Porewater Components – Cations
Ca; Na; K; Mg; Fe; Fe (Fe^{2+}); Cd; Cs; Cu; U; Al; Si; NH$_4$; Ba; B; Mn; Mn (Mn^{2+}); Sr [mg/l]

Porewater Components – Anions
Cl; SO$_4$; HCO$_3$; Br; I; NO$_3$; NO$_2$; F[mg/l]

PETROPHYSICAL PARAMETERS	
Density Bulk Saturated [t/m^3]:	
Density Bulk Dry [t/m^3]:	
Density Grain Average [t/m^3]:	
Water Content (water weight/dry weight) [%]:	*Water Content as water weight loss (105°C/24h)/dry solid weigh.t*
Water Content (water weight/total weight) [%]:	*Water Content as water weight loss (105°C/24h)/total saturated solid weight.*
Porosity calculated from water content at 105-110 C° [%vol]:	*If no measurement available, calculated porosity for saturated clay = 100 (w%*gs)/(100 + w%*gs) where W%: Water Content (%) at saturation & gs weighted-best estimate of Specific Gravity (dimensionless, in clays close to 2.70).*
Porosity Hg Injection Total lab. tests [%vol]:	
Porosity Hg Injection Macro lab. tests [%vol]:	*Pore-space filled with Hg at 1 atm (> equivalent pore-radii of >7.5 μm).*
Porosity Hg Injection Micro lab. tests [%vol]:	*Pore-space filled with pressures up to 2 000 atmospheres.*
Porosity He [%vol]:	
Porosity Geochemical [%vol]:	*According to "Pearson definition".*
Porosity Other Methods [%vol]:	*Indicate methodologies.*
Specific Surface Internal [m^2/g]:	*Using H$_2$O isotherms.*
Specific Surface External [m^2/g]:	*Measured by N$_2$-adsorbsion (BET method).*
Thermal Conductivity [W/mK°]:	*Indicate tests conditions: lab. or in situ, orientation towards bedding…*

Thermal Conductivity (⊥) [W/mK°]:	*idem*
Thermal Conductivity (⫽) [W/mK°]:	*idem*
Specific Heat Massic [J/kgK°]:	*idem*
Specific Heat Massic Dry [J/kgK°]:	*idem*
Specific Heat Massic Humid [J/kgK°]:	*idem*
Heat Capacity Volumic [MJ/m^{3}K°]:	*idem*
Heat Capacity Volumic Dry [MJ/m^{3}K°]:	*idem*
Heat Capacity Volumic Humid [MJ/m^{3}K°]:	*idem*
Seismic Velocity Vp [m/s]:	*idem*
Seismic Velocity Vp lab. tests [m/s]:	*Indicate tests conditions (numerous types of measurements to be distinguished), lab. or in situ, orientation towards bedding…*
Seismic Velocity Vs lab. tests [m/s]:	*idem*
Seismic Velocities Ratio Vp/Vs lab. tests [-]:	*idem*
Seismic Velocity Vp (⊥) lab. tests [m/s]:	*idem*
Seismic Velocity Vs (⊥) lab. tests [m/s]:	*idem*
Seismic Velocities Ratio Vp/Vs (⊥) lab. tests [-]:	*idem*
Seismic Velocity Vp (⫽) lab. tests [m/s]:	*idem*
Seismic Velocity Vs (⫽) lab. tests [m/s]:	*idem*
Seismic Velocities Ratio Vp/Vs (⫽) lab. tests [-]:	*idem*
Seismic Velocity *in situ* tests [m/s]:	*idem*
Seismic Velocity Vp *in situ* tests [m/s]:	*idem*
Seismic Velocity Vs *in situ* tests [m/s]:	*idem*
Seismic Velocities Ratio Vp/Vs *in situ* tests [-]:	*idem*

FLOW AND SOLUTE TRANSPORT PARAMETERS	
Osmotic Efficiency *in situ* tests [%]:	*Indicate tests conditions: lab. or in situ, orientation towards bedding…*
Osmotic Conductivity [m/s]:	*idem*
Osmotic Permeability *in situ* tests [m^{5}s^{-1}mole^{-1}]:	*idem*
Hydraulic Conductivity lab. tests [m/s]:	*idem*
Hydraulic Conductivity (⫽) lab. tests [m/s]:	*idem*
Hydraulic Conductivity (⊥) lab. tests [m/s]:	*idem*
Hydraulic Conductivity Anisotropy (⫽/⊥) lab. tests [-]:	*idem*

Hydraulic Conductivity *in situ* tests [m/s]:	*idem*
Hydraulic Conductivity (⫽) *in situ* tests [m/s]:	*idem*
Hydraulic Conductivity (⊥) *in situ* tests [m/s]:	*idem*
Hydraulic Conductivity Anisotropy (⫽/⊥) *in situ* tests [-]:	*idem*
Hydraulic Conductivity (⫽) lab. or *in situ* tests [m/s]:	*idem*
Hydraulic Conductivity (⊥) lab. or *in situ* tests [m/s]:	*idem*
Hydraulic Conductivity Anisotropy (⫽/⊥) lab. or *in situ* tests [-]:	*idem*
Storativity Specific *in situ* tests [m^{-1}]:	*Indicate tests conditions: lab. or in situ field testing…*
Permeability lab. tests [m^2]:	*idem*
Permeability Water lab. tests [m^2]:	*idem*
Permeability Gas lab. tests [m^2]:	*idem*
Permeability *in situ* tests [m^2]:	*idem*
Diffusion Effective Coeff. De (^{3}H) (⫽) lab. tests [m^2/s]:	*Indicate tests conditions: chemical species, lab. or in situ, orientation towards bedding…*
Diffusion Effective Coeff. De (^{3}H) (⊥) lab. tests [m^2/s]:	*idem*
Diffusion Effective Coeff. De (^{3}H) Anisotropy (⫽/⊥) lab. tests [-]:	*idem*
Diffusion Effective Coeff. De (I$^-$) (⫽) lab. tests [m^2/s]:	*idem*
Diffusion Effective Coeff. De (I$^-$) (⊥) lab. tests [m^2/s]:	*idem*
Diffusion Effective Coeff. De (I$^-$) Anisotropy (⫽/⊥) lab. tests [-]:	*idem*
Diffusion Effective Coeff. De (Cl$^-$) (⫽) lab. tests [m^2/s]:	*idem*
Diffusion Effective Coeff. De (Cl$^-$) (⊥) lab. tests [m^2/s]:	*idem*
Diffusion Effective Coeff. De (Cl$^-$) Anisotropy (⫽/⊥) lab. tests [-]:	*idem*
Diffusion Effective Coeff. De (^{3}H) (⫽) *in situ* tests [m^2/s]:	*idem*
Diffusion Effective Coeff. De (^{3}H) (⊥) *in situ* tests [m^2/s]:	*idem*
Diffusion Effective Coeff. De (^{3}H) Anisotropy (⫽/⊥) *in situ* tests [-]:	*idem*
Diffusion Effective Coeff. De (Other Species) *in situ* tests [m^2/s]:	*idem*
Diffusion Effective Coeff. De (^{2}H & ^{18}O) from analytical evaluation of *in situ* profiles (led to Da values): De values calculated using assumed porosities *in situ* tests [m^2/s]:	*idem*

Diffusion Effective Coeff. De (Cl^- & Br^-) from analytical evaluation of *in situ* profiles (led to Da values): De values calculated using assumed porosities *in situ* tests [m^2/s]:	*idem*
Diffusion Effective Coeff. De (Na^+) from analytical evaluation of *in situ* profiles (led to Da values): De values calculated using assumed porosities *in situ* tests [m^2/s]:	*idem*
Dispersivity Longitudinal lab. tests [m]:	*Indicate tests conditions: lab. or in situ...*
Dispersivity Transversal [m]:	*idem*

GEOMECHANICAL PARAMETERS	
Uniaxial Compressive Strength lab. tests [MPa]:	*Indicate tests conditions: lab. or in situ, orientation towards bedding… For materials with soil-like behaviour, “Uniaxial strength” is equivalent to Unconfined compressive strength and can also be calculated as twice (2 x) the Undrained shear strength*
Uniaxial Compressive Strength (⊥) lab. tests [MPa]:	*idem*
Uniaxial Compressive Strength (oblique) lab. tests [MPa]:	*idem*
Uniaxial Compressive Strength (//) lab. tests [MPa] :	*idem*
Uniaxial Compressive Strength Anisotropy (⊥///) lab. tests [-]:	*idem*
Uniaxial Tensile Strength lab. tests [MPa]:	*idem*
Uniaxial Tensile Strength (⊥) lab. tests [MPa]:	*idem*
Uniaxial Tensile Strength (//) lab. tests [MPa]:	*idem*
Uniaxial Tensile Strength Anisotropy (⊥///) lab. tests [-]:	*idem*

Young's Modulus Static lab. or *in situ* tests [MPa]:	*Indicate tests conditions: static or dynamic, short or long term, lab. or in situ, orientation towards bedding… May be stress-dependent (may require a simple qualifier such as “tangent modulus at 50% uniaxial strength”).*
Young's Modulus Static lab. tests [MPa]:	*idem*
Poisson's Ratio Static lab. tests [-]:	*idem*
Young's Modulus Static E_1 (⊥) lab. tests [MPa]:	*idem*
Young's Modulus Static E_2=E_3 (//) lab. tests [MPa]:	*idem*

Young's Modulus Static Anisotropy (⊥/∕∕) lab. tests [-]:	*idem*
Poisson's Ratio $\nu_{12}=\nu_{13}$ Static lab. tests (∕∕) [-]:	*idem*
Poisson's Ratio ν_{23} Static lab. tests (⊥) [-]:	*idem*
Poisson's Ratio Static Anisotropy (⊥/∕∕) lab. tests [-]:	*idem*
Young's Modulus Dynamic lab. tests [MPa]:	*idem*
Poisson's Ratio Dynamic lab. tests [-]:	*idem*
Young's Modulus Dynamic (⊥) lab. tests [MPa]:	*idem*
Poisson's Ratio Dynamic (⊥) lab. tests [-]:	*idem*
Young's Modulus Dynamic (∕∕) lab. tests [MPa]:	*idem*
Poisson's Ratio Dynamic (∕∕) lab. tests [-]:	*idem*
Young's Modulus Static *in situ* tests [MPa]:	*idem*
Young's Modulus Static E_1 (⊥) *in situ* tests [MPa]:	*idem*
Young's Modulus Static $E_2=E_3$ (∕∕) *in situ* tests [MPa]:	*idem*
Young's Modulus Static Anisotropy (⊥/∕∕) *in situ* tests [-]:	*idem*
Young's Modulus Dynamic *in situ* tests [MPa]:	*idem*
Poisson's Ratio $\nu_{12}=\nu_{13}$ Dynamic *in situ* tests [-]:	*idem*
Shear Modulus $G_{12}=G_{13}$ (∕∕) lab. tests [MPa]:	*Indicate tests conditions: short or long term, lab. or in situ, orientation towards bedding…*
Cohesion lab. tests [MPa]:	*Indicate tests conditions: lab. or in situ, orientation towards bedding…Parameters of the Mohr-Coulomb failure criterion.*
Internal Friction Angle lab. tests [°]:	*idem*
Cohesion (⊥) lab. tests [MPa]:	*idem*
Internal Friction Angle (⊥) lab. tests [°]:	*idem*
Cohesion (oblique) lab. tests [MPa]:	*idem*
Internal Friction Angle (oblique) lab. tests [°]:	*idem*
Cohesion (∕∕) lab. tests [MPa]:	*idem*
Internal Friction Angle (∕∕) lab. tests [°]:	*idem*
Swelling Pressure lab. tests [MPa]:	*Indicate tests conditions: lab. or in situ, orientation towards bedding… For rock-like materials, "Swelling Pressure" is equivalent to the Swelling Pressure Index (Ref. "Rock Characterisation, Testing and Monitoring: ISRM Suggested Methods", E.T. Brown ed., Pergamon Press (1981).*
Swelling Pressure (⊥) lab. tests [MPa]:	*idem*
Swelling Pressure (∕∕) lab. tests [MPa]:	*idem*

Swelling Pressure Anisotropy (⊥/∕∕) lab. tests [-]:	*idem*
Swelling Strain lab. tests [%]:	*Indicate tests conditions: lab. or in situ, orientation towards bedding…*
Swelling Strain (⊥) lab. tests [%]:	*idem*
Swelling Strain (∕∕) lab. tests [%]:	*idem*
Swelling Strain Anisotropy (⊥/∕∕) lab. tests [-]:	*idem*

Plastic Limit [%]:	*Not applicable for rock-like materials.*
Liquid Limit [%]:	*idem*
Plasticity Index [%]:	*idem*

GENERAL GUIDELINES

- Parameters are expressed as “minimum”, “best estimate” (most representative or best estimate from experts) and “maximum” values.

- The Excavation Disturbed Zone (E.D.Z.) conditions are not taken into consideration.

- Parameters are not supposed to be affected by surface effects such as weathering or decompression.

- As far as possible, the degree of anisotropy for a given parameter is mentioned, taking into account the sedimentary origin of the clay formation.

- The level of details and conditions of measurement of a given parameter are described.

- As far as possible, scale(s) of measurement and/or method(s) of measurement should accompany each parameter value.

- The list of geomechanical parameter reflects both the “rock mechanics approach” and the “soil mechanics approach” to materials characterisation.

- When appropriate, a distinction is made for geomechanical parameters, between “drained” parameters, which relate to effective stresses and “undrained” parameters that relate to total stresses.

- An assessment of the quality of data and thus of the confidence in the values (1 to 3: 1 being best guess, 3 being tested and validated data) is added. An example for the seismic velocity (Vp) parameter is given in the Table 2 below.

- The presented data are the ones that were initially given by and under the responsibility of the respective participating organisations.

- The present catalogue is the result of a progressive work with various levels of iteration/updating per formation. The presented datasets are therefore not fully consistent in terms of data acquisition.

- As far as possible, bibliographic references should refer to open, published literature.

- If not possible, some data corresponding to either preliminary or estimated values, should be referenced as “expert opinion or best guess”.

Table 2: **Example of data presentation for the seismic velocity (Vp) parameter**

Parameters [Unit]	Minimum	Best estimate	Maximum	Measurement scale	Method	Confidence	References	footnotes:
Seismic velocity Vp [m/s]	xx.xx	yy.yy	zz.zz	Laboratory		1, 2 or 3 (increasing)	1, 2, 3, …	a, b, c, …
Seismic velocity Vp [m/s]	xx.xx	yy.yy	zz.zz	Borehole geophysics	VSP, sonic log	1, 2 or 3 (increasing)	1, 2, 3, …	a, b, c, …
Seismic velocity Vp [m/s]	xx.xx	yy.yy	zz.zz	Surface geophysics	Reflection seismic	1, 2 or 3 (increasing)	1, 2, 3, …	a, b, c, …
Seismic velocity Vp [m/s]	xx.xx	yy.yy	zz.zz	Single well test		1, 2 or 3 (increasing)	1, 2, 3, …	a, b, c, …
Seismic velocity Vp [m/s]	xx.xx	yy.yy	zz.zz	Multiple well test	Cross-hole tomography	1, 2 or 3 (increasing)	1, 2, 3, …	a, b, c, …

LIMITATIONS OF THE CATALOGUE

The authors would like to highlight the inherent limitations of such a catalogue in order to avoid mis- or over-interpretation:

- The co-existence of “old” data already completed or/and abandoned many years ago with “new” data from recent or/and ongoing investigations programmes for active radioactive waste disposal projects.
- Disparities exist between the various scales of the presented formations e.g. from local studies based on outcrops, few boreholes or underground laboratories to regional scales. Therefore many parameters cannot really be directly compared. Another issue concerns the difficulty to properly represent spatial heterogeneities of a formation since each parameter is reduced to only three numbers (min/mean/max). Various types of investigations, wide or specific (using only geophysics for example) are conducted.
- Despite a careful compilation of numeric values, a number of peculiarities and internal inconsistencies might be observed. A variety of consistency cross-checks has been applied, indicating the remaining problems. Some of them are listed here, such as: stratigraphic age vs. absolute age, thickness of formation vs. bottom minus top of formation, sum of clay minerals vs. calculated sum of individual species, sum of all minerals vs. sum of best estimates of individual species, sum of feldspars vs. sum of albite plus K feldspars, sum of carbonates vs. sum of individual carbonate species, TDS and Ionic strength vs. sum of all chemical species, sum of exchangeable ions vs. sum of individual species, consistent link between bulk dry and bulk saturated rock density, consistent link water content relative to dry rock and to saturated rock density, consistency between water content porosity and gravimetric water content, between total porosity as presented with the value calculated from grain and bulk density, consistency of anisotropies of various parameters with the numbers given for parallel and normal samples.
- An additional point concerns the recurrent observation that in many cases, no “best estimate value” is given, but only range, minimum or maximum values. This might be justified by the degree/level of knowledge of a parameter but may entail, difficulties to compare one data set containing min/max values to another data set containing only best estimates ones.

In that respect, and as previously mentioned, this catalogue must not be used as a detailed description of a particular geological formation, as a judgmental tool for evaluating the quality of various geological formations with respect to their ability to host a radioactive waste disposal facility or as a database directly usable for making a performance assessment without any additional quality procedures.

LIST OF CONSIDERED CLAY FORMATIONS

The Map hereafter locates the various argillaceous formations that are characterised within the Catalogue.

Map 1: **Studied argillaceous rock formations location**

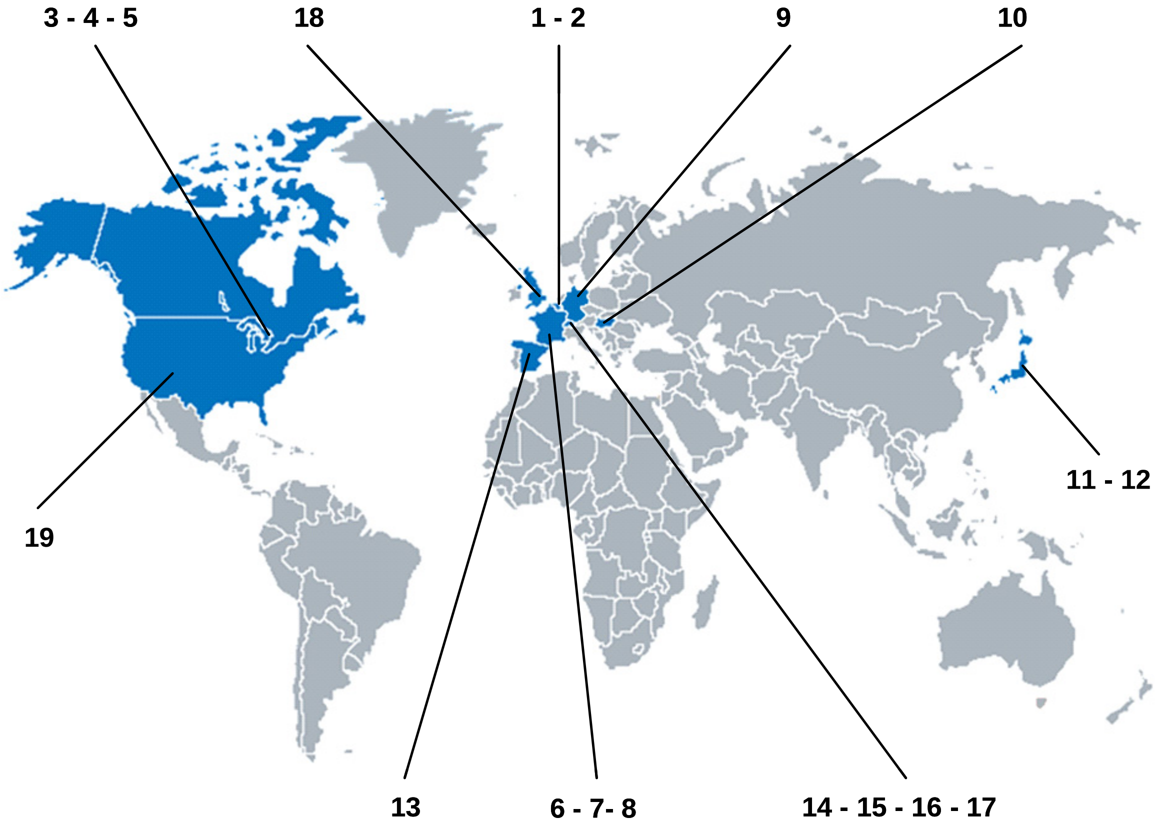

Table 3 presents the list of argillaceous rock formations that are detailed in the catalogue.

Table 3: List of considered clay formations

Location on Map 1	Argillaceous rock formation	Country	Catalogue last revision date
1	BOOM CLAY	BELGIUM	30/09/2001
2	YPRESIAN CLAYS	BELGIUM	31/07/2001
3	GEORGIAN BAY FORMATION	CANADA	01/01/1992
4	KENOGAMI RIVER FORMATION	CANADA	01/01/1992
5	QUEENSTOWN SHALE	CANADA	01/01/1992
6	CALLOVO-OXFORDIAN (EAST OF PARISIAN BASIN)	FRANCE	21/11/2002
7	CRETACEOUS (SOUTH-EAST FRANCE SEDIMENTARY BASIN)	FRANCE	17/05/1996
8	DOMERIAN AND TOARCIAN MARLS AND ARGILLITES FROM THE CAUSSES BASIN (TOURNEMIRE SITE)	FRANCE	01/07/2001
9	CLAYSTONES OF MIDDLE JURASSIC AGE & CLAYSTONES AND SILTSTONES OF LOWER CRETACEOUS AGE (KONRAD MINE)	GERMANY	15/11/2003
10	BODA CLAYSTONE FORMATION (BCF)	HUNGARY	13/04/2003
11	KOETOI & WAKKANAI FORMATIONS (HORONOBE U.R.C.)	JAPAN	07/08/2003
12	MIZUNAMI GROUP (TOKI LIGNITE FORMATION)	JAPAN	07/07/2003
13	SPANISH REFERENCE (SR) CLAY	SPAIN	15/10/2001
14	OPALINUS CLAY (OPALINUS-TON) NE SWITZERLAND, ZÜRCHER WEINLAND	SWITZERLAND	30/08/2002
15	MONT TERRI ROCK LABORATORY: OPALINUS CLAY (ARGILES A OPALINUS)	SWITZERLAND	15/07/2002
16	LOWER FRESHWATER MOLASSE, UNTERE SÜSSWASSERMOLASSE (USM)	SWITZERLAND	15/09/1992
17	CRETACEOUS MARLS AND TERTIARY SHALES (PALFRIS FORMATION AT WELLENBERG, CENTRAL SWITZERLAND)	SWITZERLAND	15/10/2002
18	OXFORD CLAY (LOCALITY OF AEA TECHNOLOGY, HARWELL LABORATORY, OXFORDSHIRE)	UNITED KINGDOM	17/08/1993
19	PIERRE SHALE	UNITED STATES	28/07/1994

UTILISATION OF THE DATABASE – SOME ILLUSTRATIONS

Annexes 1 and 2 illustrate some potential utilisations of the data base that are compiled in the MS-Excel tables (see attached CD-ROM).

The figures are presented for a selection of key parameters, with respect to the list of Table 1. These figures also illustrate the large variety of clay formations that are or were considered and studied with respect to radioactive waste disposal issues. They might be used in view of comparing clay data.

However as already mentioned in Section 4, this must be done cautiously with respect to drawing any conclusions out of the related comparison.

Figure 1 to Figure 20 (see Annex 1) illustrate the key parameters that are usually considered as relevant for geological disposal investigations.

Figure 21 to Figure 25 (see Annex 2) deal with a selection of well-known correlations confirming all the interest and usefulness of this data base.

Abbreviations that were mentioned in the figures for each formation are as follows:

Table 4: **Abbreviations corresponding to each official name of formations used in the figures**

Abbreviation	Official name of the formation	Country
B_boom	BOOM CLAY	BELGIUM
B_yper	YPRESIAN CLAYS	BELGIUM
CND_georg	GEORGIAN BAY FORMATION	CANADA
CND_kenog	KENOGAMI RIVER FORMATION	CANADA
CND_queenst	QUEENSTON SHALE	CANADA
F_bure	CALLOVO-OXFORDIAN (EAST OF PARISIAN BASIN)	FRANCE
F_gard	CRETACEOUS (SOUTH-EAST FRANCE SEDIMENTARY BASIN)	FRANCE
F_tournm	DOMERIAN AND TOARCIAN MARLS AND ARGILLITES FROM THE CAUSSES BASIN (TOURNEMIRE SITE)	FRANCE
D_kon	CLAYSTONES AND SILTSTONES OF LOWER CRETACEOUS AGES (KONRAD MINE)	GERMANY

Abbreviation	Official name of the formation	Country
D_kon-hau	CLAYSTONES AND SILTSTONES OF LOWER CRETACEOUS AGE (KONRAD MINE): HAUTERIVIAN	GERMANY
D_kon-bar	CLAYSTONES AND SILTSTONES OF LOWER CRETACEOUS AGE (KONRAD MINE): BARREMIAN	GERMANY
D_kon-apt	CLAYSTONES AND SILTSTONES OF LOWER CRETACEOUS AGE (KONRAD MINE): APTIAN	GERMANY
D_kon-alb	CLAYSTONES AND SILTSTONES OF LOWER CRETACEOUS AGE (KONRAD MINE): ALBIAN	GERMANY
H_bcf	BODA CLAYSTONE FORMATION (B.C.F.)	HUNGARY
J_horo-koet	KOETOI FORMATION (HORONOBE U.R.C.)	JAPAN
J_horo-wakk	WAKKANAI FORMATION (HORONOBE U.R.C.)	JAPAN
J_mizu	MIZUNAMI GROUP (TOKI LIGNITE FORMATION)	JAPAN
E_srclay	SPANISH REFERENCE (SR) CLAY	SPAIN
CH_opabenk	OPALINUS CLAY (OPALINUS-TON) NE SWITZERLAND, ZÜRICH WEINLAND	SWITZERLAND
CH_opamterri	MONT TERRI ROCK LABORATORY: OPALINUS CLAY (ARGILES A OPALINUS)	SWITZERLAND
CH_usm	LOWER FRESHWATER MOLASSE, UNTERE SÜSSWASSERMOLASSE (USM)	SWITZERLAND
CH_wellenbg	CRETACEOUS MARLS AND TERTIARY SHALES (PALFRIS FORMATION AT WELLENBERG, CENTRAL SWITZERLAND)	SWITZERLAND
UK_oxford	OXFORD CLAY (LOCALITY OF AEA TECHNOLOGY HARWELL LABORATORY, OXFORDSHIRE)	UNITED KINGDOM
US_pierresh	PIERRE SHALE	UNITED STATES OF AMERICA

Some relevant key parameters

As stated, the first set of figures presents some key parameters usually considered as representative and relevant for geological disposal investigations.

For each selected parameter, it is possible with one figure to "localise" one formation from the wide spectrum of considered "clay formations"

- Figure 1 illustrates the present day top of the formations burial depth *vis-à-vis* its maximum burial depth in the past. These two parameters help to give an overall picture of the geological history of one dedicated formation, and illustrate the probable state of (over)consolidation of the material. Moreover, maximum and minimum values provide a good idea of the potential regularity with respect to the lateral extension of the formation.
- The thickness, as illustrated in Figure 2 shows complementary information on that subject (potential thickness, variability). If known, confidence in the value of the mentioned parameter is reported on the right side axis (confidence values between 1 to 3: 1 being best guess, 3 being tested and validated data).
- Amount of mineralogical parameters helps further defining the nature and clay content of argillaceous formations such as:
  - the amount of "sum of all clay minerals" (Figure 3) ranging from less than 10 % up to pure clay;
  - the amount of smectite *ss* (Figure 4) together with the content of "sum of Illite/Smectite ML + Smectite + Chlorite/Smectite ML" (Figure 5) indicating the potential behaviour towards swelling and plasticity; and
  - the amount of "sum of Carbonates" (Figure 6) confirming the pure clay nature of the considered formation, or indicating its more marly or shaly nature.

Maximum and minimum values give a good idea of the possible variability of such parameters.

- The relative importance of the pore water mineralisation is illustrated in Figure 7, showing all the collected Total Dissolved Solids values ranging from 100 to 100 000 mg/l.
- The corresponding transport (flow and solute) properties may be envisaged by the main following petrophysical and hydraulic parameters:
  - The water content (Figure 8), which gives an overall picture of the various possible physical states of the considered clay material.
  - Porosities, a direct link existing between the water content and the variability of porosity values. Numerous types of porosity measurements are considered by the different organisations: classic Mercury Injection (Figure 9), together with Physical measurements (deduced from Water content and/or densities) (Figure 10), plus some others which can be found along the data base itself. For some of these clay formations, a direct comparison between different methods can be evaluated in Figure 11.
  - The low hydraulic conductivity values of the different formations can both be seen in Figure 12: Laboratory hydraulic conductivities and in Figure 13: *In situ* hydraulic conductive. All these hydraulic conductivity values are compiled in Figure 14. The difference between hydraulic conductivities parallel or perpendicular to the bedding can be seen where possible, but *in situ versus* laboratory scale effects cannot be underscored probably due to the limited amount of data.

- All the HTO effective diffusion coefficients "D_e" are compiled in Figure 15: when data are available, it is possible to highlight the difference on the HTO D_e values due to the orientation towards stratigraphy. There is not enough data however, to draw any conclusions concerning a scale effect, between laboratory and *in situ* tests. Based on the restricted number of available data, it may be inferred that HTO diffusion coefficients are higher than those from tests with chemical species such as I- or Cl- (Figure 16).

- Petrophysical and mechanical characteristics of the different formations are illustrated with the three following parameters: laboratory seismic velocities (Vp & Vs, Figure 17) and *in situ* seismic velocities (Vp & Vs, Figure 18), laboratory uniaxial compressive strength (Figure 19) and Young's modulus (Figure 20). As a first conclusion, these parameters illustrate the difference between "soft" and "hard" clays.

Some relevant correlations

These are:

- Figure 21 presents the relative position of the various clay formations in a ternary diagram [clay minerals – carbonates – other minerals]. The diagram confirms that no "pure clay formations" exists, and that some of their characteristics and consequently behaviour may be influenced more or less by the amount of carbonates or others minerals. It might be noticed that the correlation's diagram was built from "best estimate" values.
- Figure 22 presents the correlation between porosities and maximum burial depths which can be drawn despite the restricted number of values that were available (only "best estimate" of porosities from water content and/or grain density): a general trend is recognized for the two parameters dependency.
- Figure 23 presents the correlation between porosities (from different type of measurements excluding Hg injection) and *in situ* hydraulic conductivities. This correlation is, with respect to the reliable data that can be used here, in line with some identical correlations which were provided elsewhere in the past*. This correlation underscores the difference between "hard clays" with low porosities (5 to 15 %) and low hydraulic conductivities (10^{-14} to 10^{-13} m/s), and "soft clays" with higher values (30 to 40 % for porosities and hydraulic conductivities $\geq 10^{-12}$ m/s). It should be noted that it is not possible to establish the same obvious correlation by including the porosities from mercury injection (total, macro or micro porosities). Generally speaking, porosity values obtained with this technique are too low and not fully representative for clay material.
- Figure 24 confirms the direct correlation between the various measured porosities and HTO effective diffusion coefficients. If available, the influence of the orientation towards bedding (perpendicular or parallel) is noticed on the figure.
- Finally, despite a rather large spread, it is possible to illustrate the general coupling between mechanical and hydrogeological characteristics of clay formations as shown in Figure 25: Correlation between uniaxial compressive strengths and water contents.

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* see e.g. Neuzil C.E. (1994). How permeable are clays and shales? Water Resources Res., 30 (2) pp 145-150.

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Annex I

DATABASE ILLUSTRATIONS – SOME RELEVANT KEY PARAMETERS

Figure 1**: Burial depth present day top of the formations and maximum (in the past)**

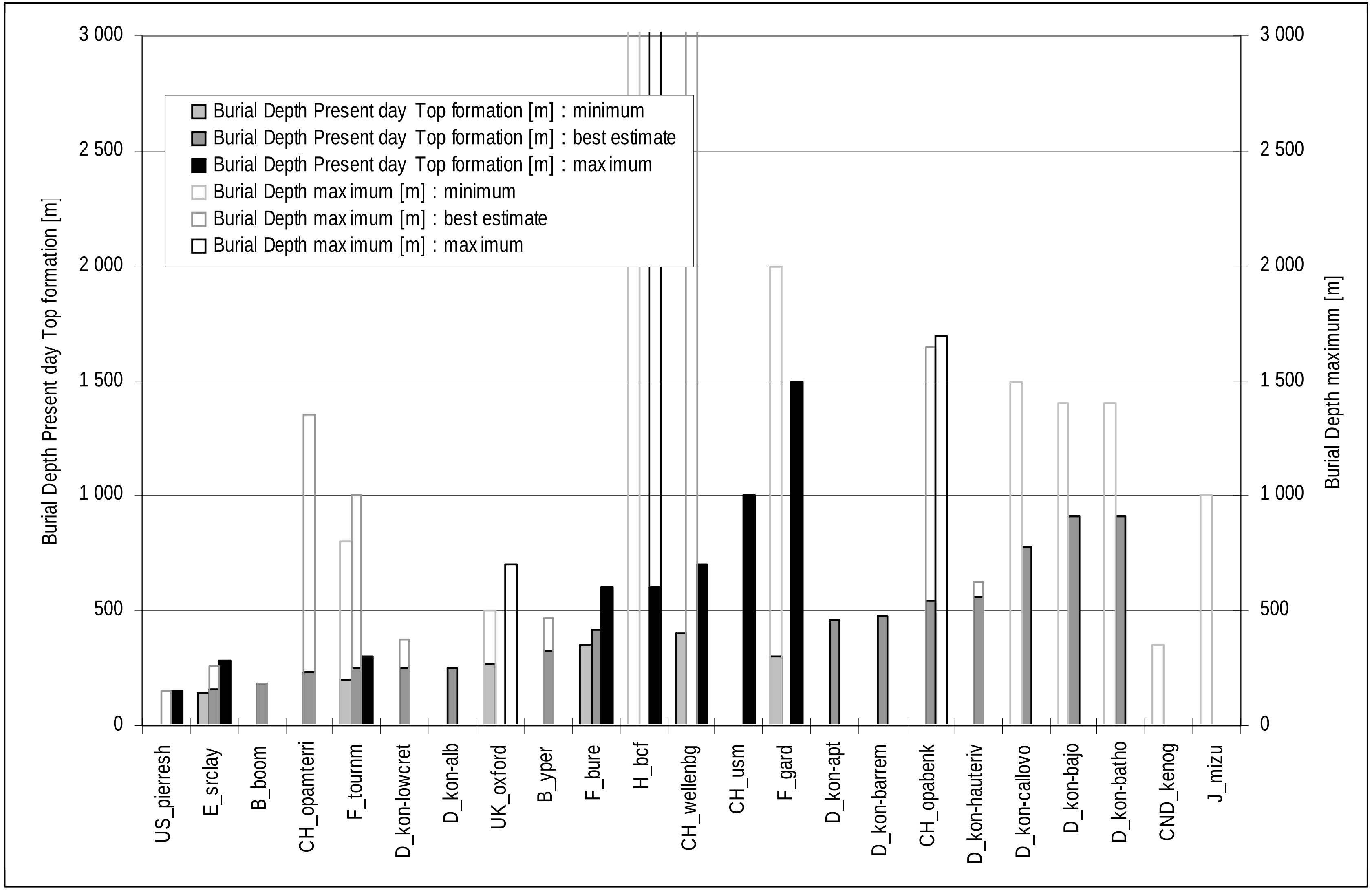


Figure 2: **Thickness of the formations**

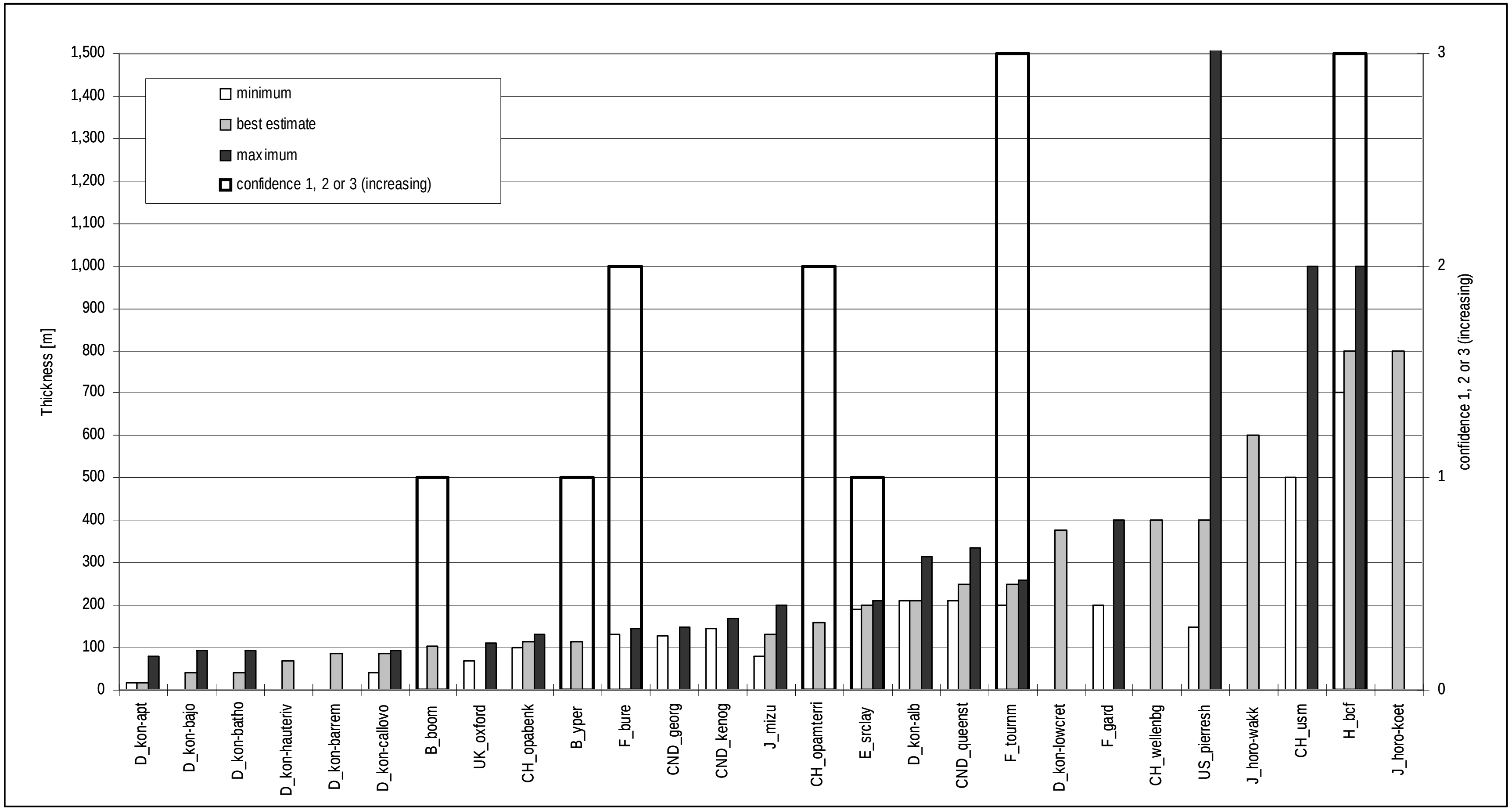


Figure 3: **Content of sum of all clay minerals**

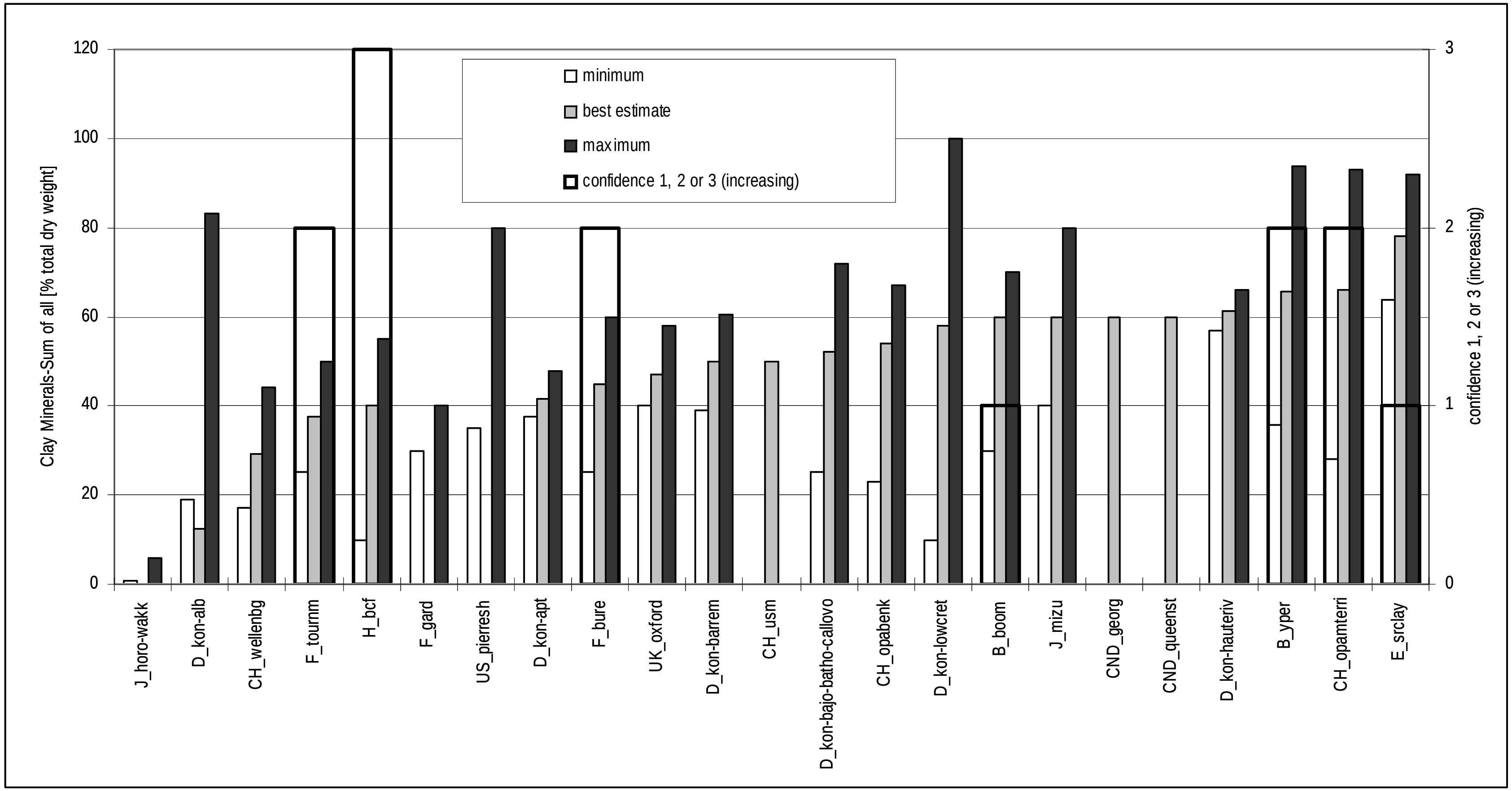


Figure 4: **Content of Smectite**

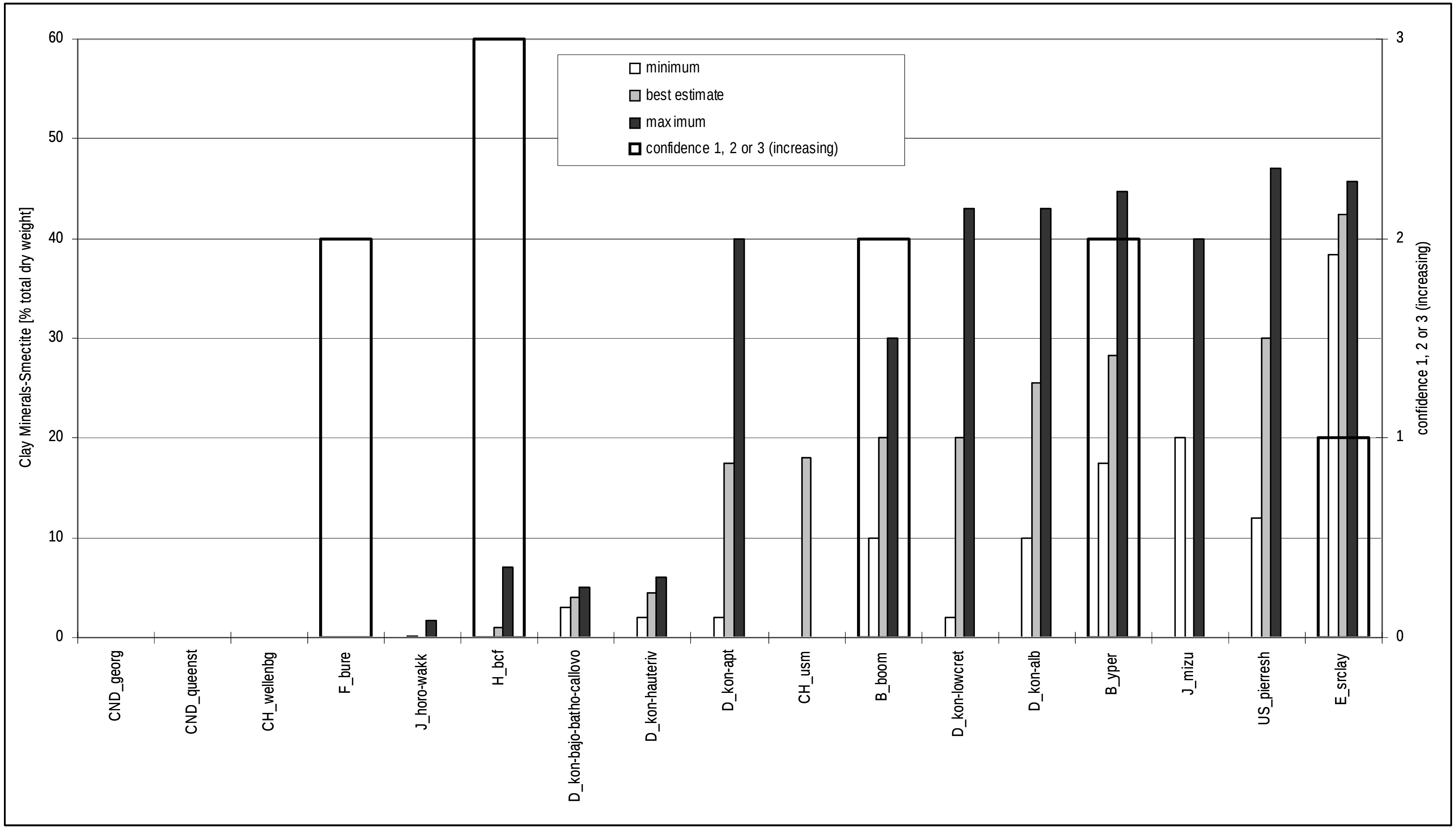


Figure 5: **Content of sum of Illite/Smectite ML + Smectite + Chlorite/Smectite ML**

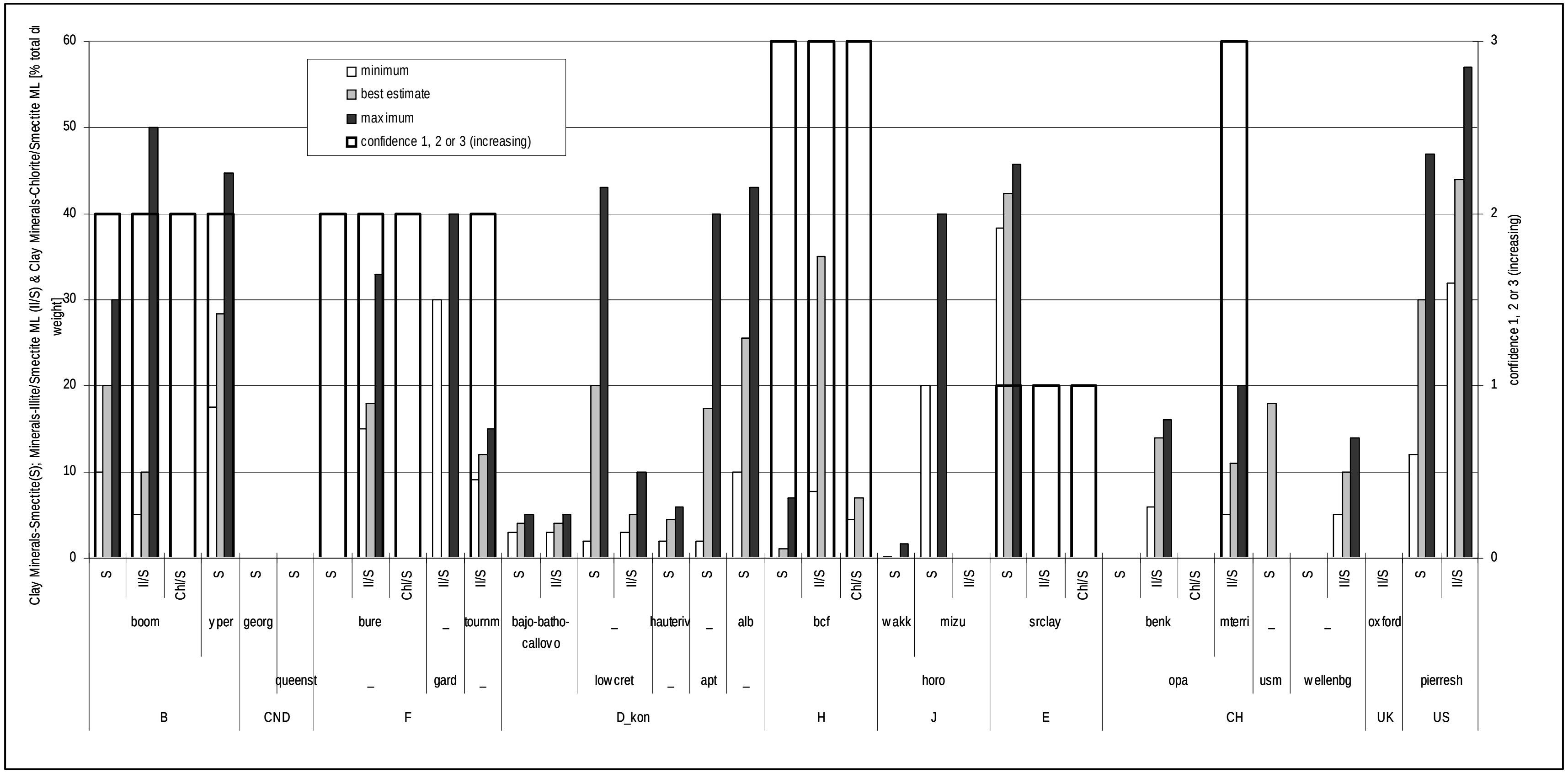


Figure 6: **Content of sum of Carbonates**

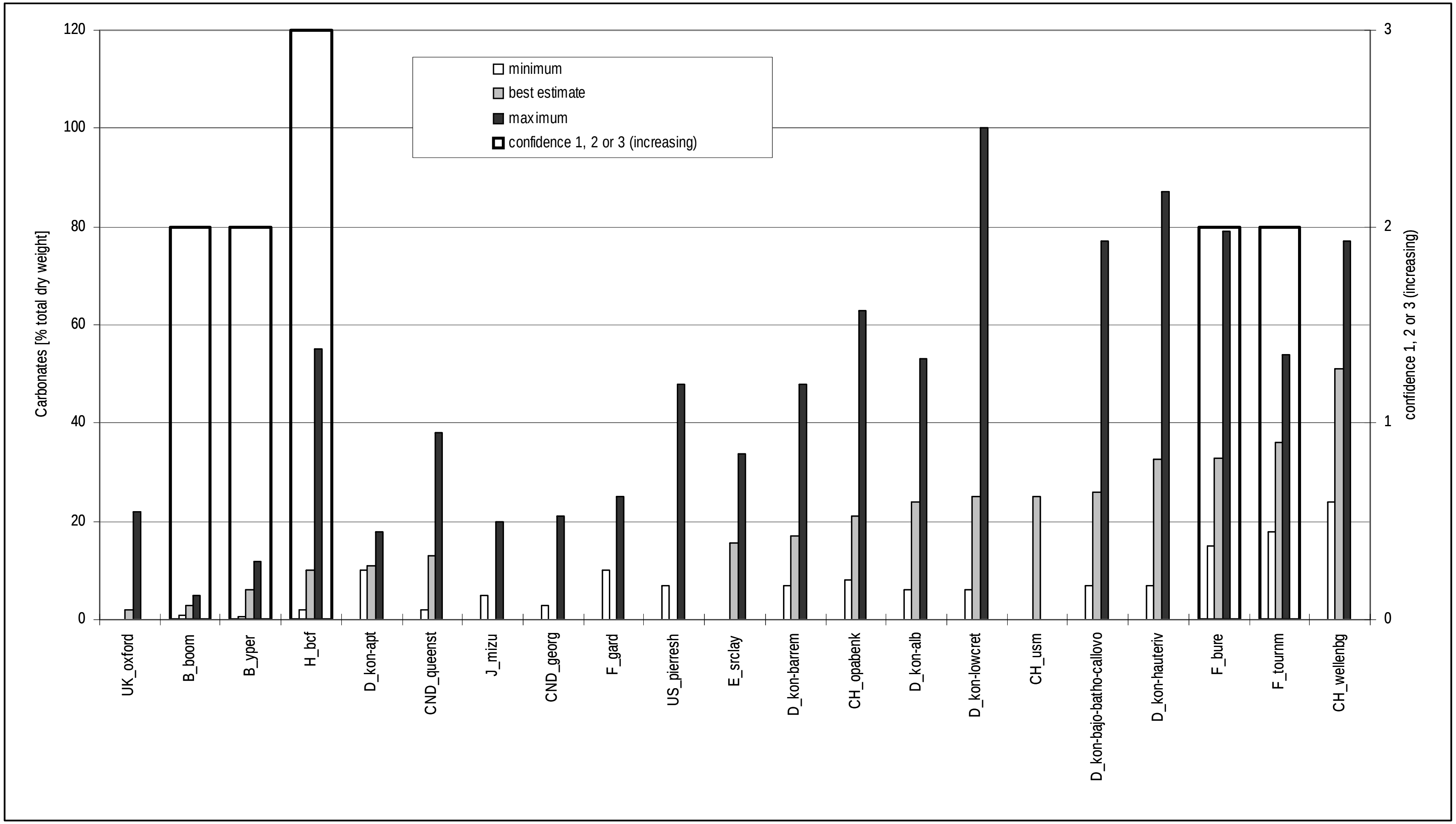


Figure 7: **Total dissolved mineralisation in the porewater**

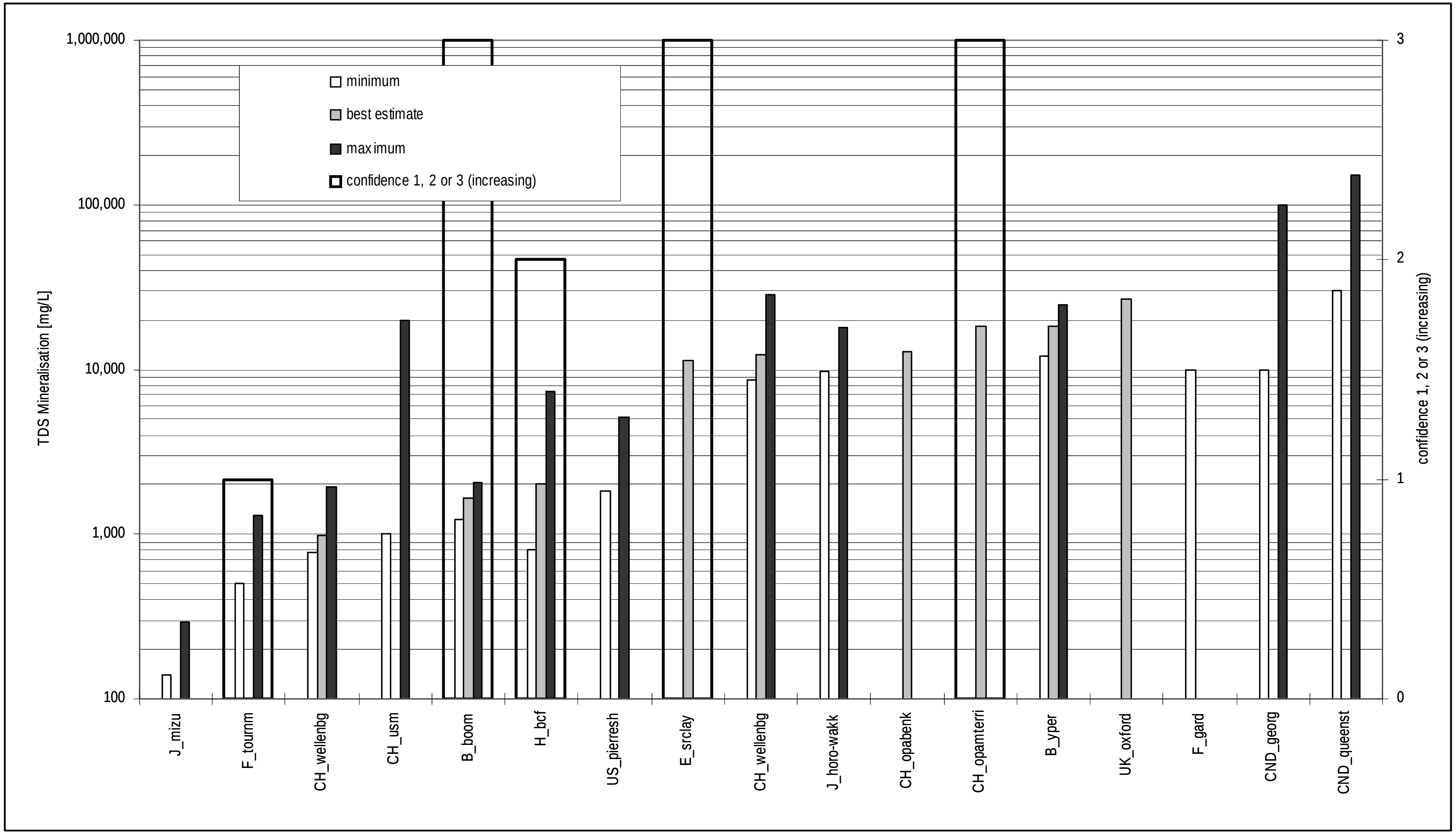


Figure 8: **Water content**

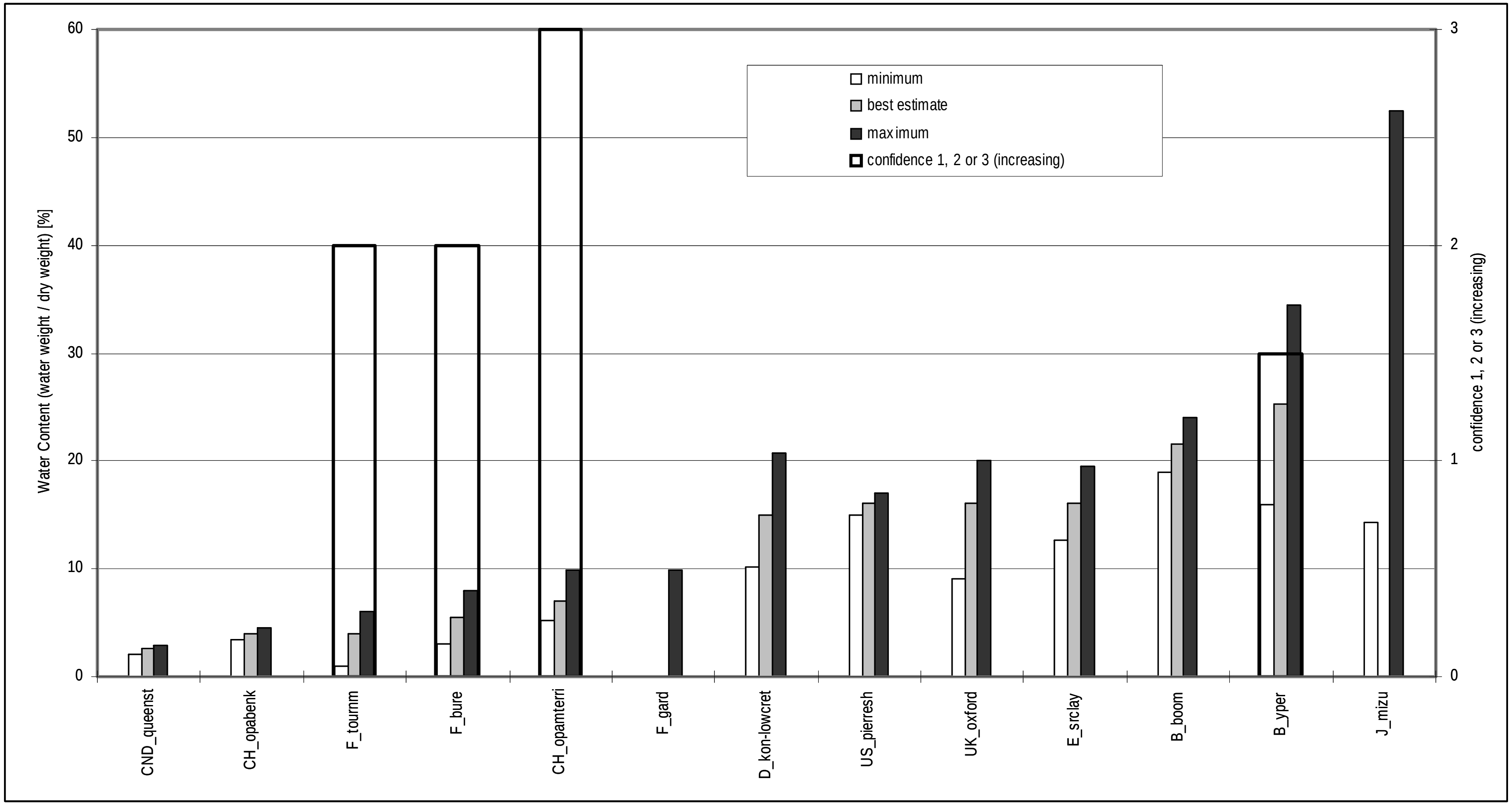


Figure 9: **Porosities from Hg injection**

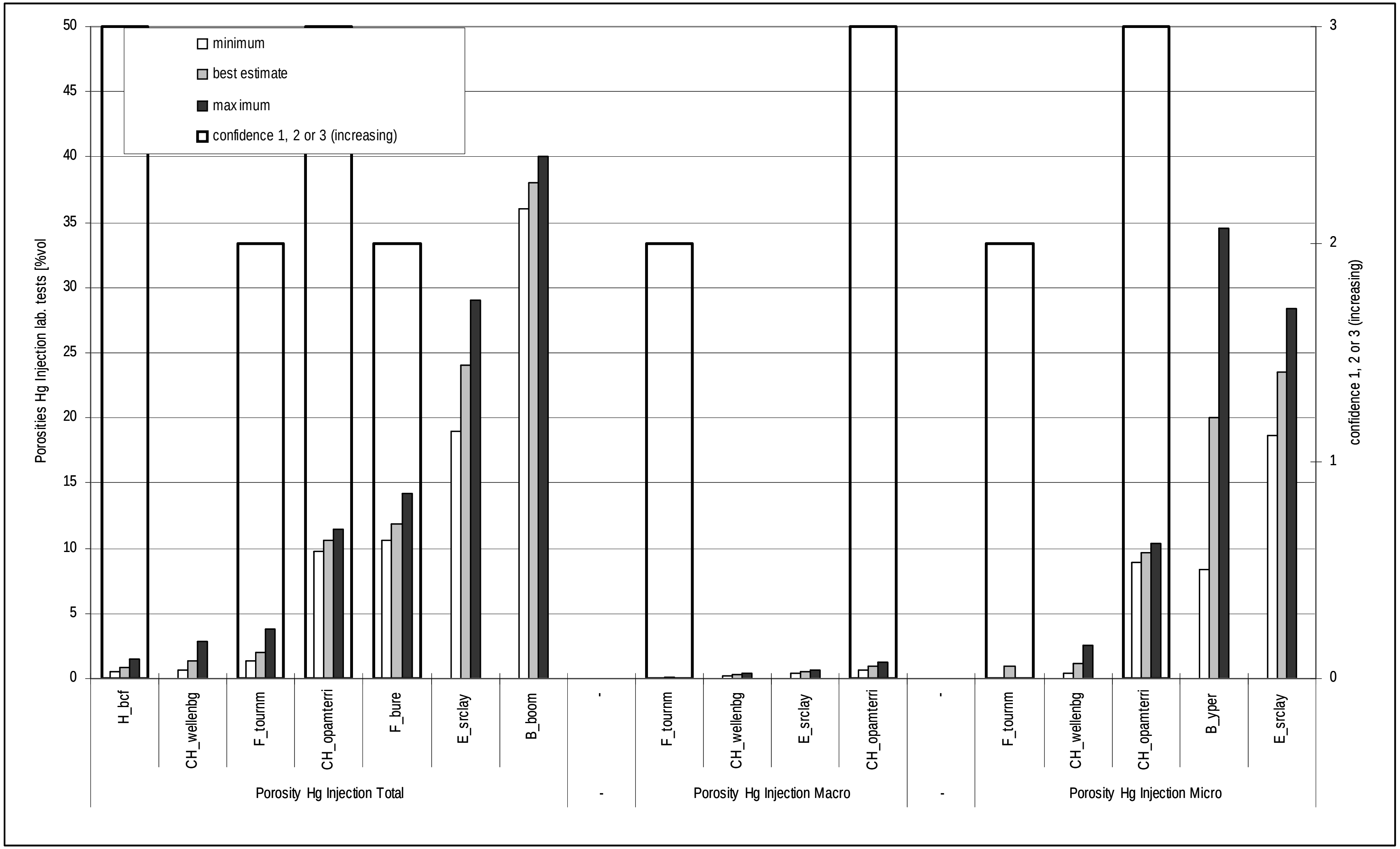


Figure 10: **Porosities from water content and grain density**

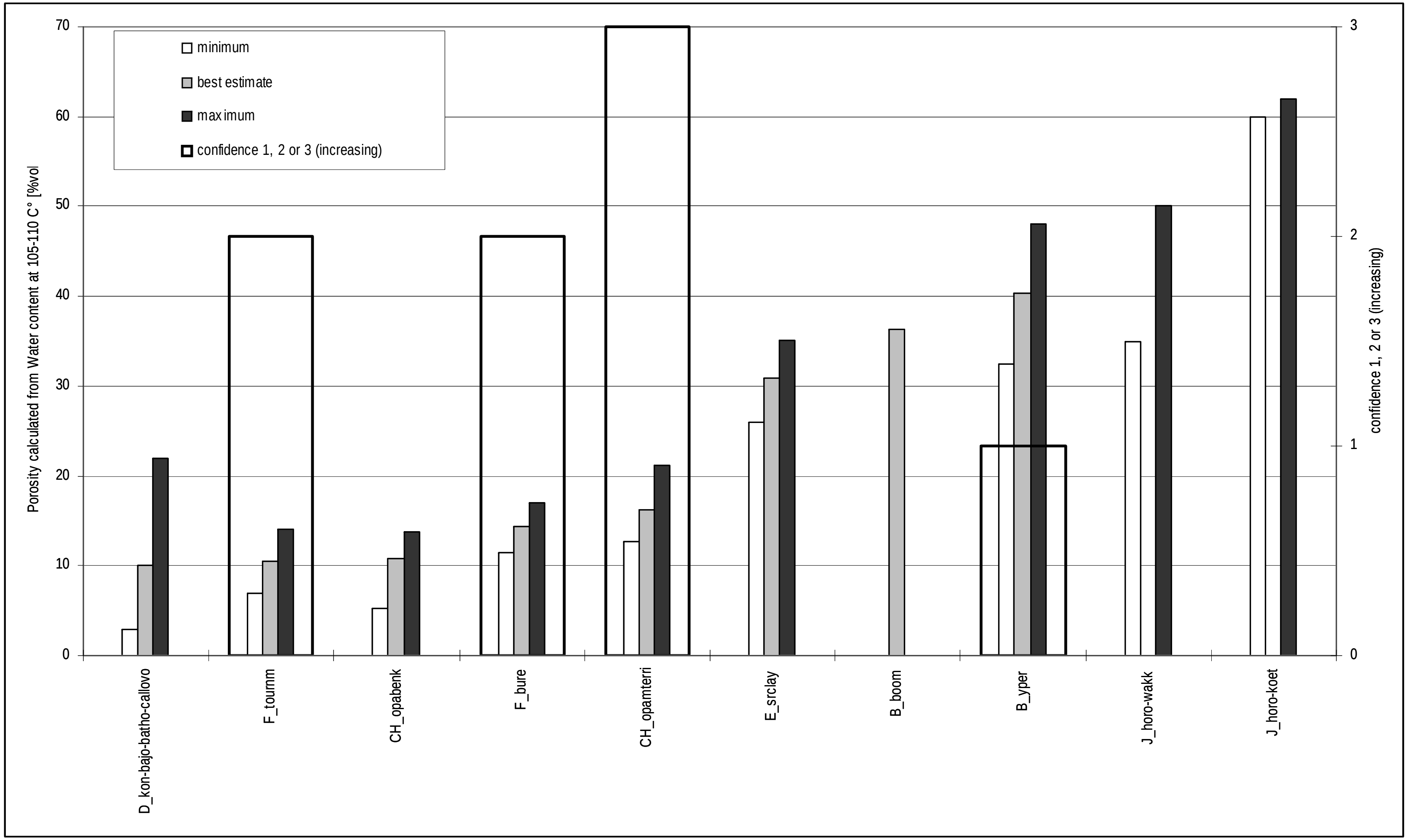


Figure 11: **Porosities measured with different methods**

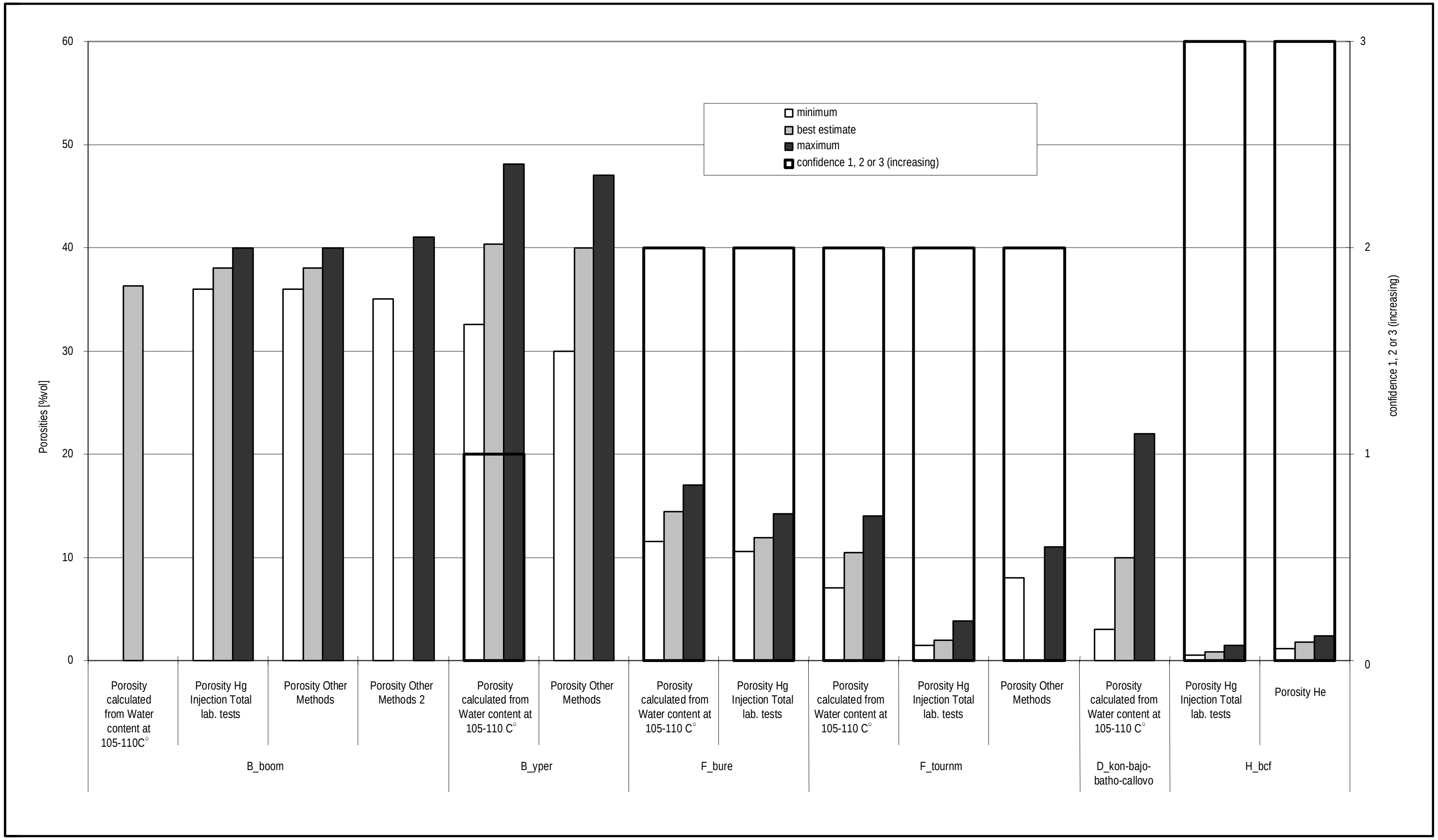


Figure 11 (cont'd): **Porosities measured with different methods**

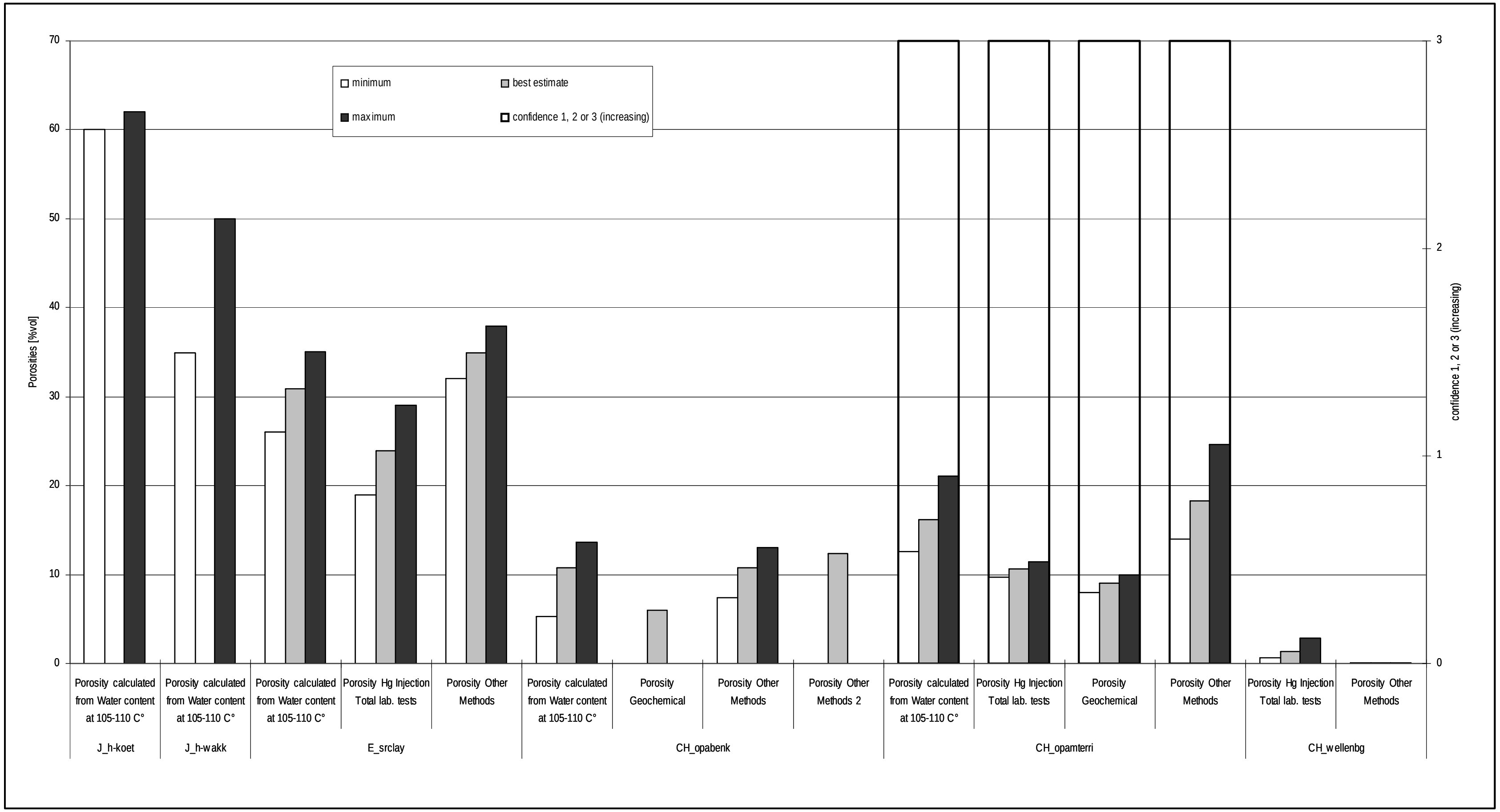


Figure 12: **Laboratory hydraulic conductivities**

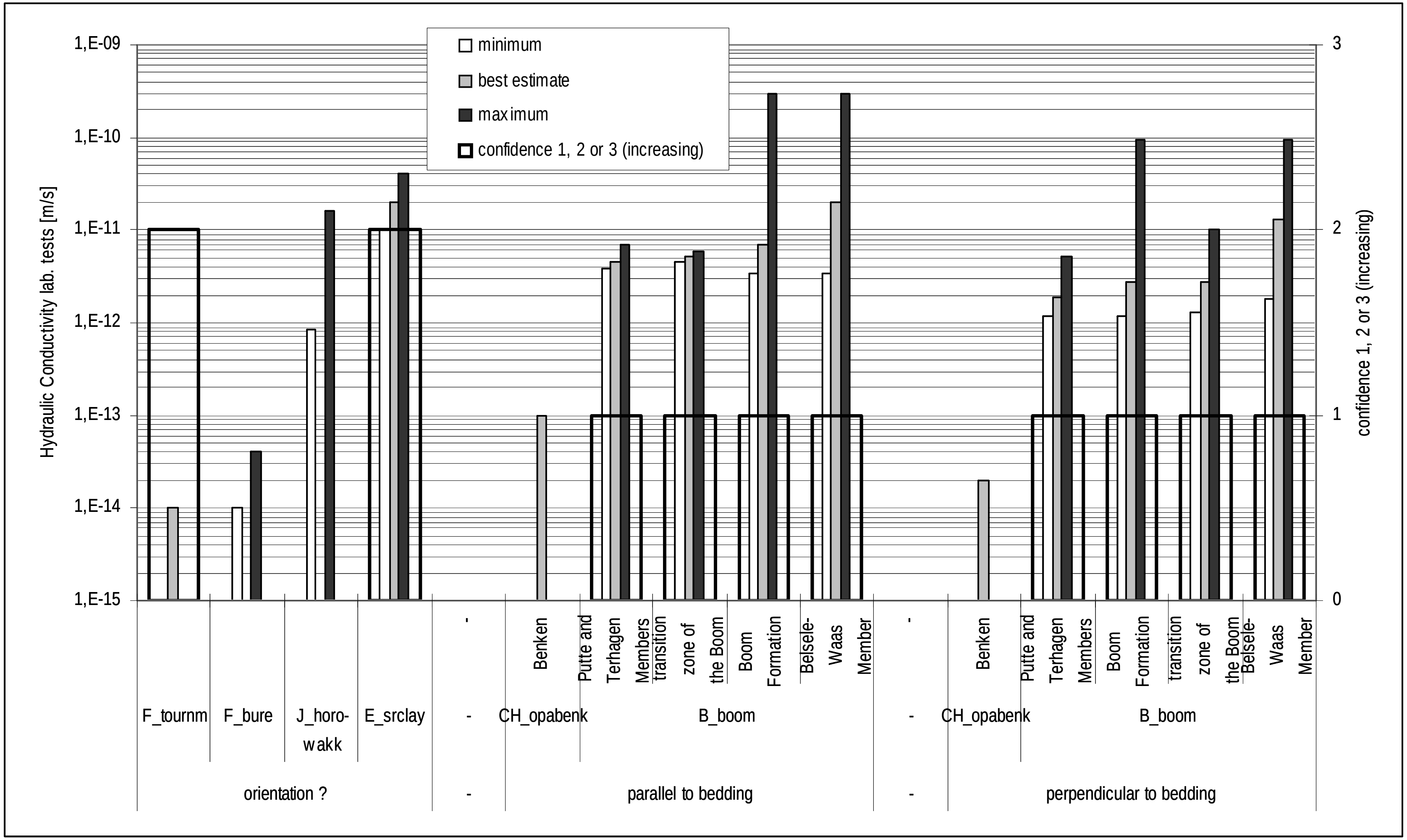


Figure 13: ***In situ* hydraulic conductivities**

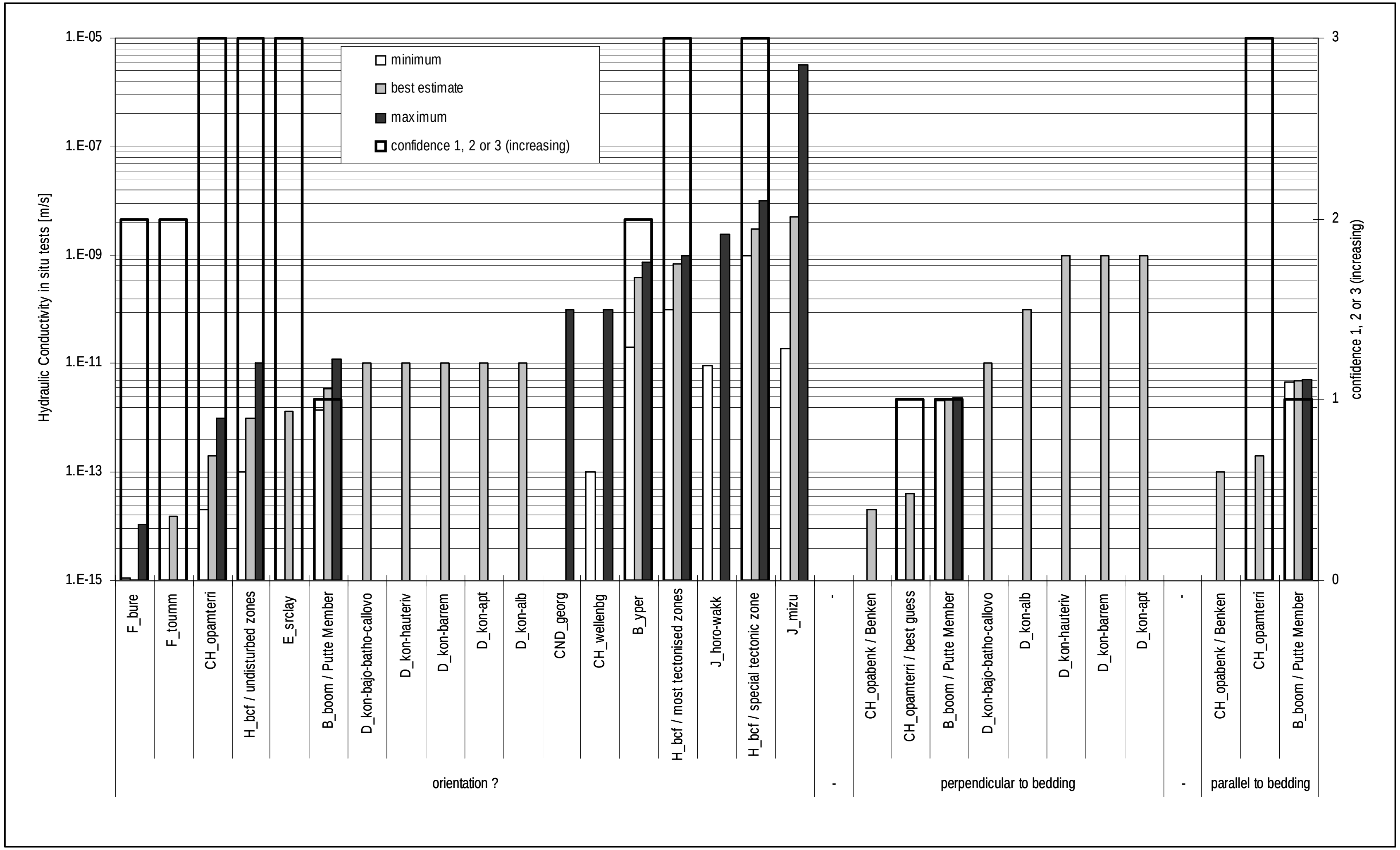


Figure 14: **Hydraulic conductivities**

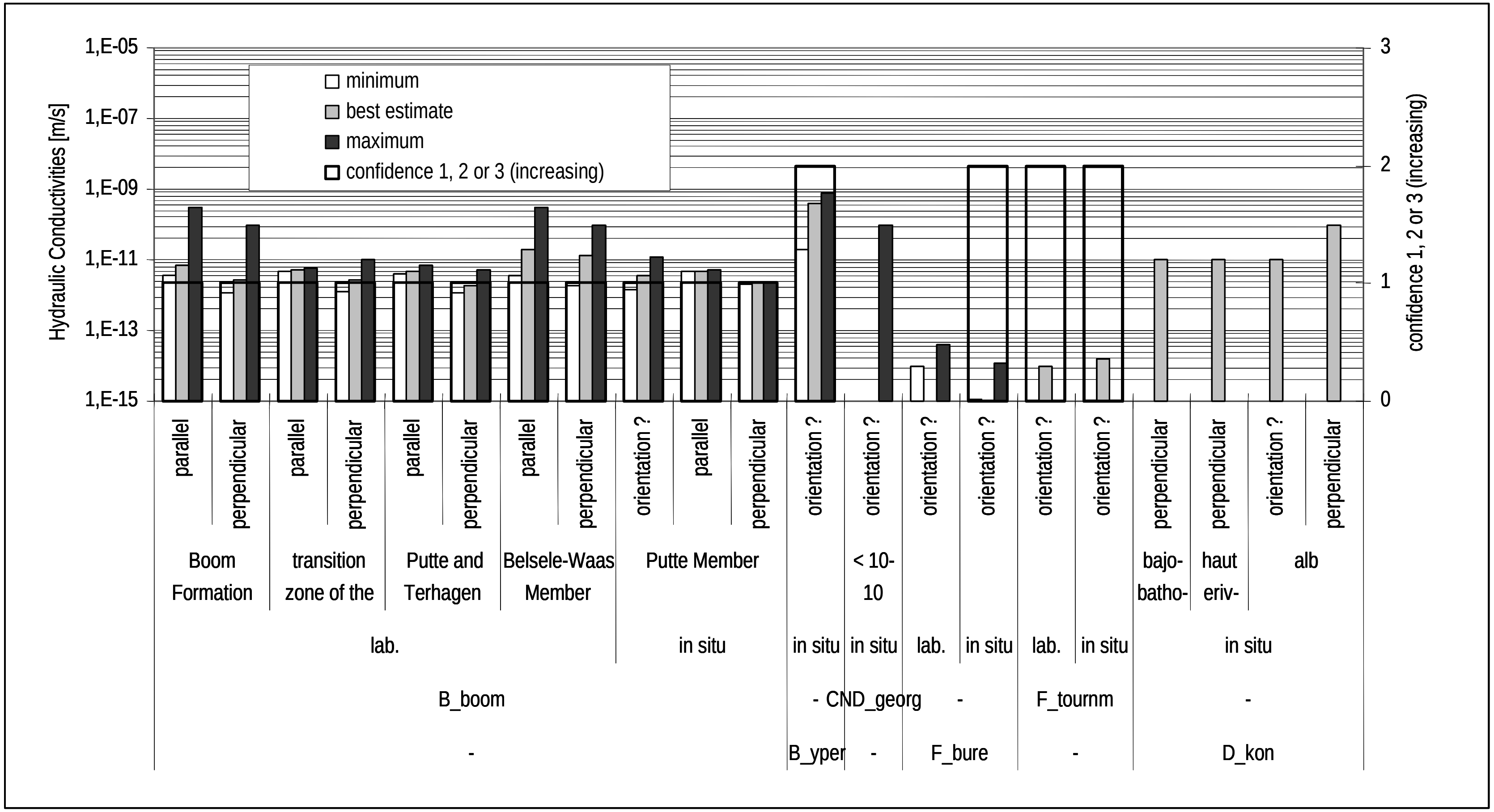


Figure 14 (cont'd): **Hydraulic conductivities**

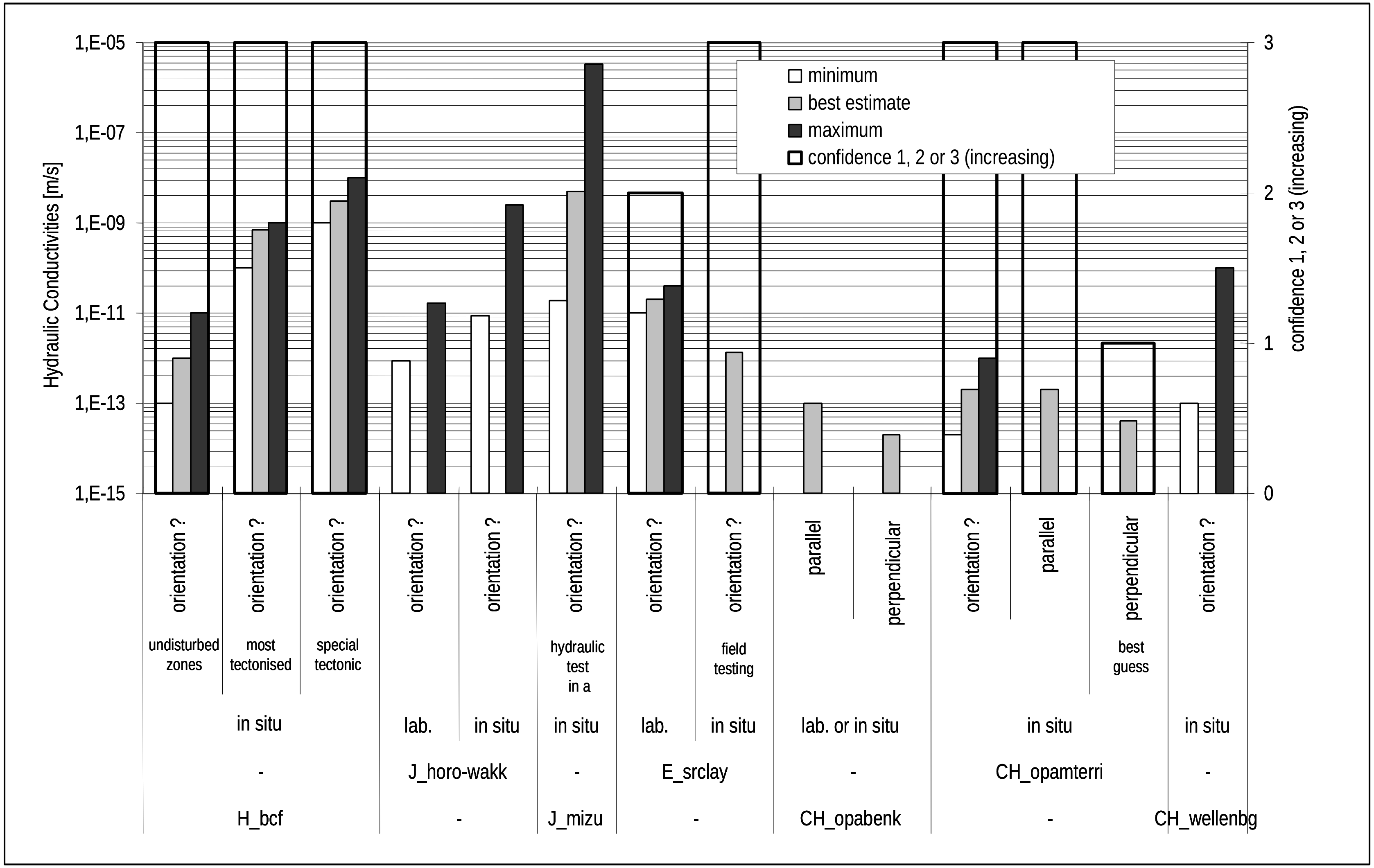


Figure 15: **HTO effective diffusion coefficient**

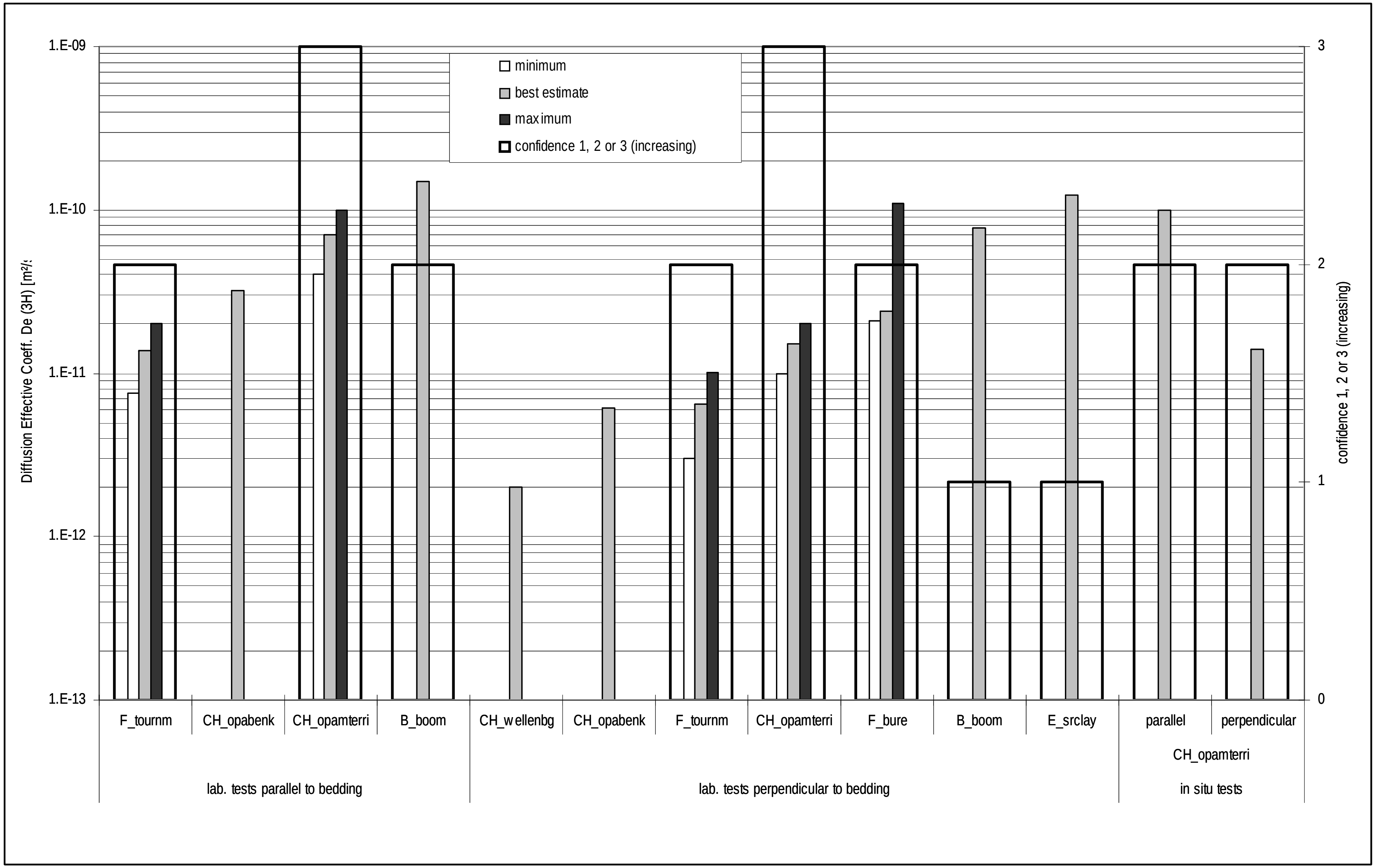


Figure16: **HTO, I & Cl effective diffusion coefficients**

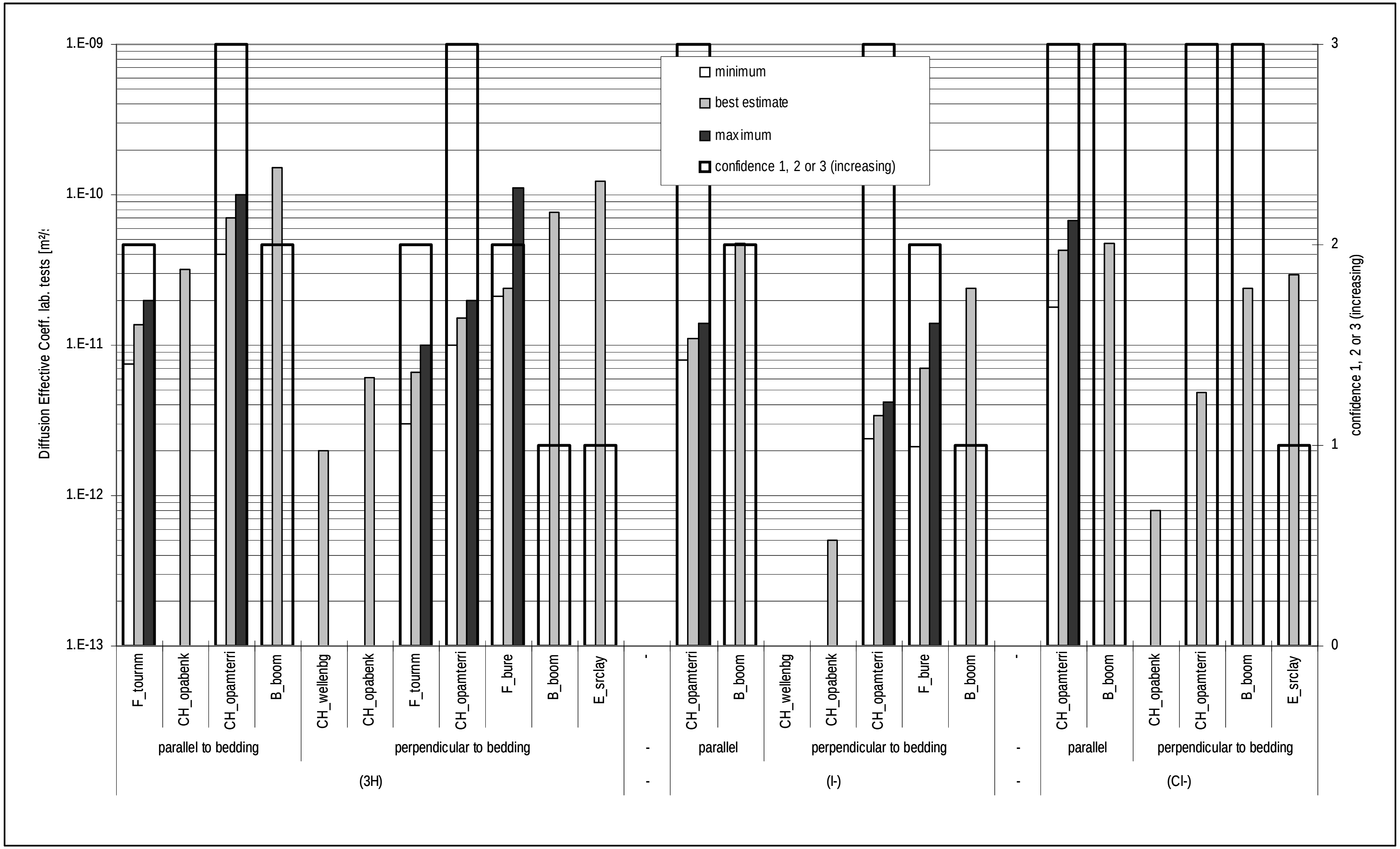


Figure 17: **Laboratory seismic velocities (Vp & Vs)**

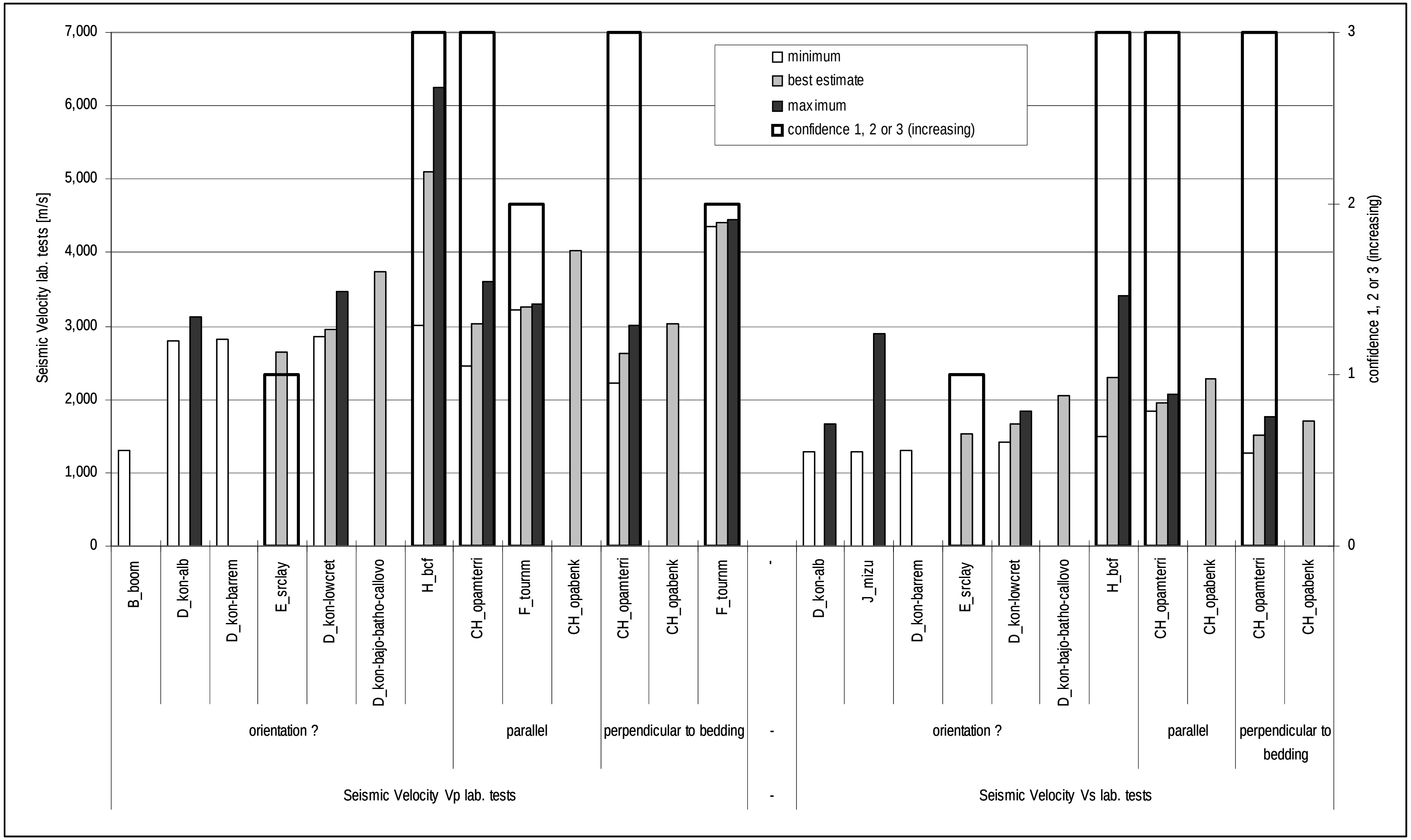


Figure 18: ***In situ* seismic velocities (Vp & Vs)**

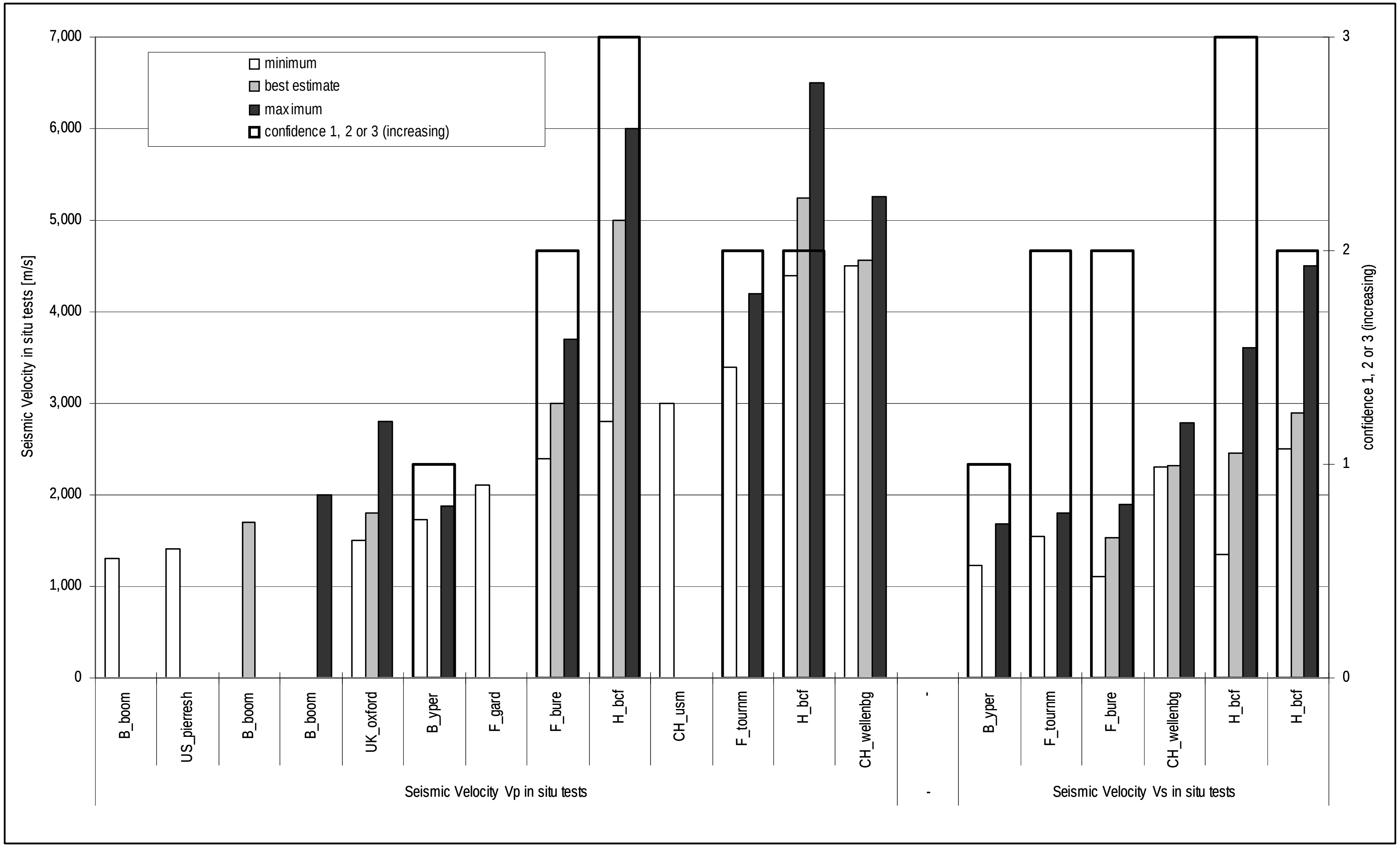


Figure 19: **Laboratory uniaxial compressive strength**

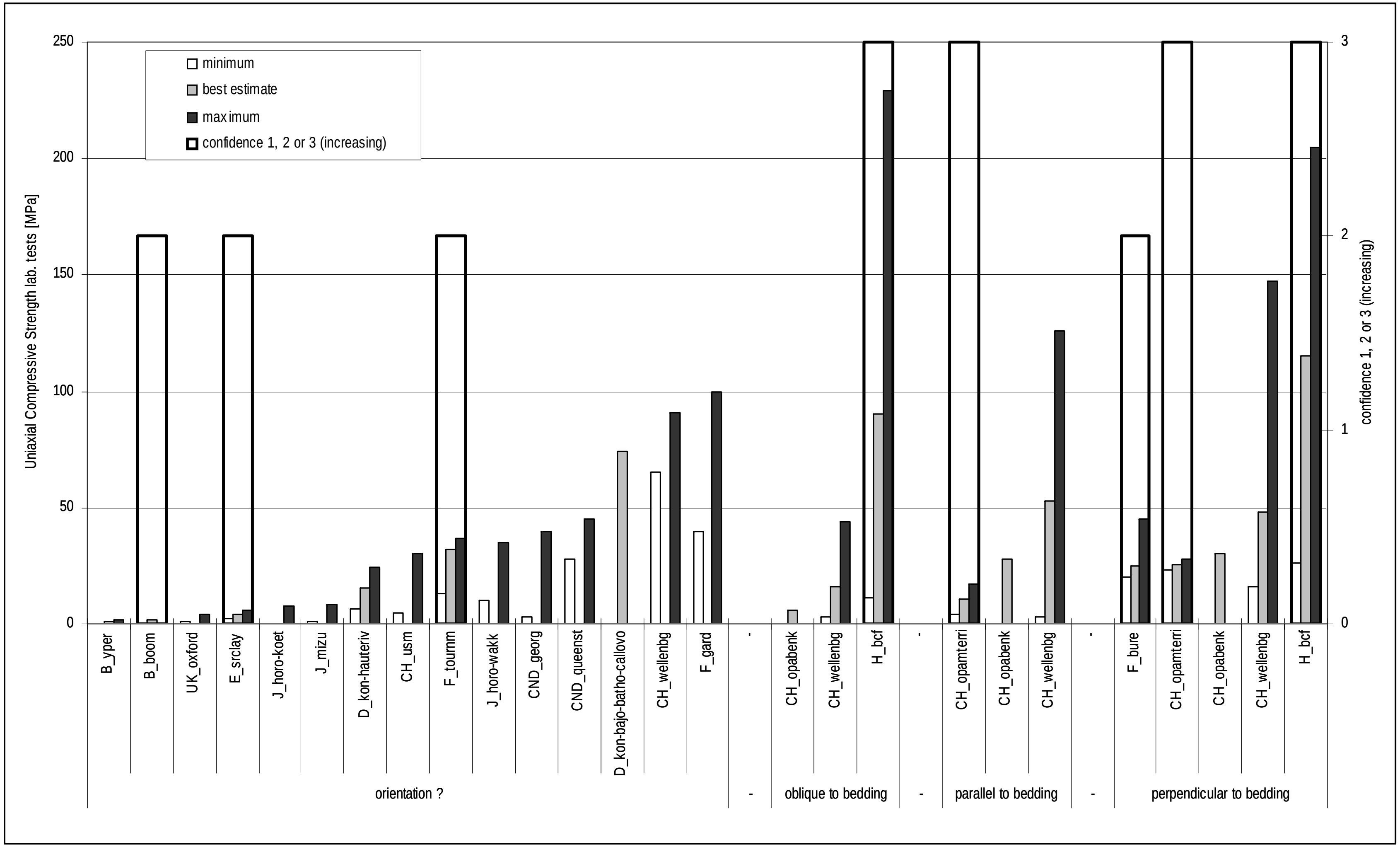
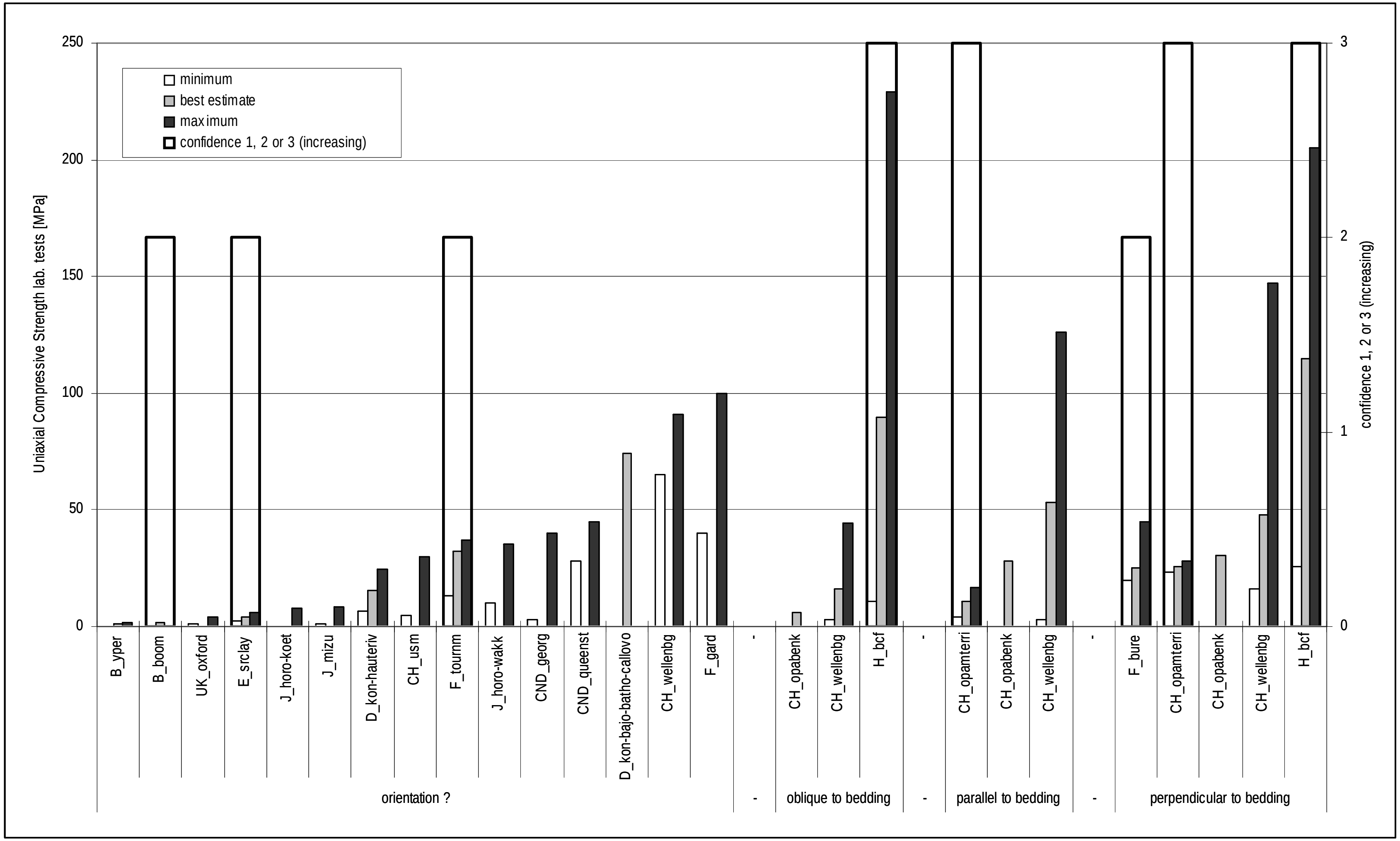


Figure 20: **Young's modulus**



Annex II

DATABASE ILLUSTRATIONS – SOME RELEVANT CORRELATIONS

Figure 21: **Ternary diagram for (sum of all clay minerals – sum of carbonates – sum of other minerals) content**
(nb: only “best estimate” values for the two first parameters)

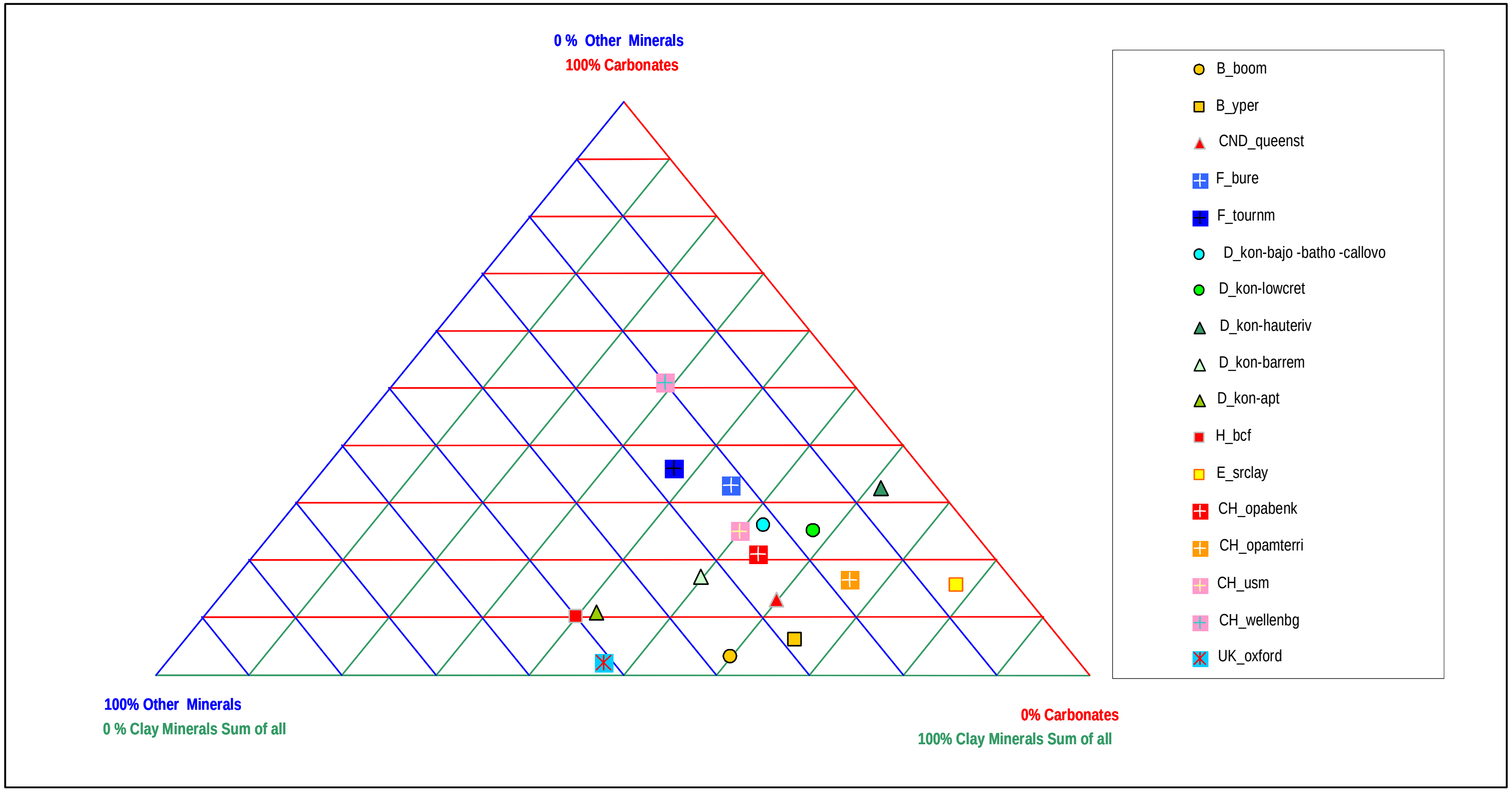


Figure 22: **Correlation between porosities (from water content and grain density) and maximum burial depths**

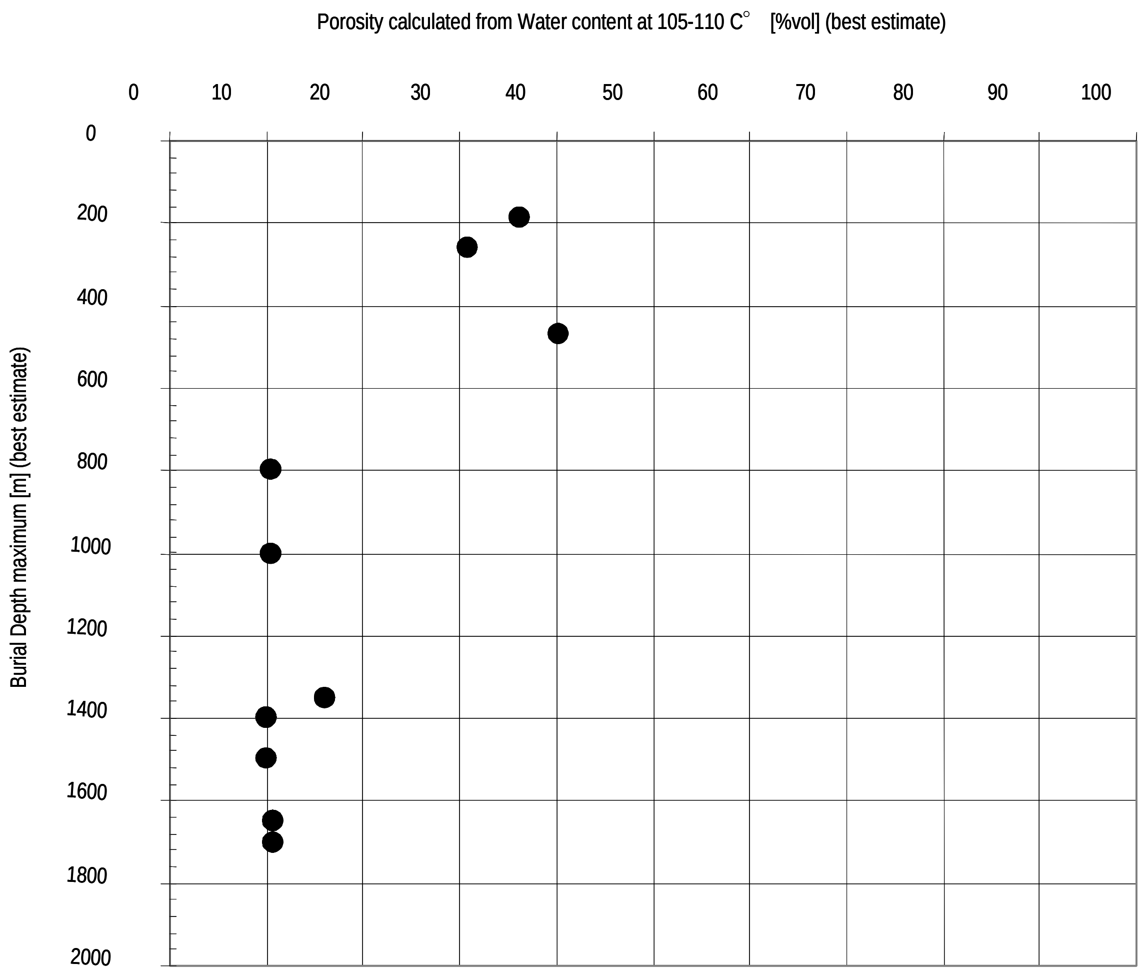


Figure 23: **Correlation between porosities (from different type of measurements excluding Hg injection) and *in situ* hydraulic conductivities**
[see list of symbols hereafter]

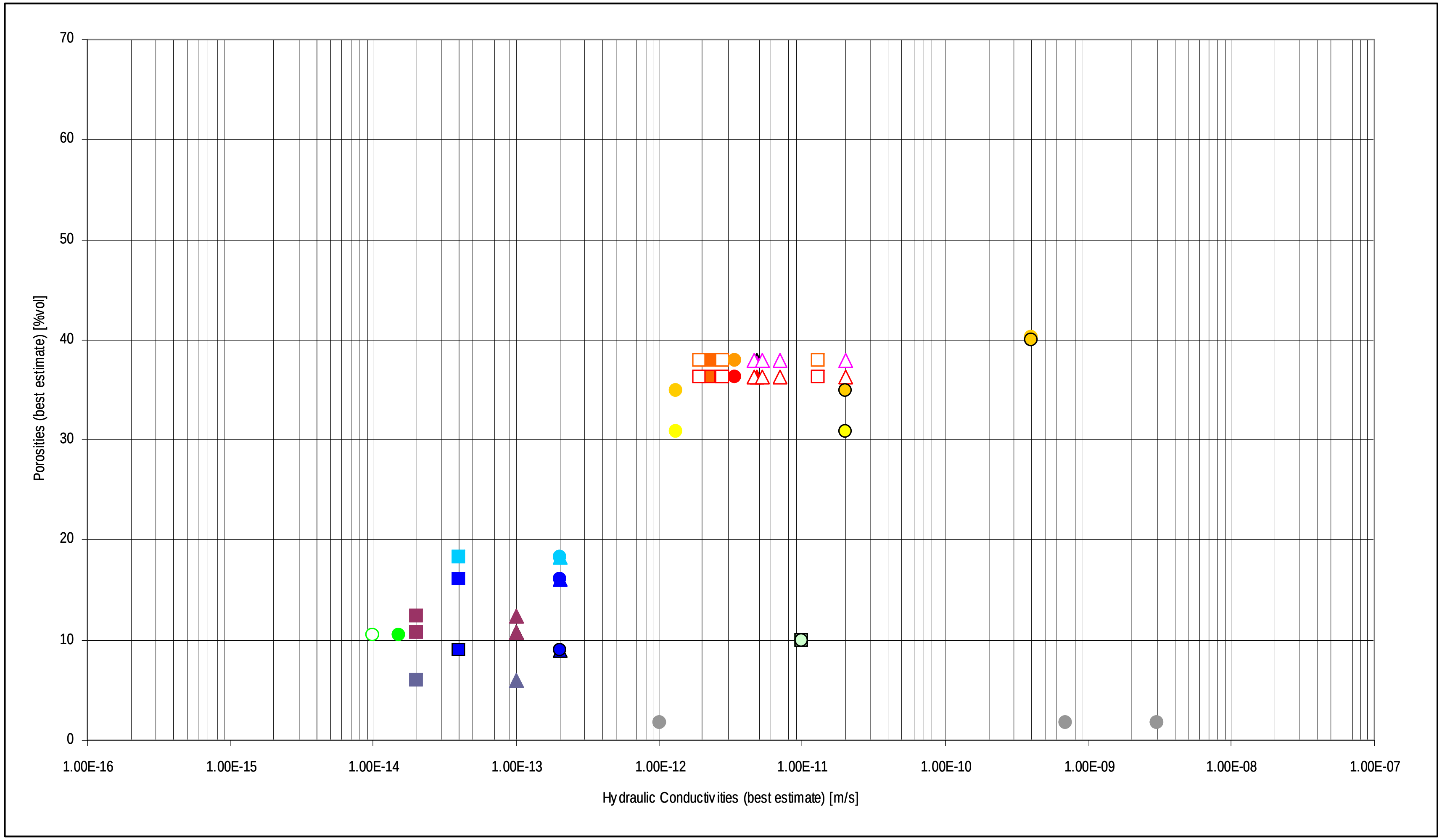


Figure 23 (cont'd): **List of symbols: Correlation between porosities (from different type of measurements excluding Hg injection) and *in situ* hydraulic conductivities**

▲ B_boom Porosity calculated from Water content at 105-110 C° [%vol] vs. Hydraulic Conductivity (??) in situ tests [m/s]
△ B_boom Porosity calculated from Water content at 105-110 C° [%vol] vs. Hydraulic Conductivity (??) lab. tests [m/s]
■ B_boom Porosity calculated from Water content at 105-110 C° [%vol] vs. Hydraulic Conductivity (?) in situ tests [m/s]
□ B_boom Porosity calculated from Water content at 105-110 C° [%vol] vs. Hydraulic Conductivity (?) lab. tests [m/s]
● B_boom Porosity calculated from Water content at 105-110 C° [%vol] vs. Hydraulic Conductivity (orientation ?) in situ tests [m/s]
▲ B_boom Porosity Other Methods [%vol] vs. Hydraulic Conductivity (??) in situ tests [m/s]
△ B_boom Porosity Other Methods [%vol] vs. Hydraulic Conductivity (??) lab. tests [m/s]
■ B_boom Porosity Other Methods [%vol] vs. Hydraulic Conductivity (?) in situ tests [m/s]
□ B_boom Porosity Other Methods [%vol] vs. Hydraulic Conductivity (?) lab. tests [m/s]
● B_boom Porosity Other Methods [%vol] vs. Hydraulic Conductivity (orientation ?) in situ tests [m/s]
● B_yper Porosity calculated from Water content at 105-110 C° [%vol] vs. Hydraulic Conductivity (orientation ?) in situ tests [m/s]
● B_yper Porosity Other Methods [%vol] vs. Hydraulic Conductivity (orientation ?) in situ tests [m/s]
▲ CH_opabenk Porosity calculated from Water content at 105-110 C° [%vol] vs. Hydraulic Conductivity (??) lab. or in situ tests [m/s]
■ CH_opabenk Porosity calculated from Water content at 105-110 C° [%vol] vs. Hydraulic Conductivity (?) lab. or in situ tests [m/s]
▲ CH_opabenk Porosity Geochemical [%vol] vs. Hydraulic Conductivity (??) lab. or in situ tests [m/s]
■ CH_opabenk Porosity Geochemical [%vol] vs. Hydraulic Conductivity (?) lab. or in situ tests [m/s]
▲ CH_opabenk Porosity Other Methods [%vol] vs. Hydraulic Conductivity (??) lab. or in situ tests [m/s]
■ CH_opabenk Porosity Other Methods [%vol] vs. Hydraulic Conductivity (?) lab. or in situ tests [m/s]
▲ CH_opamterri Porosity calculated from Water content at 105-110 C° [%vol] vs. Hydraulic Conductivity (??) in situ tests [m/s]
■ CH_opamterri Porosity calculated from Water content at 105-110 C° [%vol] vs. Hydraulic Conductivity (?) in situ tests [m/s]
● CH_opamterri Porosity calculated from Water content at 105-110 C° [%vol] vs. Hydraulic Conductivity (orientation ?) in situ tests [m/s]
▲ CH_opamterri Porosity Geochemical [%vol] vs. Hydraulic Conductivity (??) in situ tests [m/s]
■ CH_opamterri Porosity Geochemical [%vol] vs. Hydraulic Conductivity (?) in situ tests [m/s]
● CH_opamterri Porosity Geochemical [%vol] vs. Hydraulic Conductivity (orientation ?) in situ tests [m/s]
▲ CH_opamterri Porosity Other Methods [%vol] vs. Hydraulic Conductivity (??) in situ tests [m/s]
■ CH_opamterri Porosity Other Methods [%vol] vs. Hydraulic Conductivity (?) in situ tests [m/s]
● CH_opamterri Porosity Other Methods [%vol] vs. Hydraulic Conductivity (orientation ?) in situ tests [m/s]
■ D_kon-bajo Porosity calculated from Water content at 105-110 C° [%vol] vs. Hydraulic Conductivity (?) in situ tests [m/s]
● D_kon-bajo Porosity calculated from Water content at 105-110 C° [%vol] vs. Hydraulic Conductivity (orientation ?) in situ tests [m/s]
■ D_kon-batho Porosity calculated from Water content at 105-110 C° [%vol] vs. Hydraulic Conductivity (?) in situ tests [m/s]
● D_kon-batho Porosity calculated from Water content at 105-110 C° [%vol] vs. Hydraulic Conductivity (orientation ?) in situ tests [m/s]
□ D_kon-callovo Porosity calculated from Water content at 105-110 C° [%vol] vs. Hydraulic Conductivity (?) in situ tests [m/s]
○ D_kon-callovo Porosity calculated from Water content at 105-110 C° [%vol] vs. Hydraulic Conductivity (orientation ?) in situ tests [m/s]
● E_srclay Porosity calculated from Water content at 105-110 C° [%vol] vs. Hydraulic Conductivity (orientation ?) in situ tests [m/s]
● E_srclay Porosity calculated from Water content at 105-110 C° [%vol] vs. Hydraulic Conductivity (orientation ?) lab. tests [m/s]
● E_srclay Porosity Other Methods [%vol] vs. Hydraulic Conductivity (orientation ?) in situ tests [m/s]
● E_srclay Porosity Other Methods [%vol] vs. Hydraulic Conductivity (orientation ?) lab. tests [m/s]
● F_tournm Porosity calculated from Water content at 105-110 C° [%vol] vs. Hydraulic Conductivity (orientation ?) in situ tests [m/s]
○ F_tournm Porosity calculated from Water content at 105-110 C° [%vol] vs. Hydraulic Conductivity (orientation ?) lab. tests [m/s]
● H_bcf Porosity He [%vol] vs. Hydraulic Conductivity (orientation ?) in situ tests [m/s]

Figure 24: **Correlation between different porosity measurements and HTO effective diffusion coefficients**

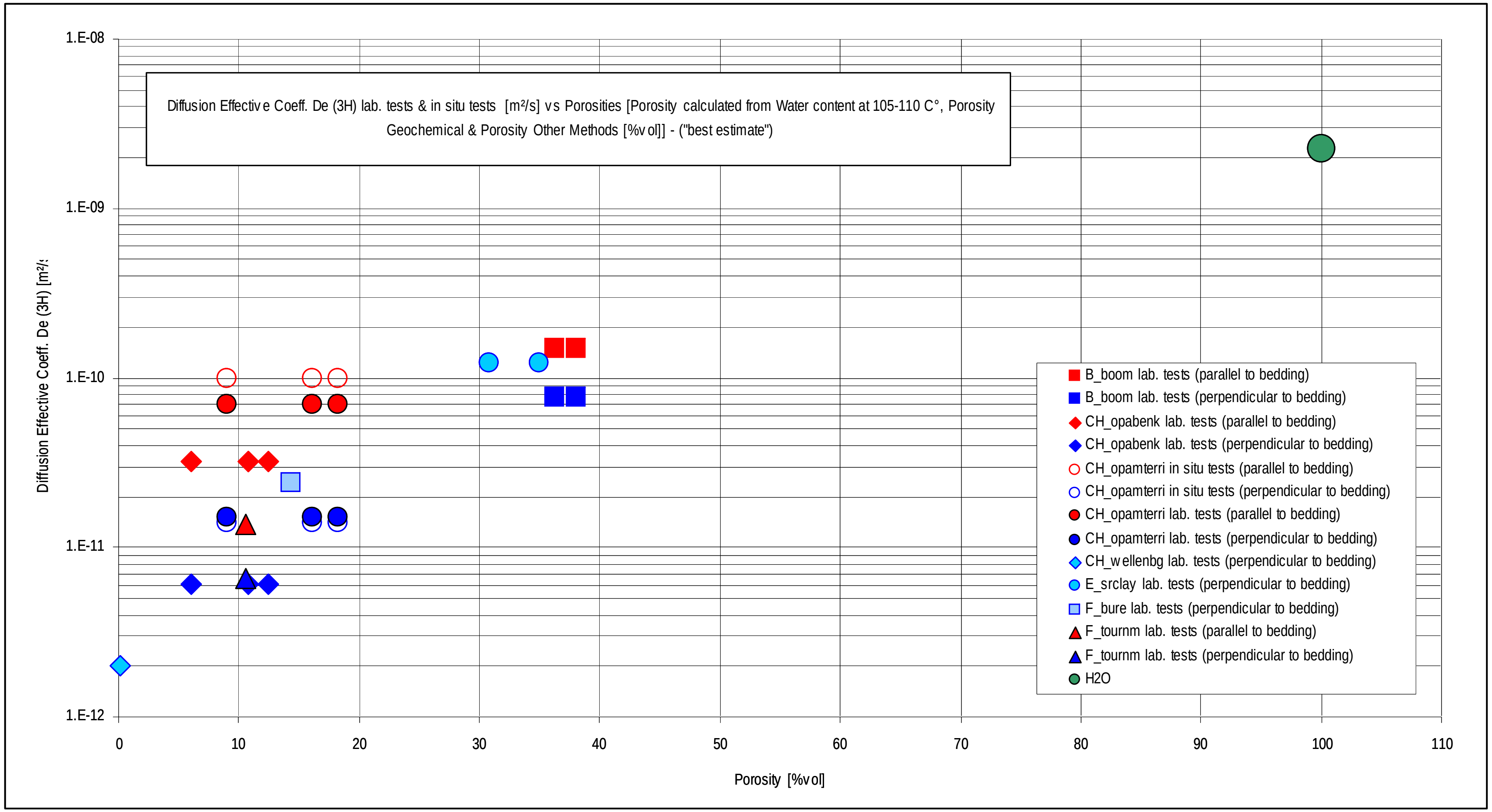
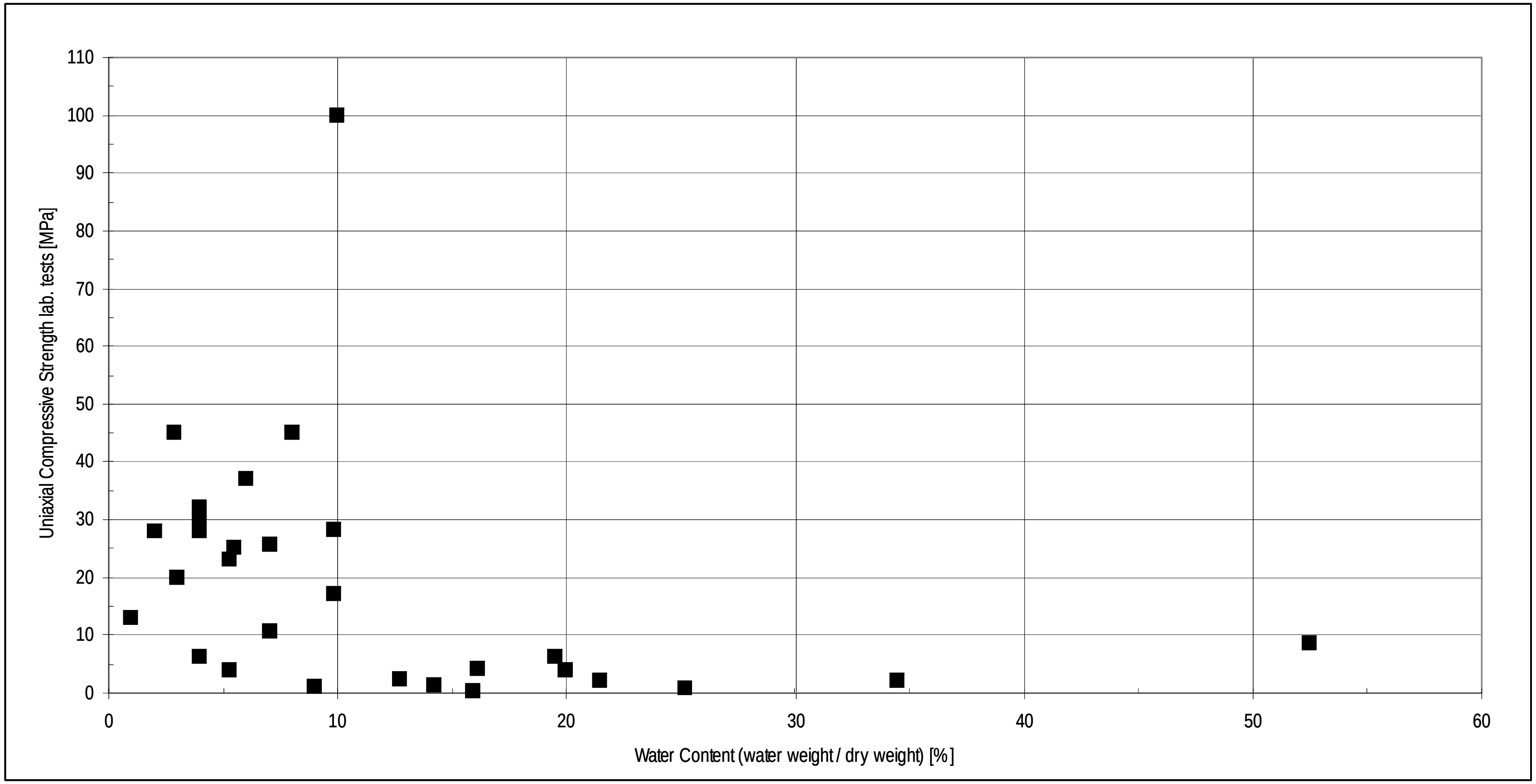


Figure 25: **Correlation between uniaxial compressive strengths and water contents**



Annex III

ARGILLACEOUS ROCK FORMATIONS DESCRIPTION

Detailed information and data are available on the attached CD-ROM

For each argillaceous rock formation, two corresponding files are inserted:

1. *MS PDF file* (“Abbreviation.pdf”) presented as follow:

   NAME OF THE ARGILLACEOUS ROCK FORMATION

   Short presentation of the formation

   Geological illustrations

   Parameters values

   References

   Footnotes

2. *MS Excel file* (“Abbreviation.xls”) within data in tabulated form

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