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Grundbau, Umweltgeotechnik,
Grundwasserhydraulik, Geothermie

# Aspects of testing of hard rock compressive strength

## Engineering to Science

**Prof. Dr.-Ing. Ulrich Burbaum**

Bsc.Eng. Schmitt, Msc.Eng. Klingelhöfer, Bsc.Eng. Haidinger
Bsc.Eng. Hofmann, Bsc.Eng. Holzwarth

University of Applied Applied Science Darmstadt,
Department of Civil- and Environmental Engineering

# Uniaxial compressive strength test (Specimen: Granodiorite)

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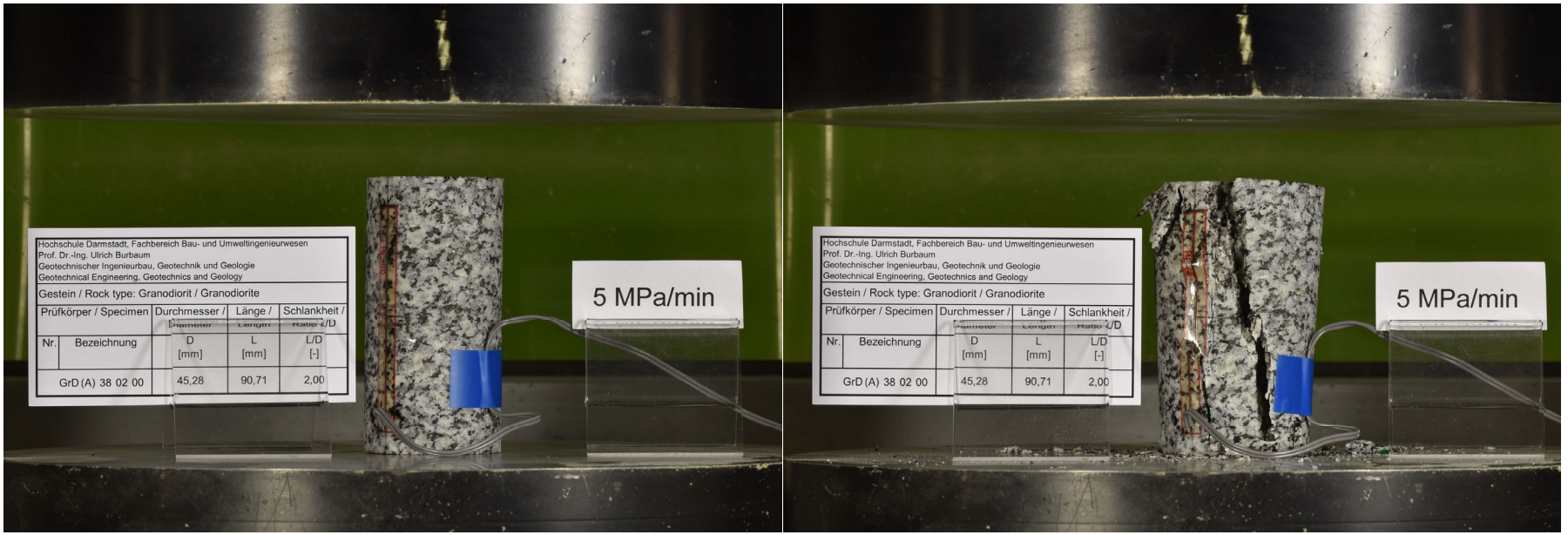

# Uniaxial compressive strength test

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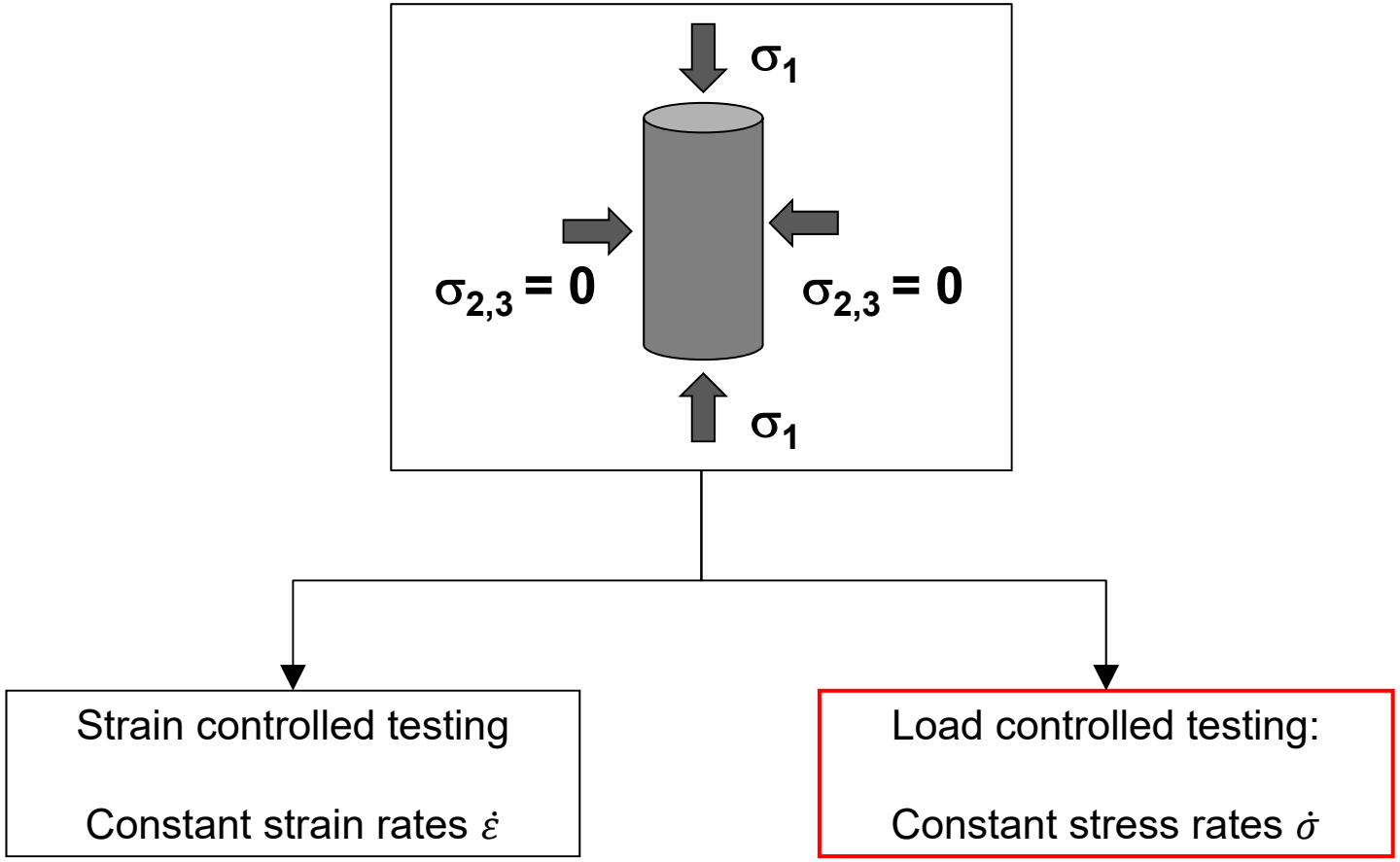

# Normalized UCS vs. stress rate static-like to dynamic stress rates

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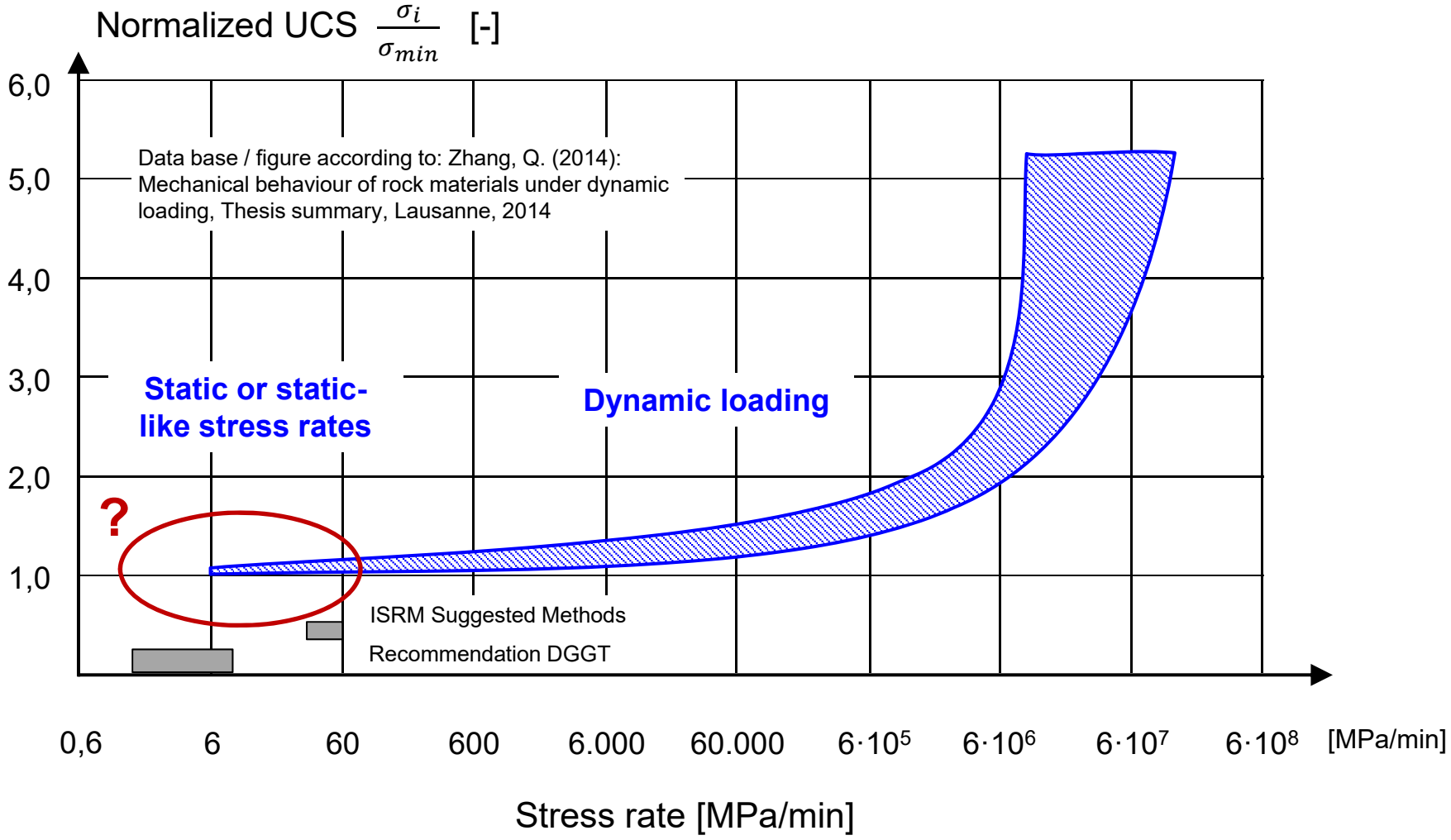

# Research as of to date
# Motivation for the research program HDA

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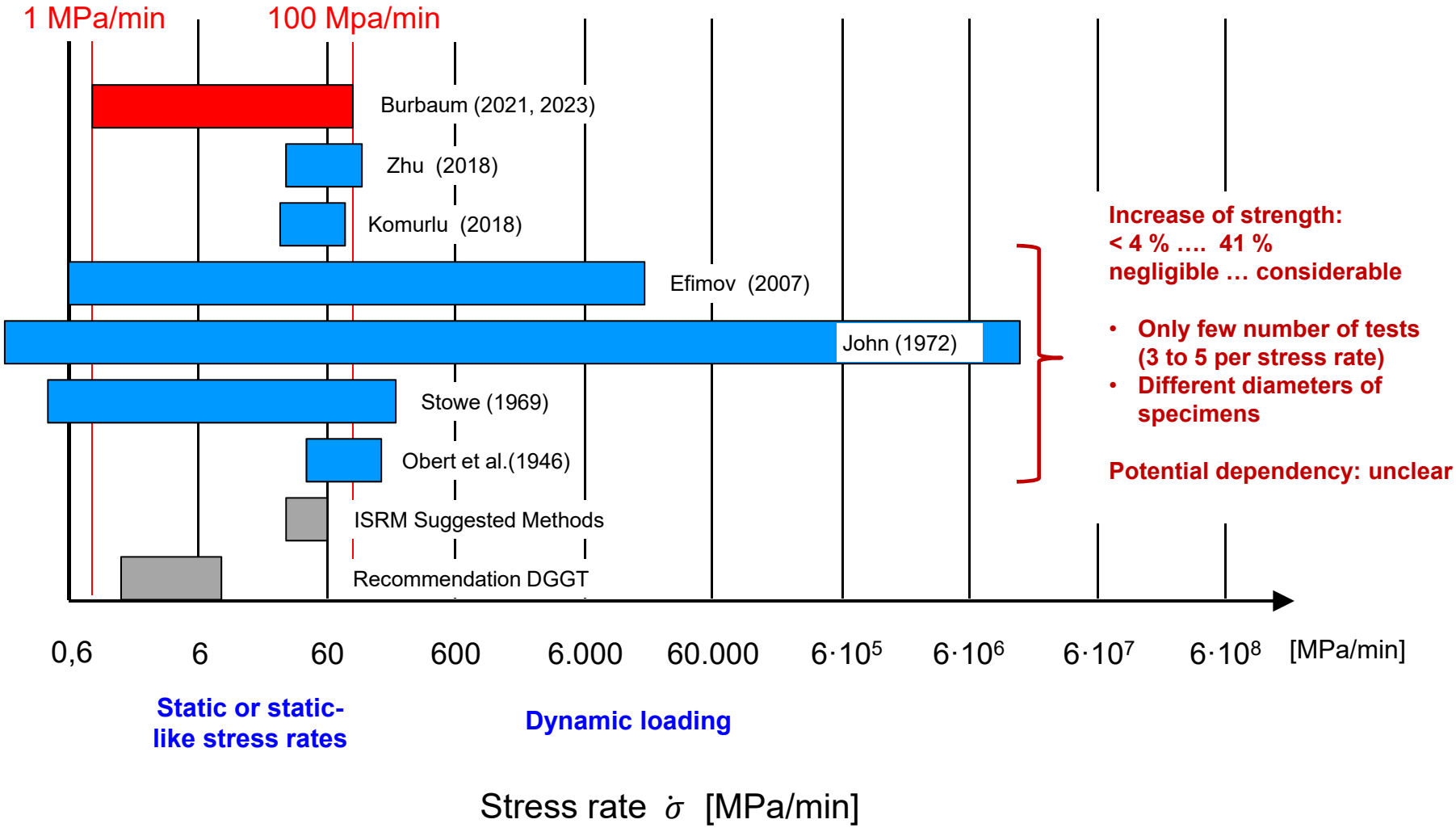

# Common standards for testing
# Research program HDA

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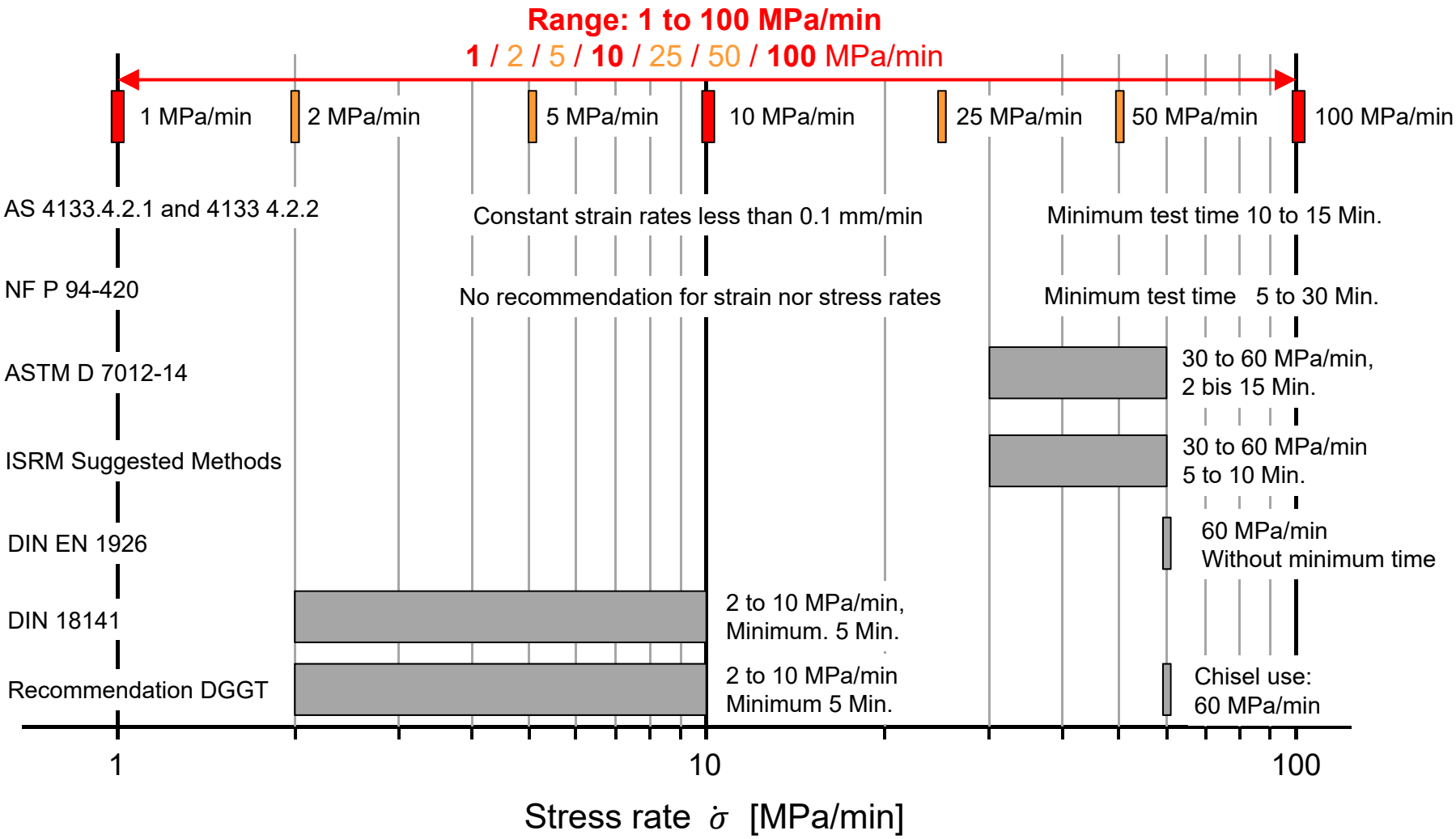

# Research program
# Tested rock types, specimens

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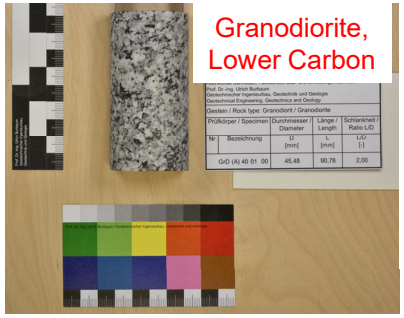

Granodiorite, Lower Carbon


Gabbro, Lower Carbon

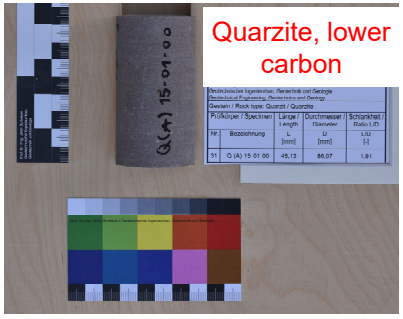

Basalt, Eocene

Ingneous rock

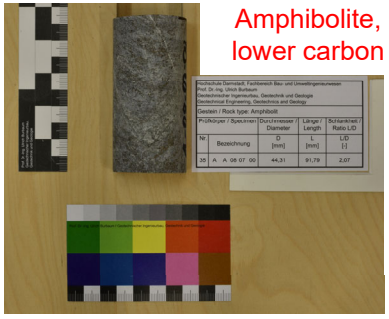
Sandstone, upper Buntsandstein


Limestone, upper jurassic

Sedimentary rocks



Quarzite, lower carbon


Amphibolite, lower carbon

Metamorphic rocks

# Origin of rocks of the research program

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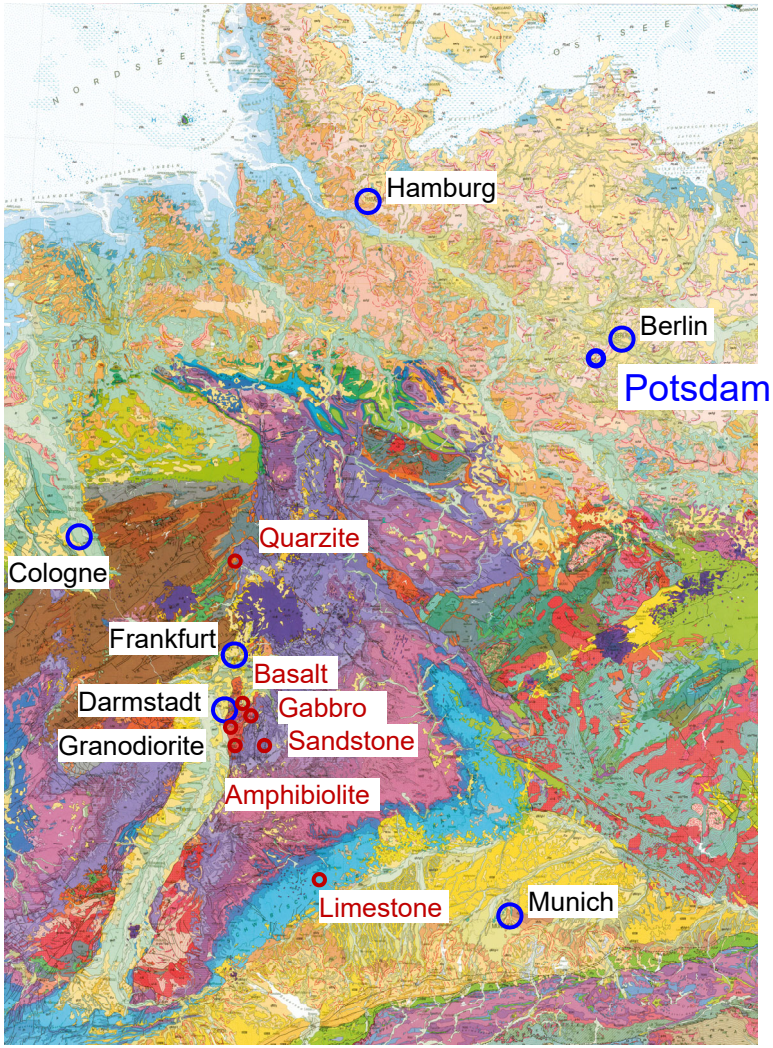

# Rock sample
# Example: Limestone

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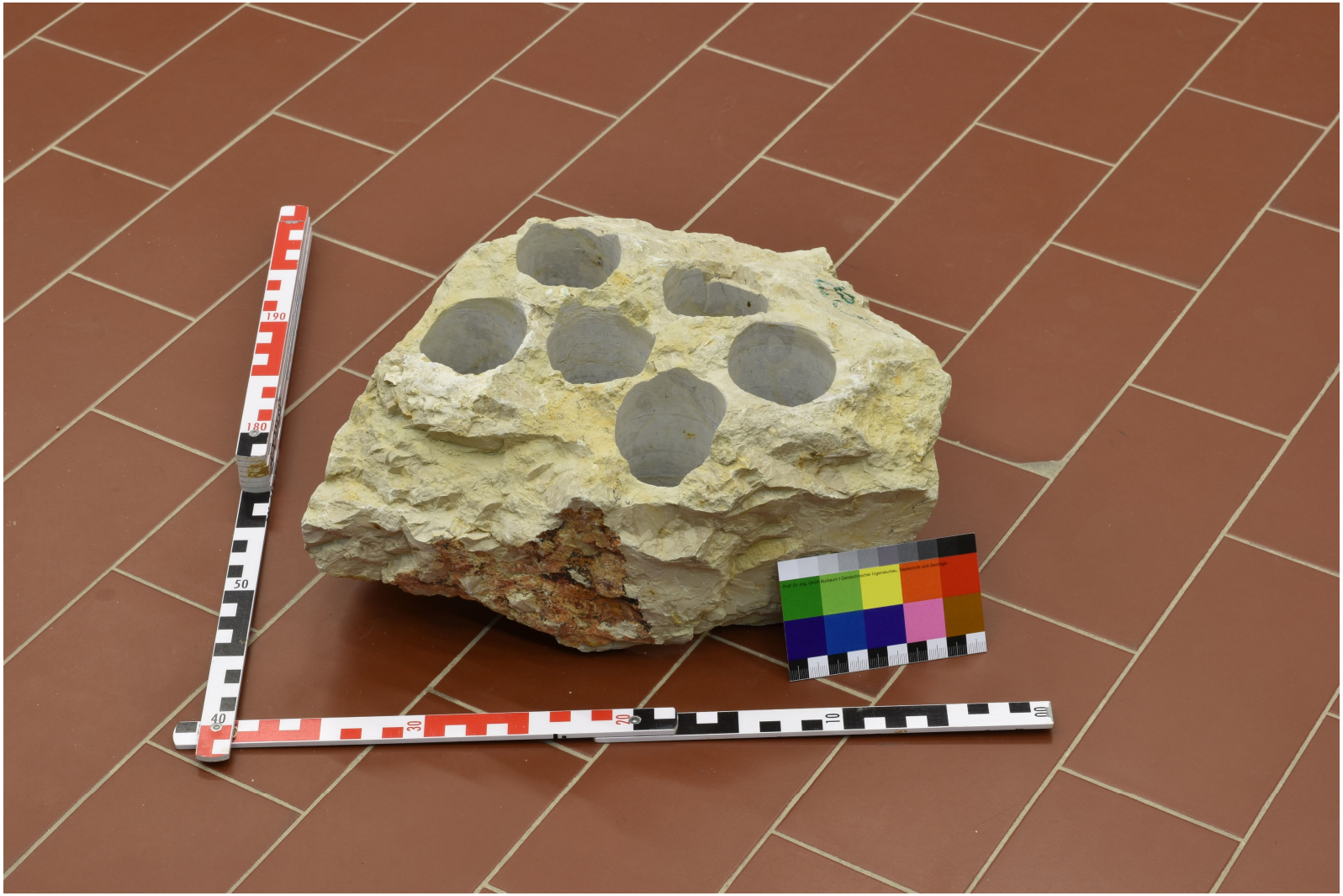

# Length-to-diameter ratio of specimens

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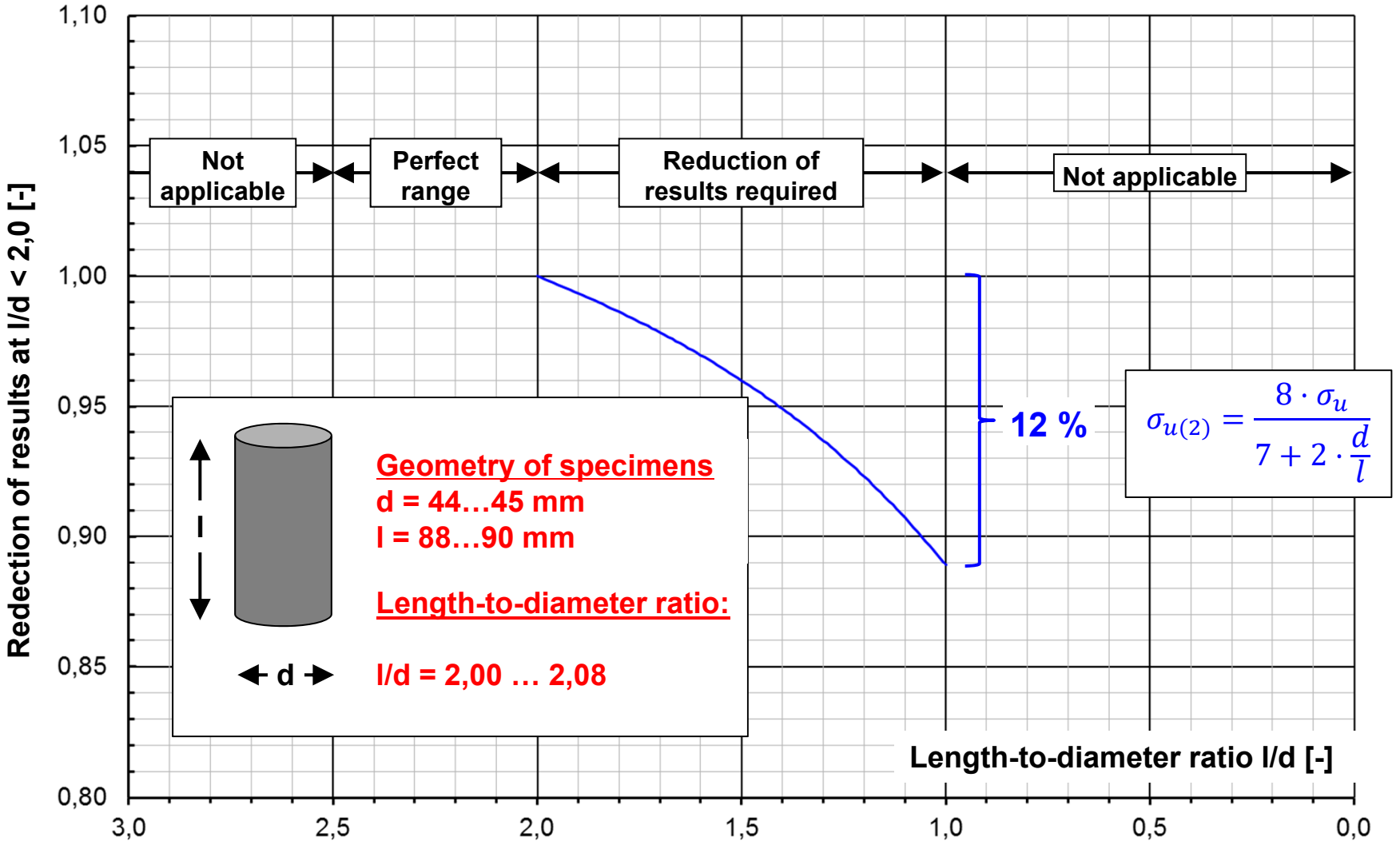

# Dry densities of specimens

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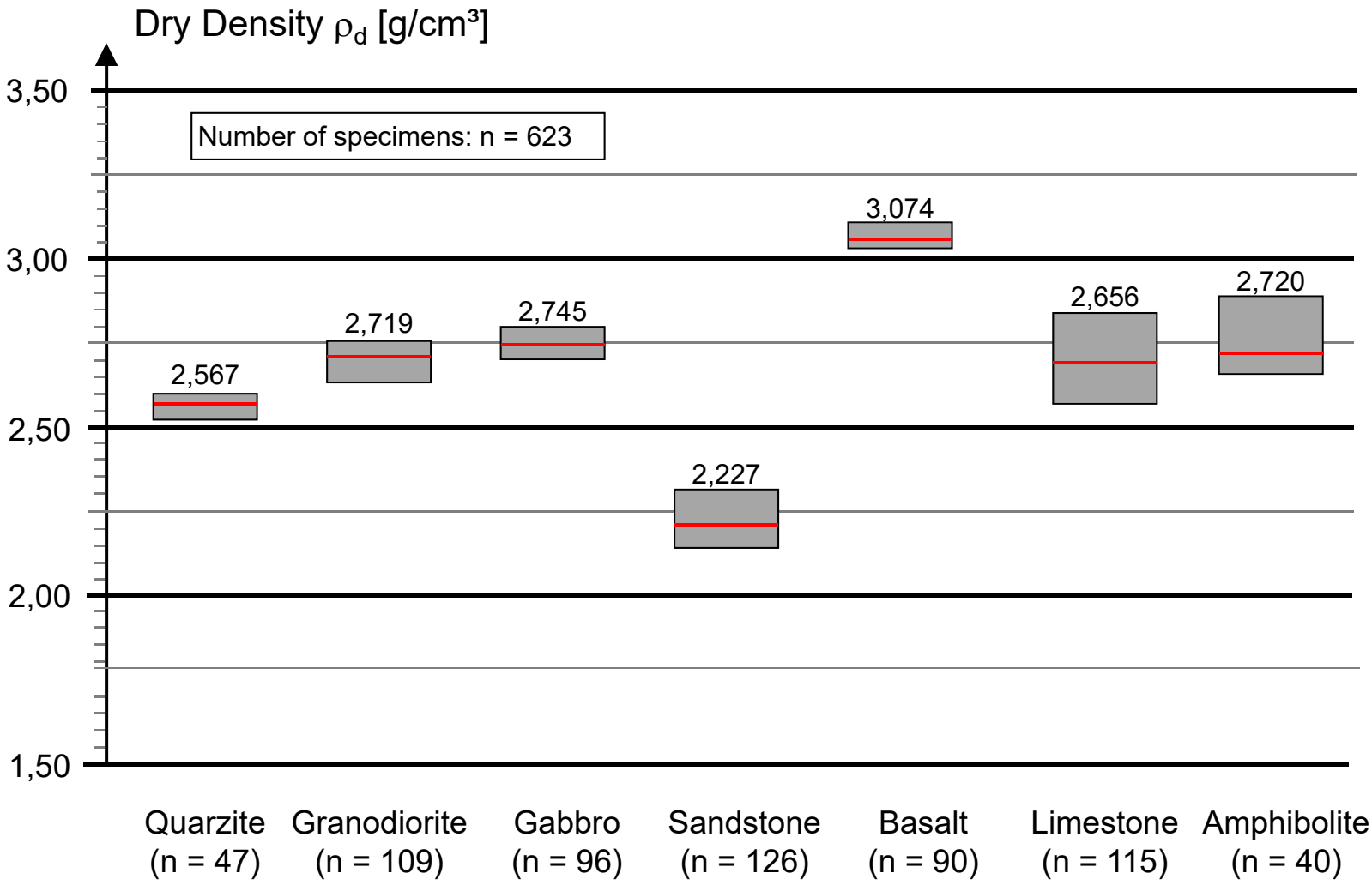

# Range of UCS of the test program Classification according to DIN EN ISO 14689

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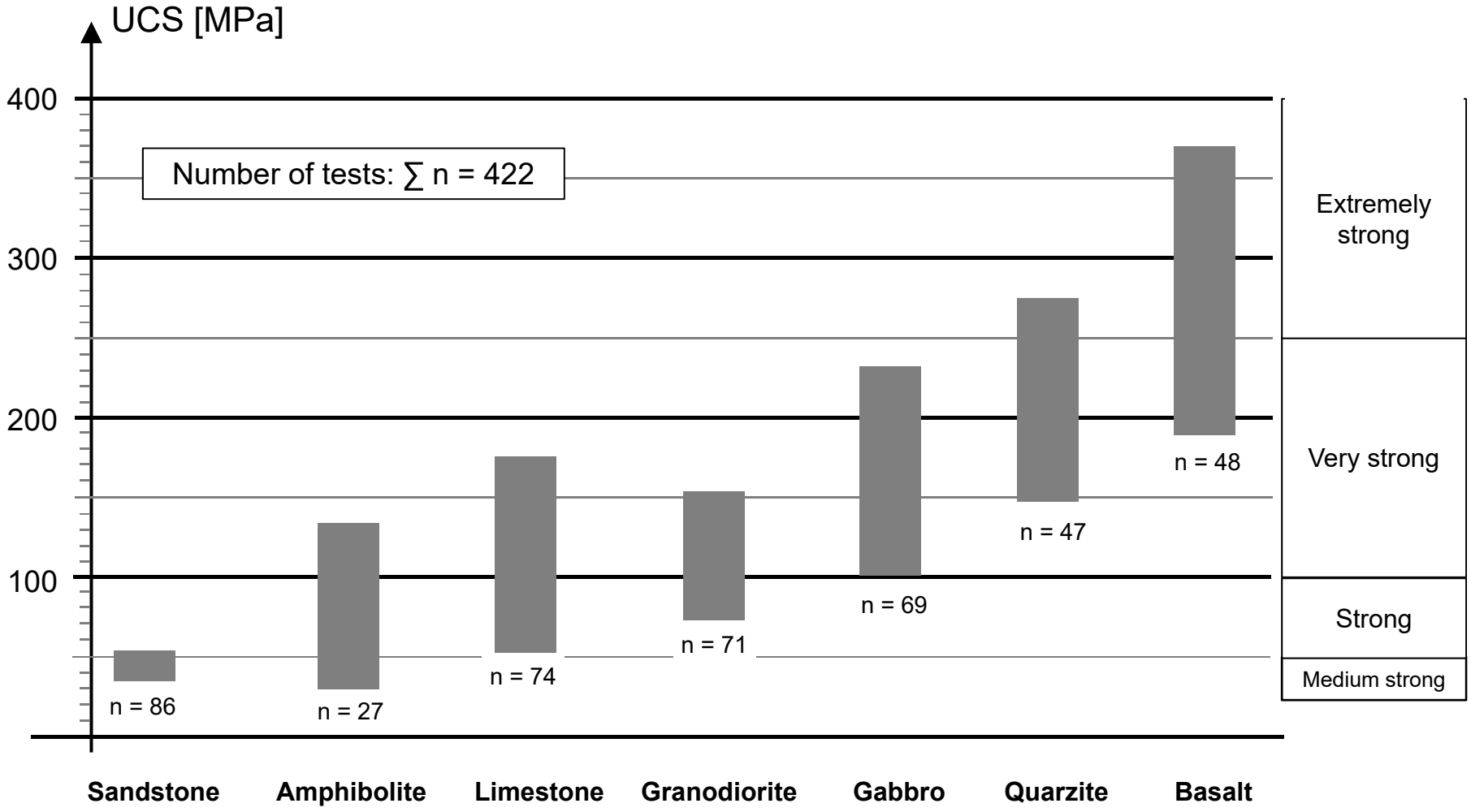

# Range of Young's modulus

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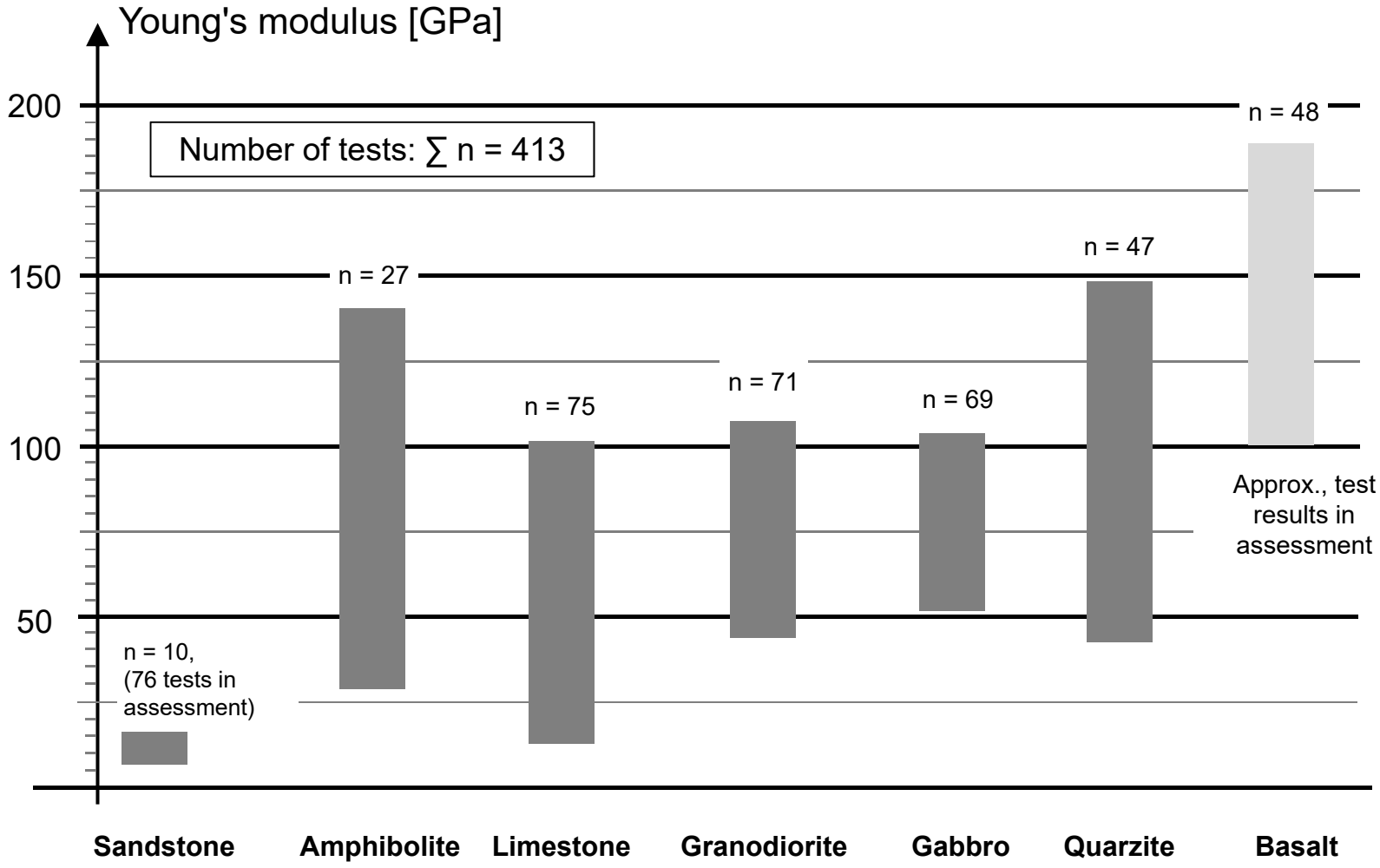

# Stress-strain curve, load only
# Gabbro, specimen Gbr (A) 10 02 00

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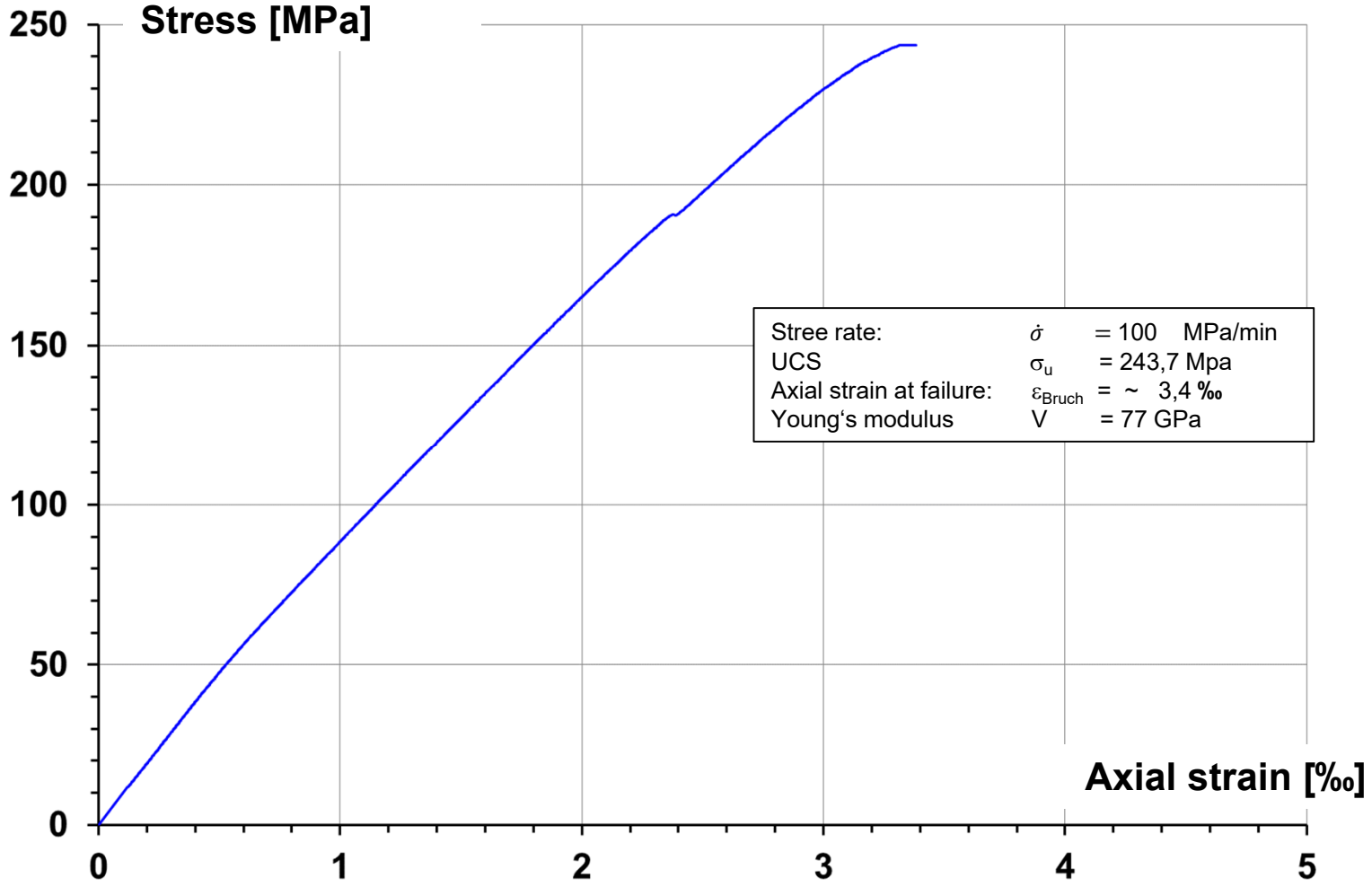

# Stress-strain curve, single load/unload cycle
# Type Granodiorit, specimen GrD(A) 09 01 00

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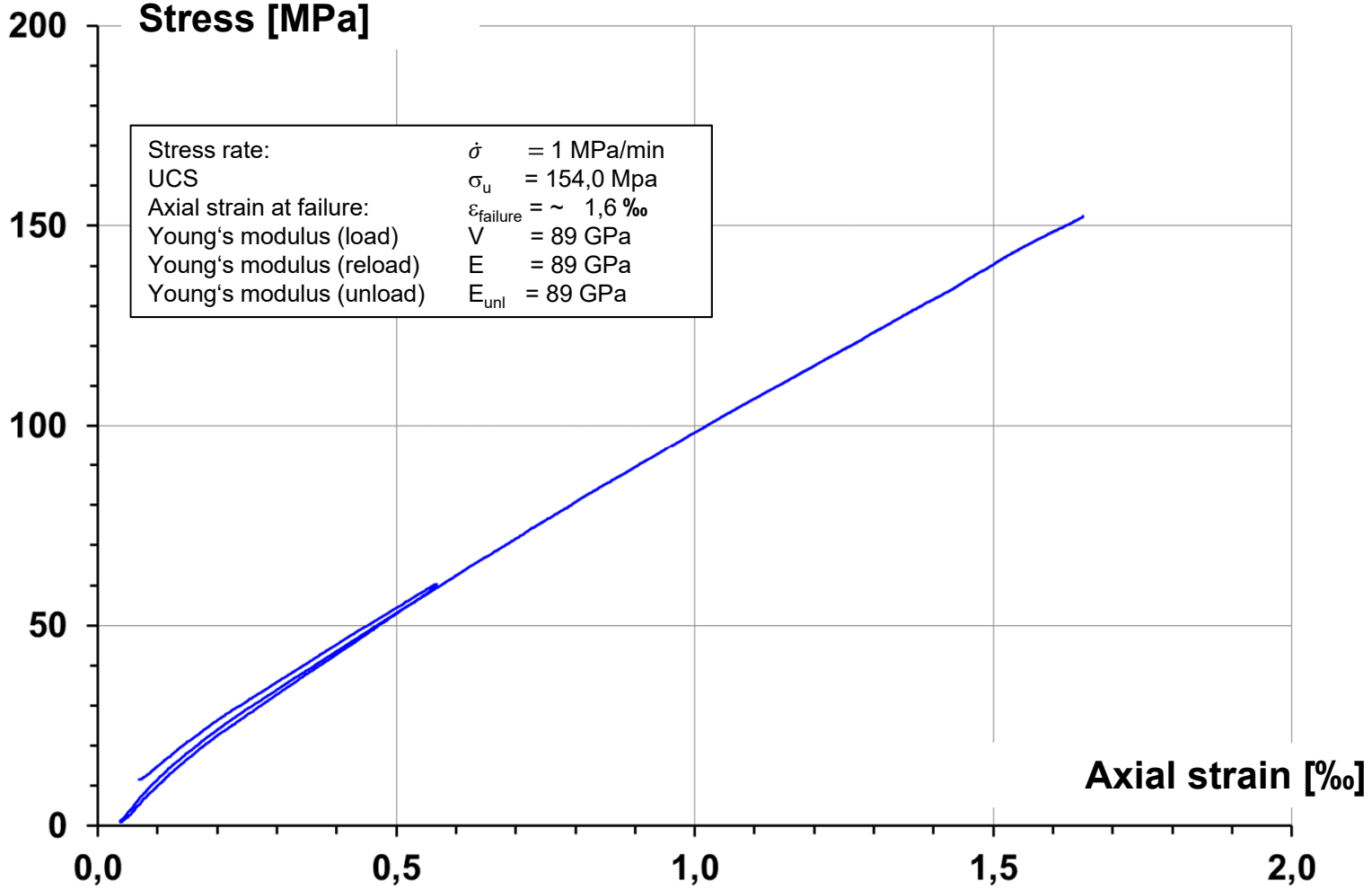

# Stress-strain curve, triple load/unload cycle Limestone, specimen Kst(A) 07 07 00

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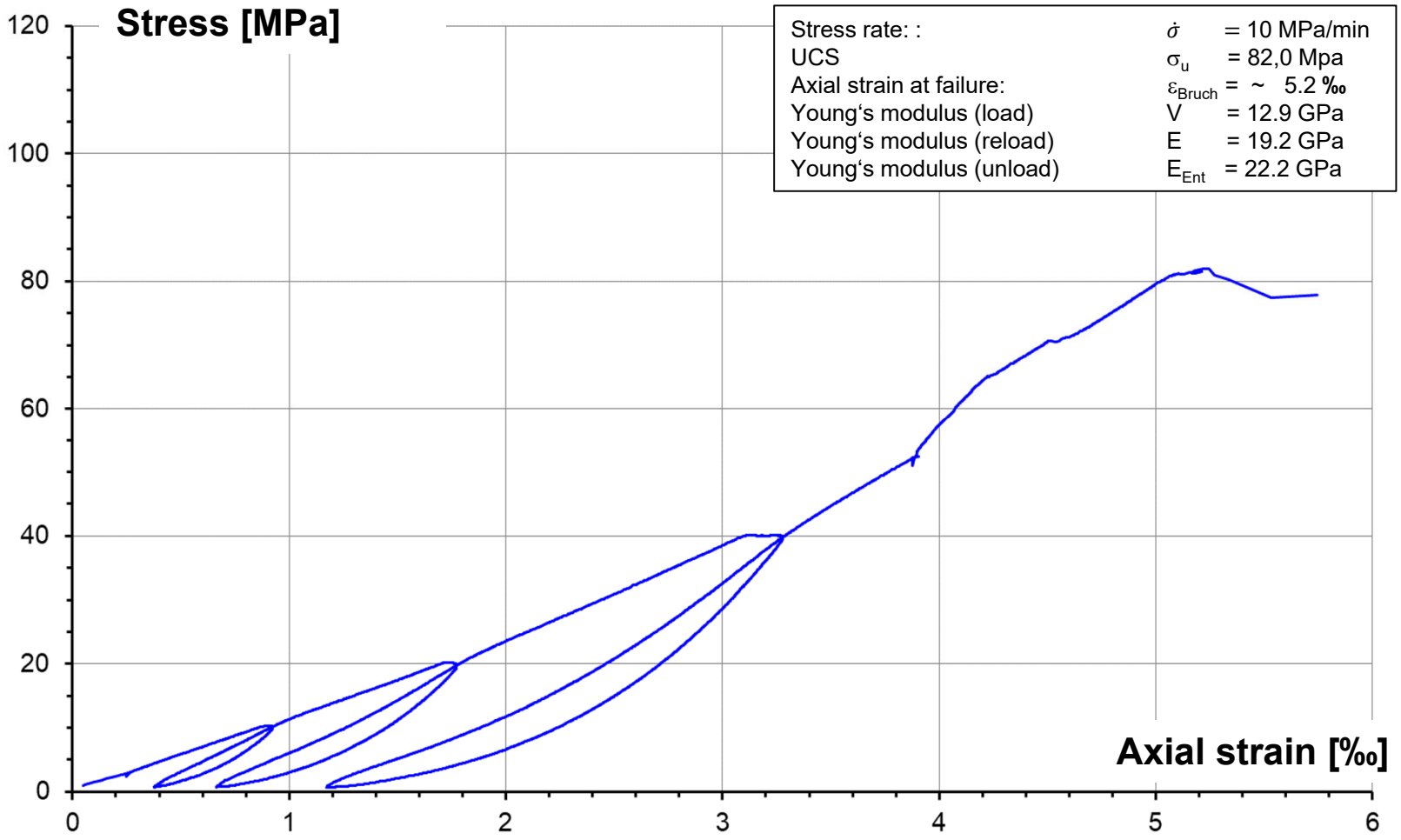

# Stress-strain curve, triple load/unload cycle
# Sandstone, specimen Sst(A) 17 01 02

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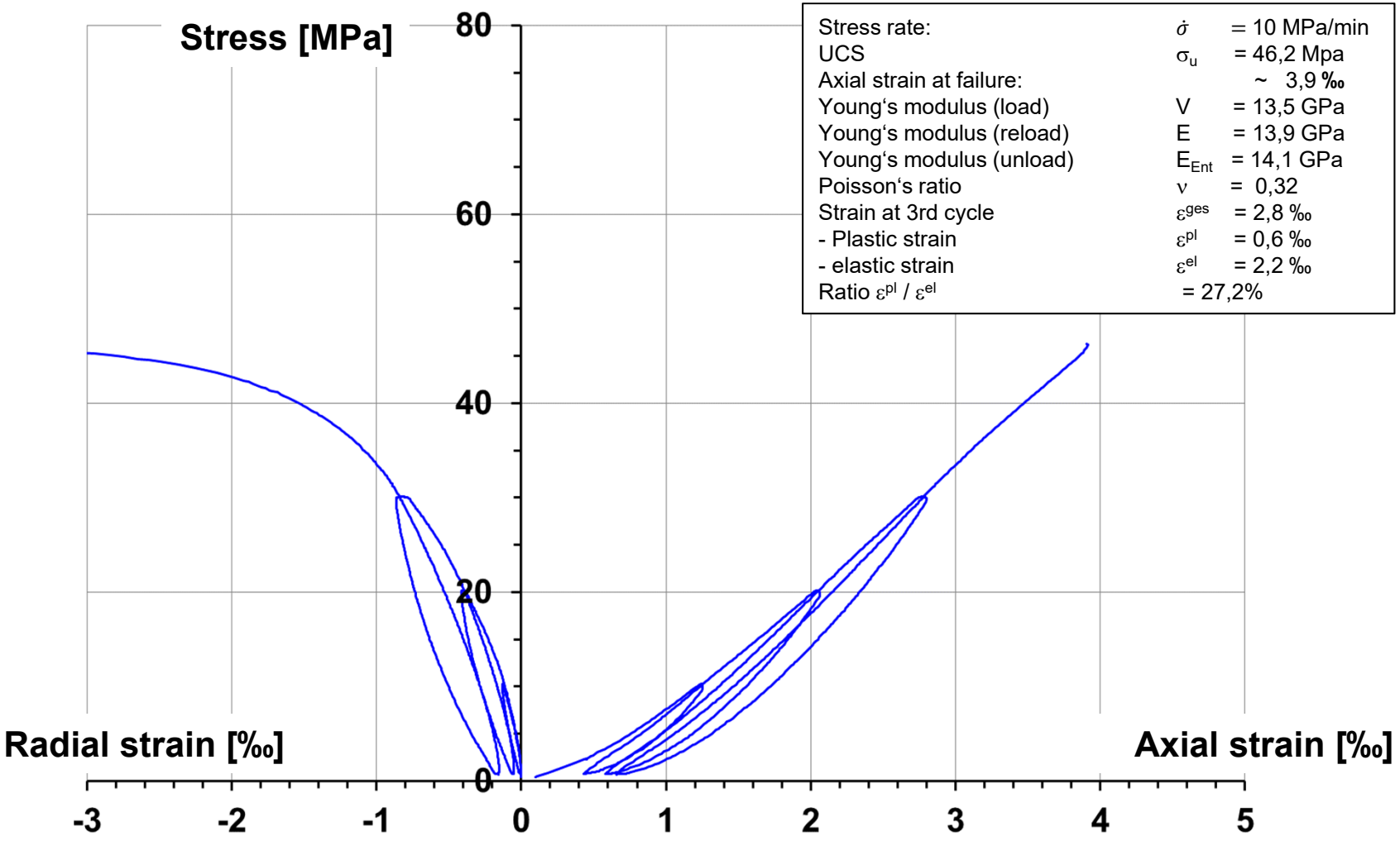


| | | |
|---|---|---|
| Stress rate: | $\dot{\sigma}$ | = 10 MPa/min |
| UCS | $\sigma_u$ | = 46,2 Mpa |
| Axial strain at failure: | | ~ 3,9 ‰ |
| Young's modulus (load) | V | = 13,5 GPa |
| Young's modulus (reload) | E | = 13,9 GPa |
| Young's modulus (unload) | $E_{Ent}$ | = 14,1 GPa |
| Poisson's ratio | $\nu$ | = 0,32 |
| Strain at 3rd cycle | $\varepsilon^{ges}$ | = 2,8 ‰ |
| - Plastic strain | $\varepsilon^{pl}$ | = 0,6 ‰ |
| - elastic strain | $\varepsilon^{el}$ | = 2,2 ‰ |
| Ratio $\varepsilon^{pl}$ / $\varepsilon^{el}$ | | = 27,2% |

# Young‘s modulus (load) vs. stress rate (Example Granodiorite)

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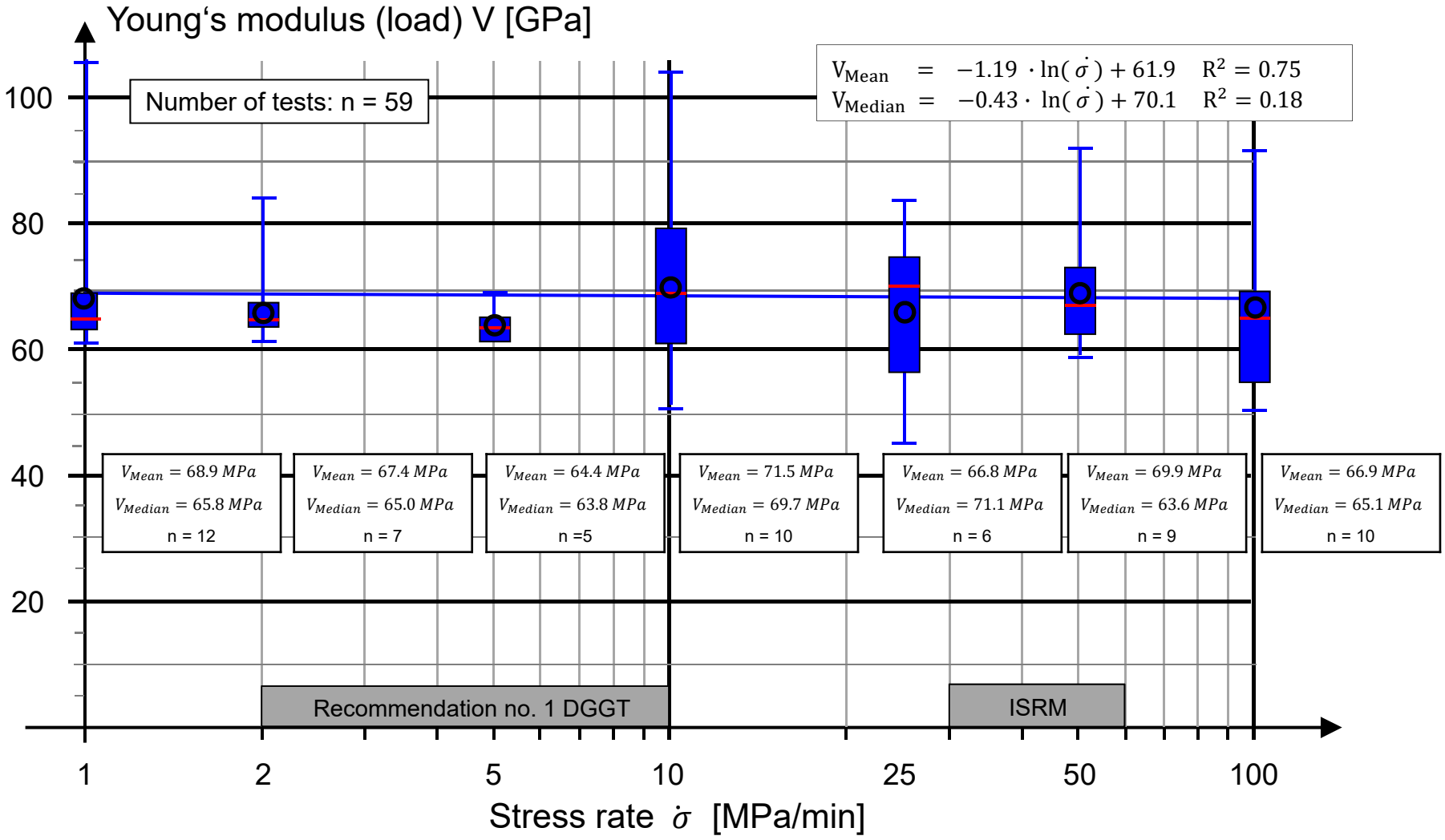

# Young‘s modulus (load) vs. stress rate (Example: Amphibolite)

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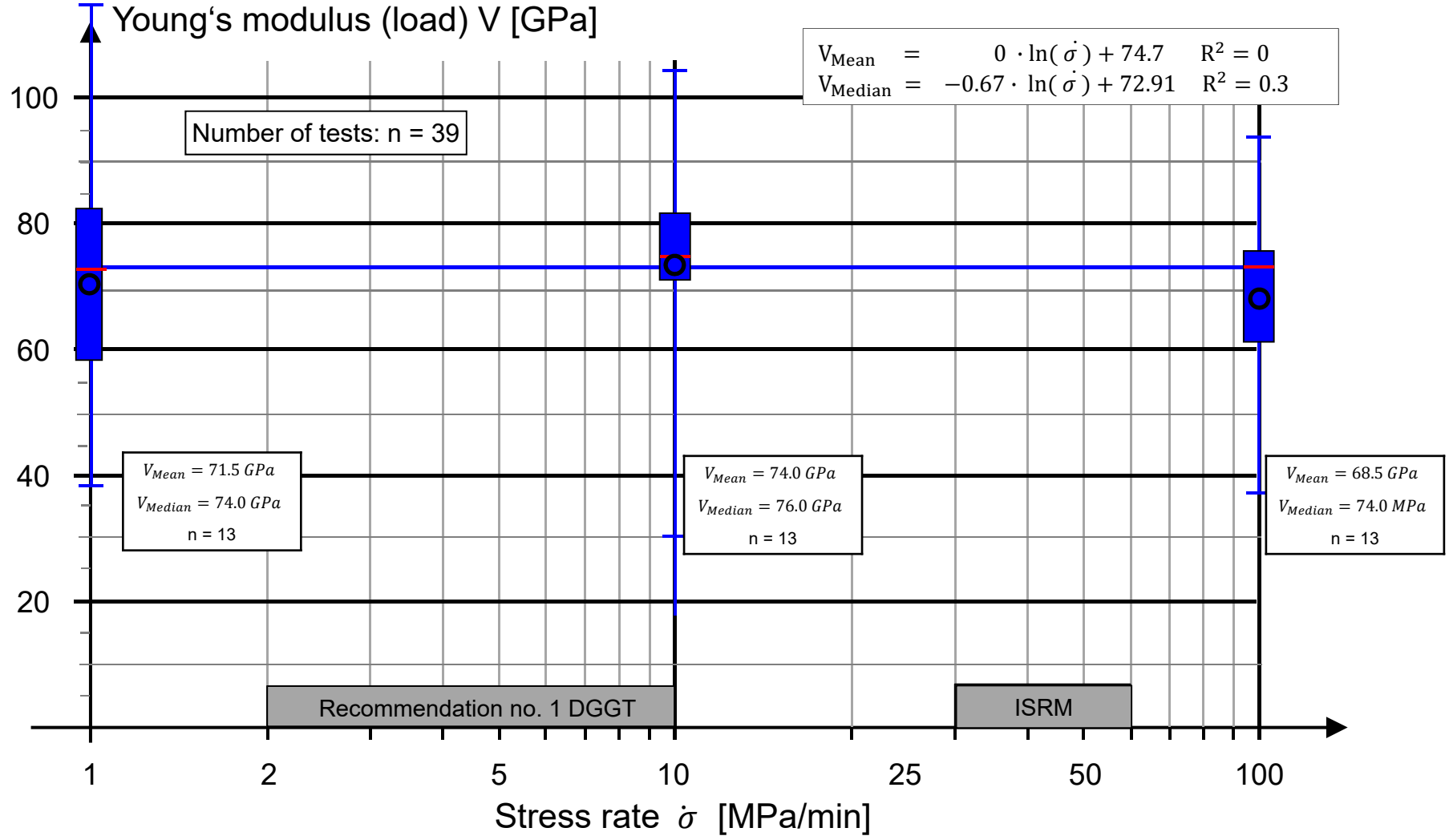

# Young‘s modulus (load) vs. stress rate, significance test (Example: Granodiorite)

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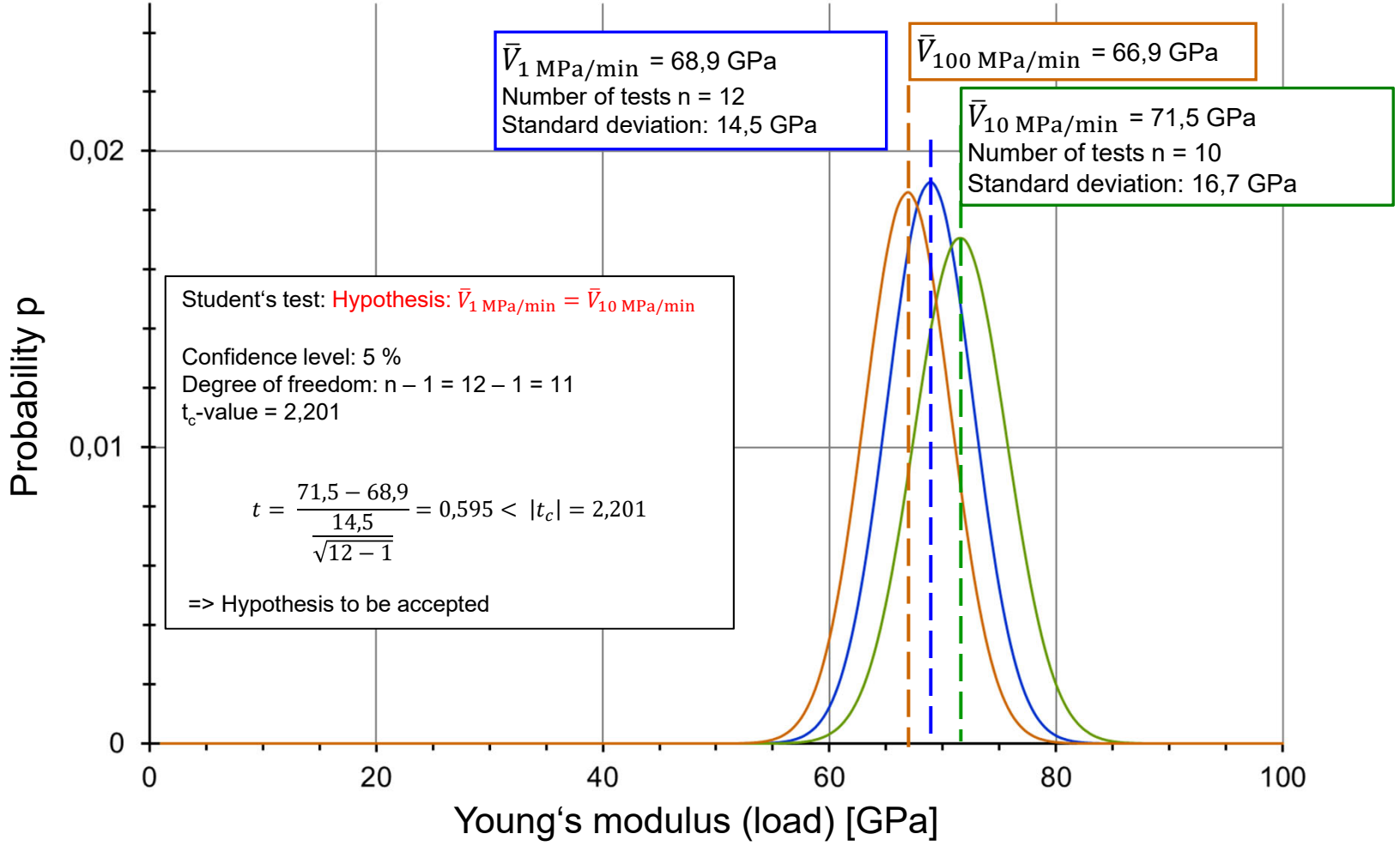

# UCS vs. stress-rate (Example: Granodiorite)

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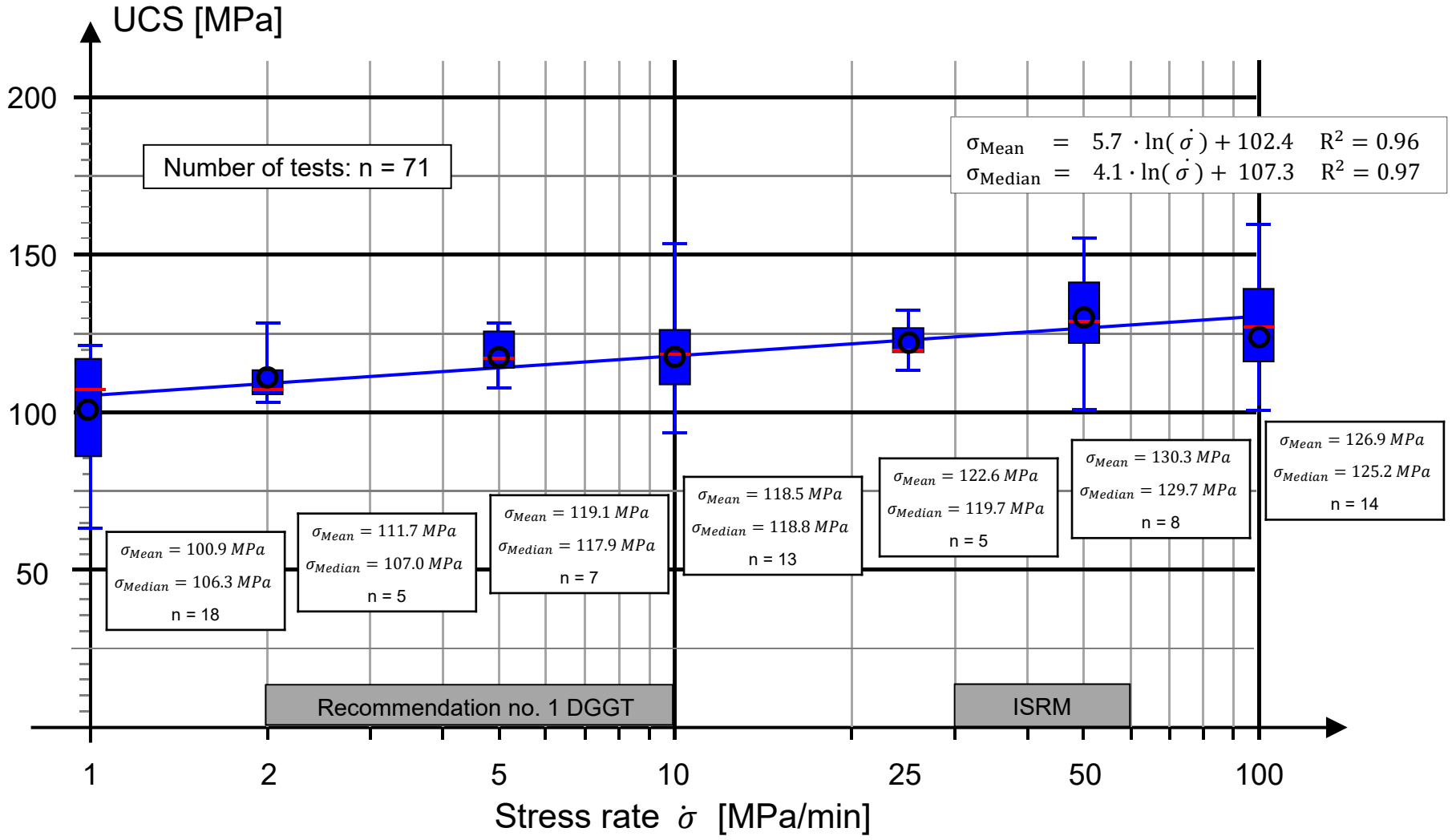

# UCS vs. stress-rate (Example: Basalt)

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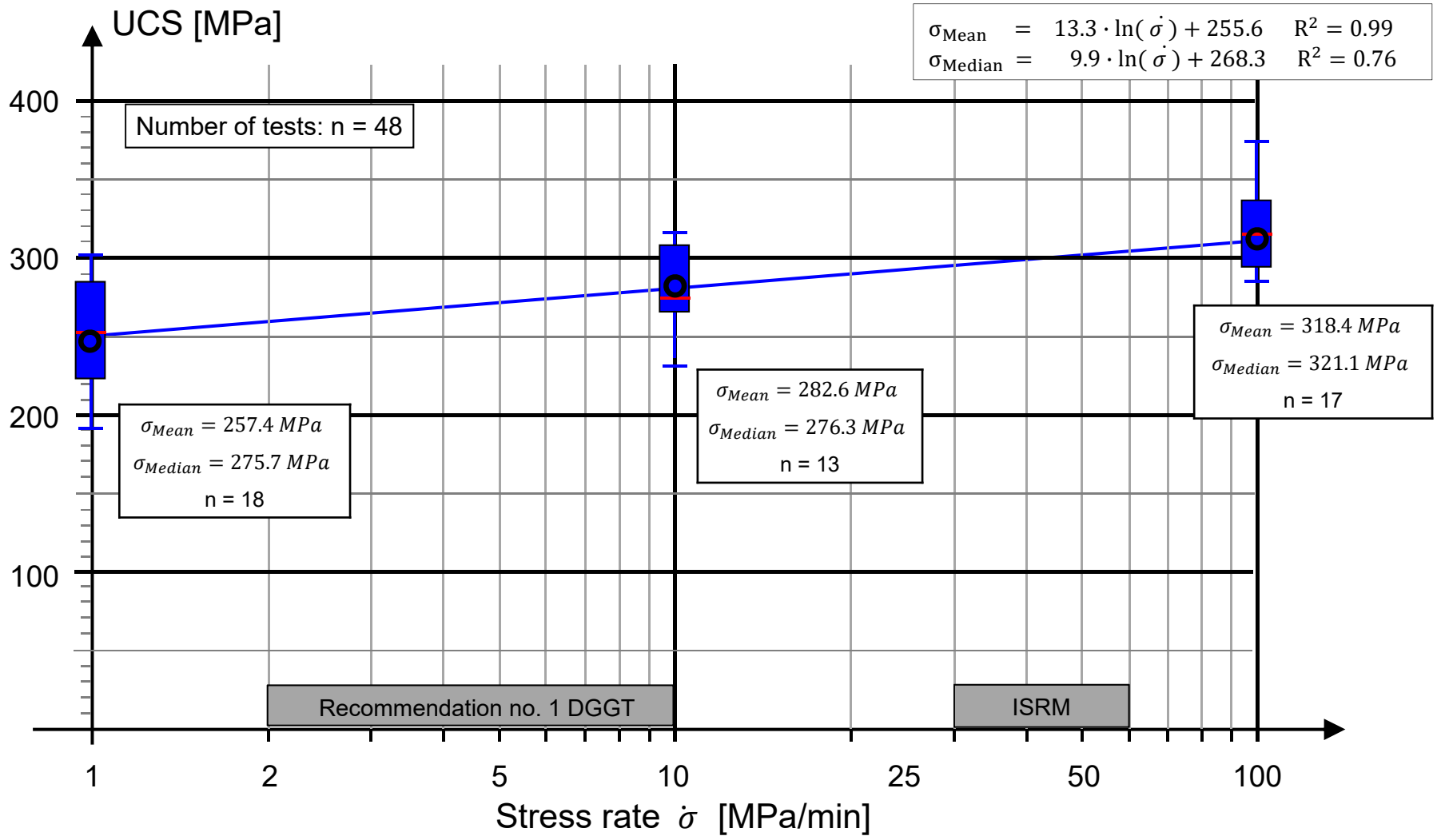

# UCS vs. stress-rate (Example: Limestone)

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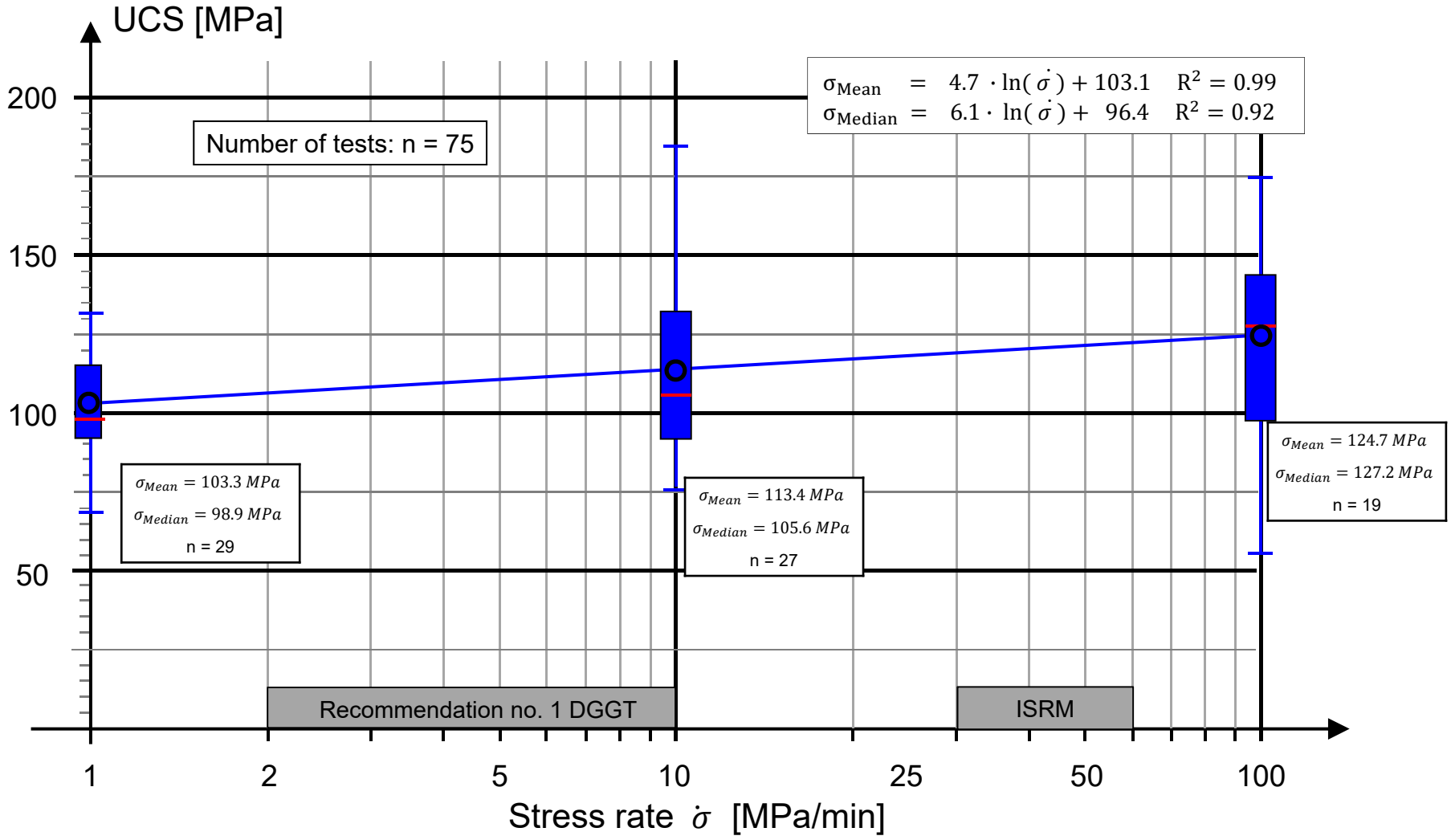

# UCS vs. stress-rate significance test (Example: Basalt)

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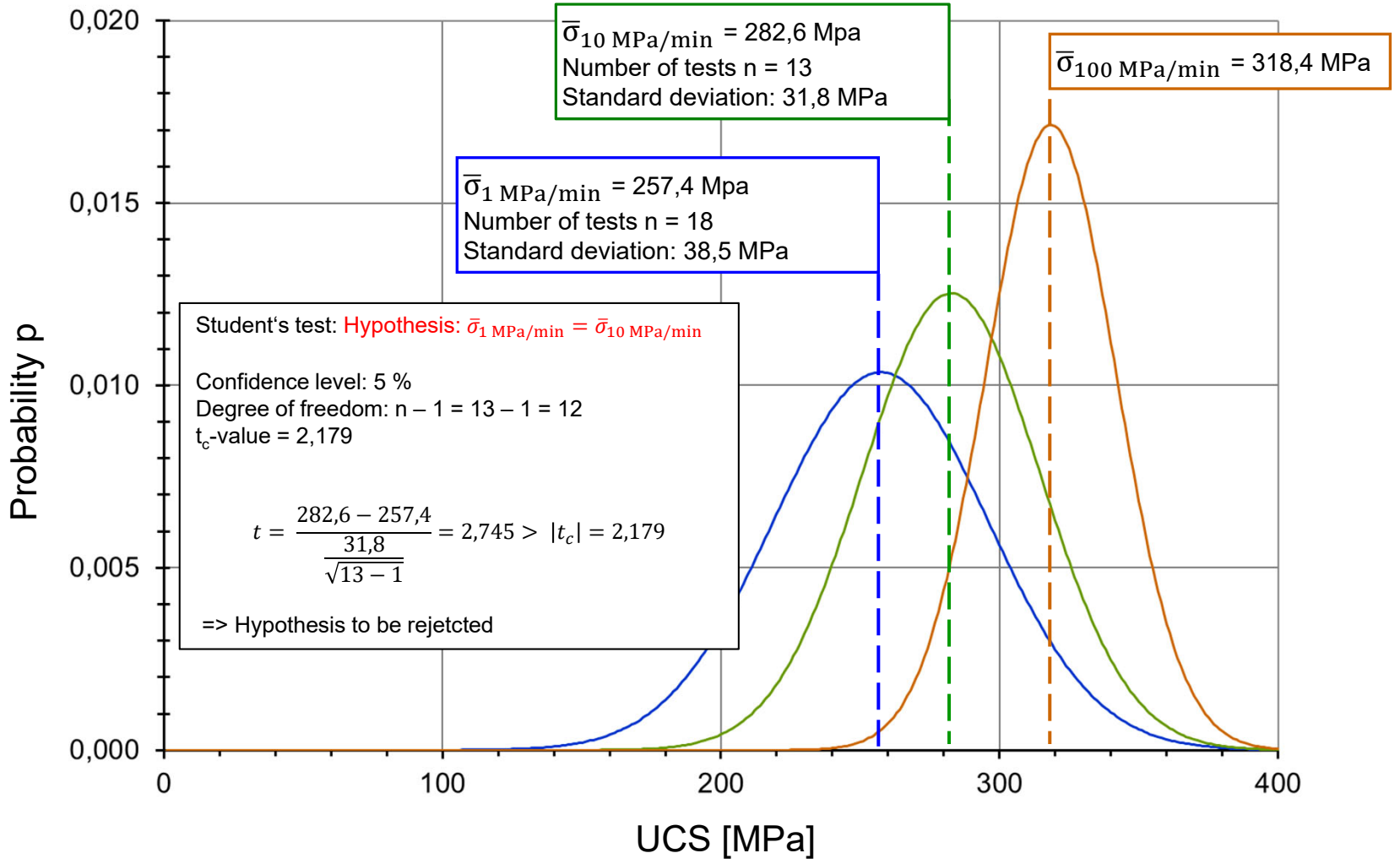

# Dependency of UCS on the stress rate

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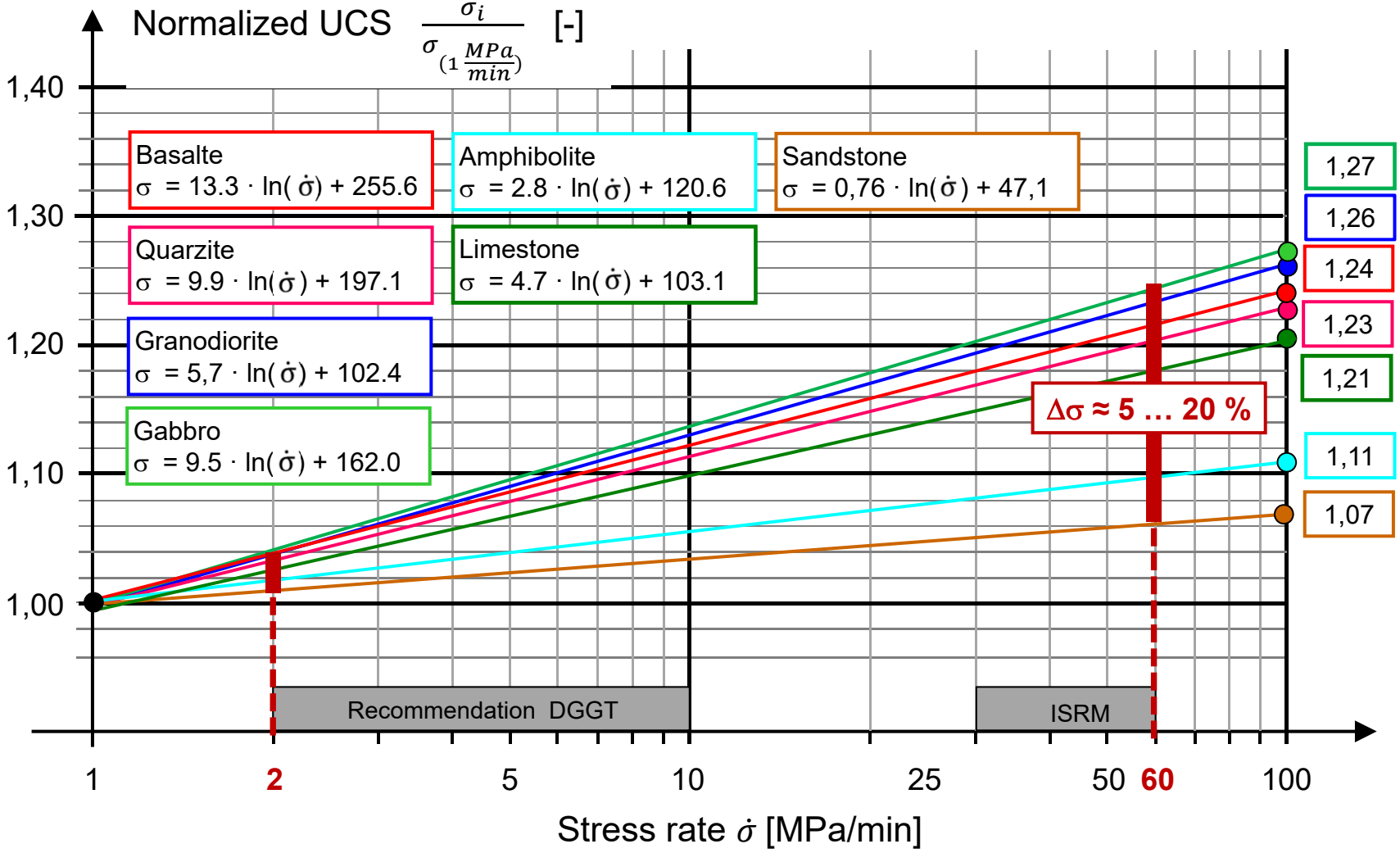

# Heterogenity: Mean increase in strength vs. single results of specimens from one block sample (Four examples of Granodiorite)

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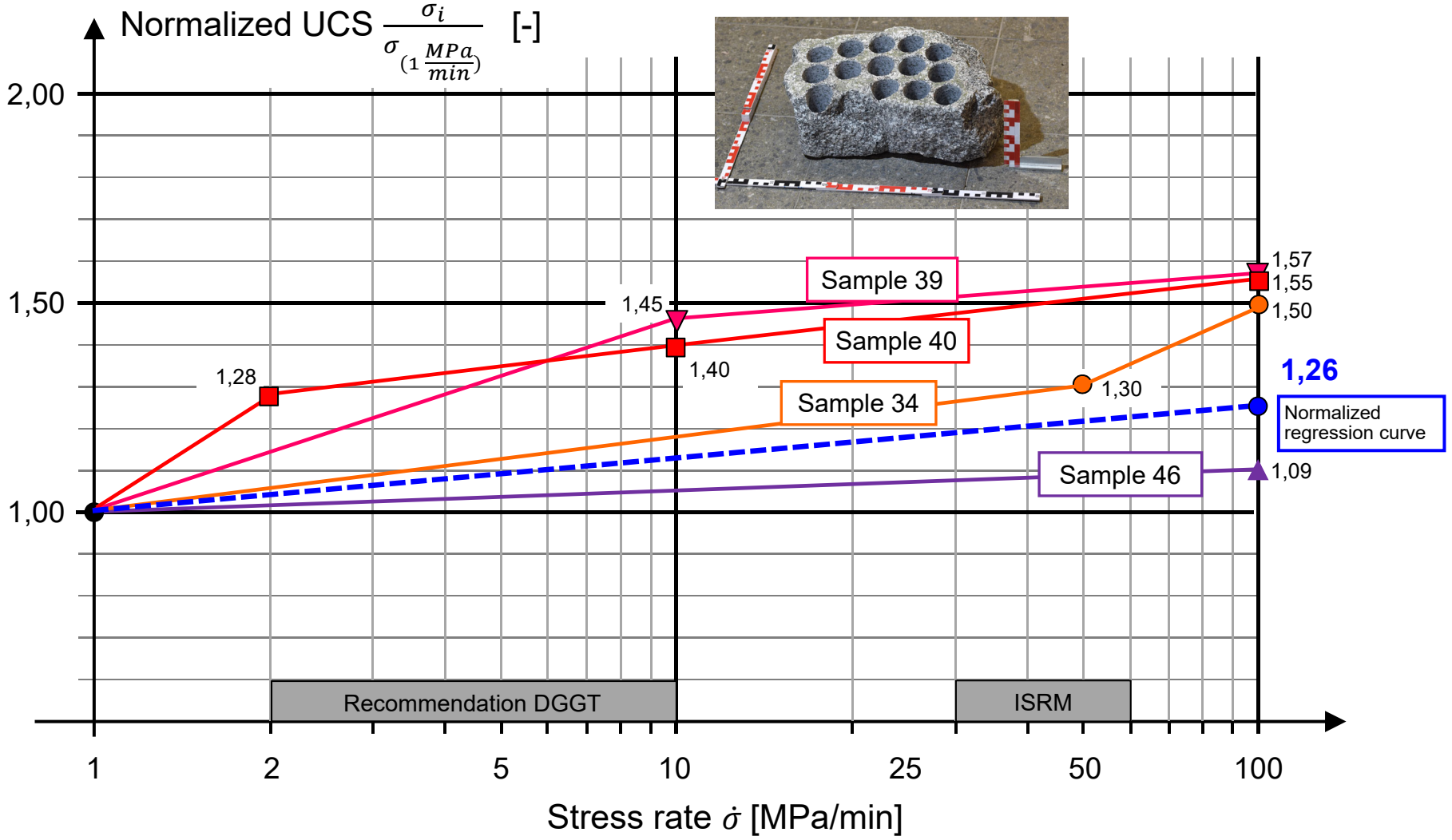

# Reliability of mean values and of standard deviation vs. number of tests (Example: Granodiorite)

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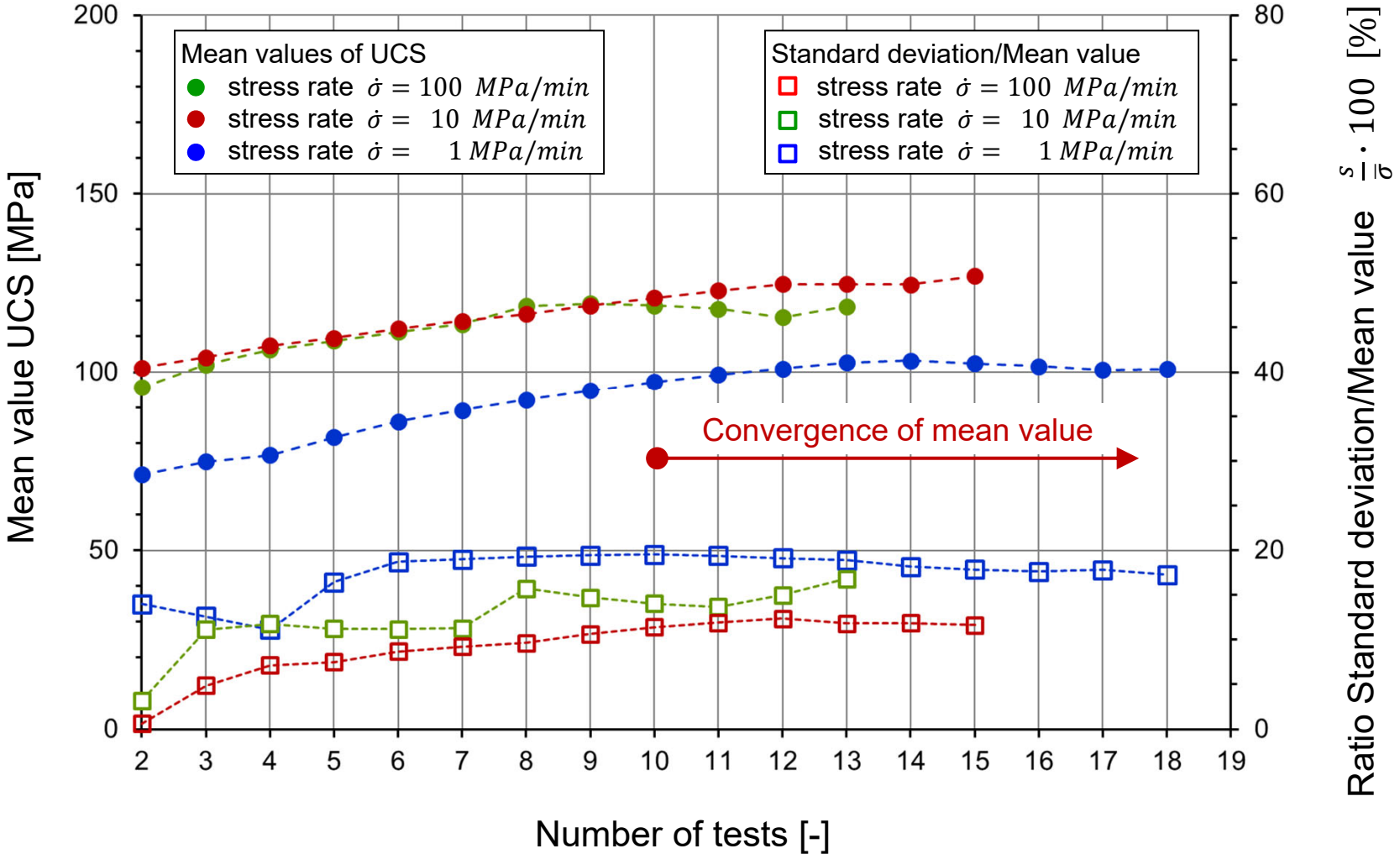

# Homogenity: single results of specimens from block samples (Two examples of Sandstone)

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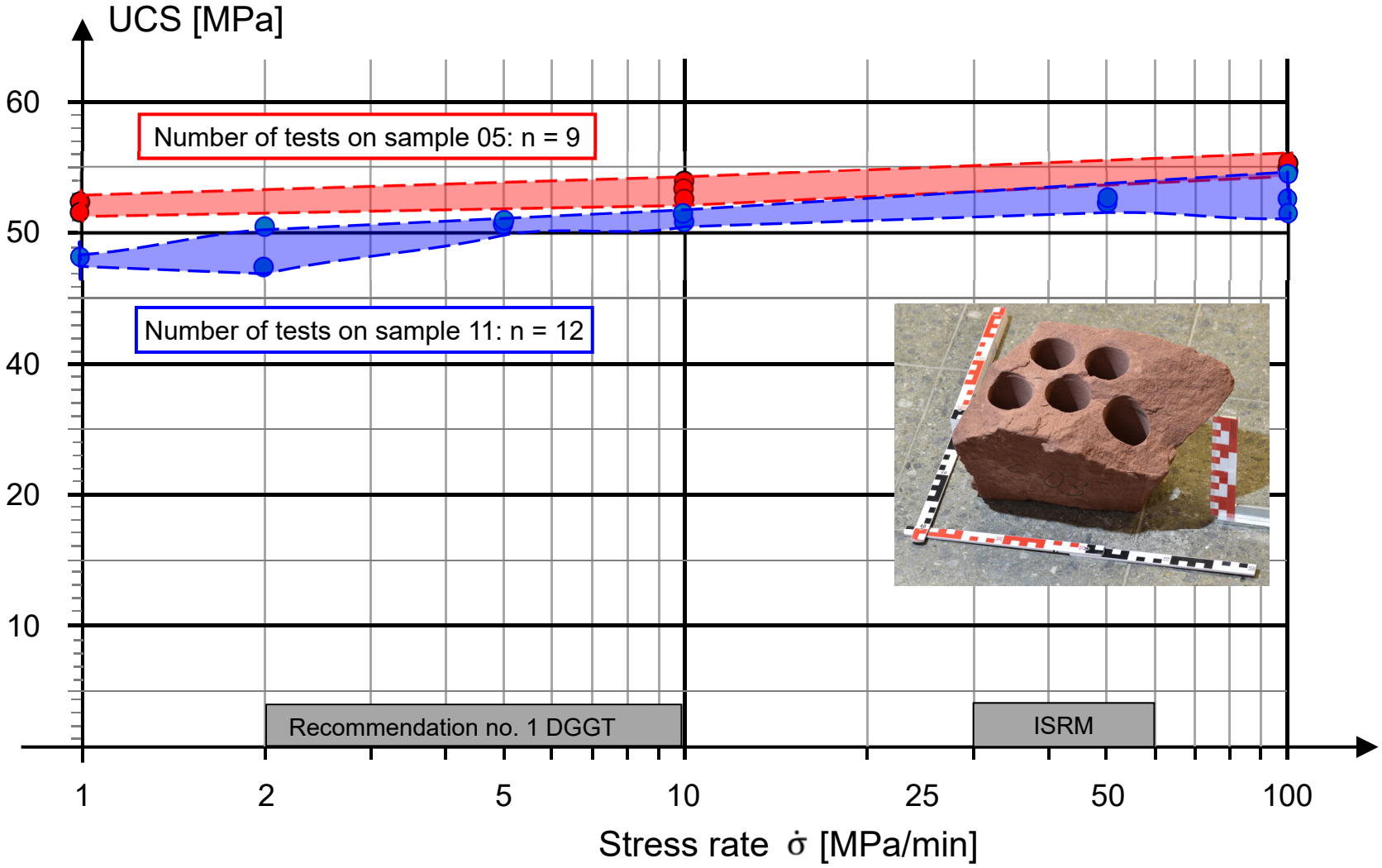

# Reliability of mean values and of standard deviation vs. number of tests (Example: Sandstone)

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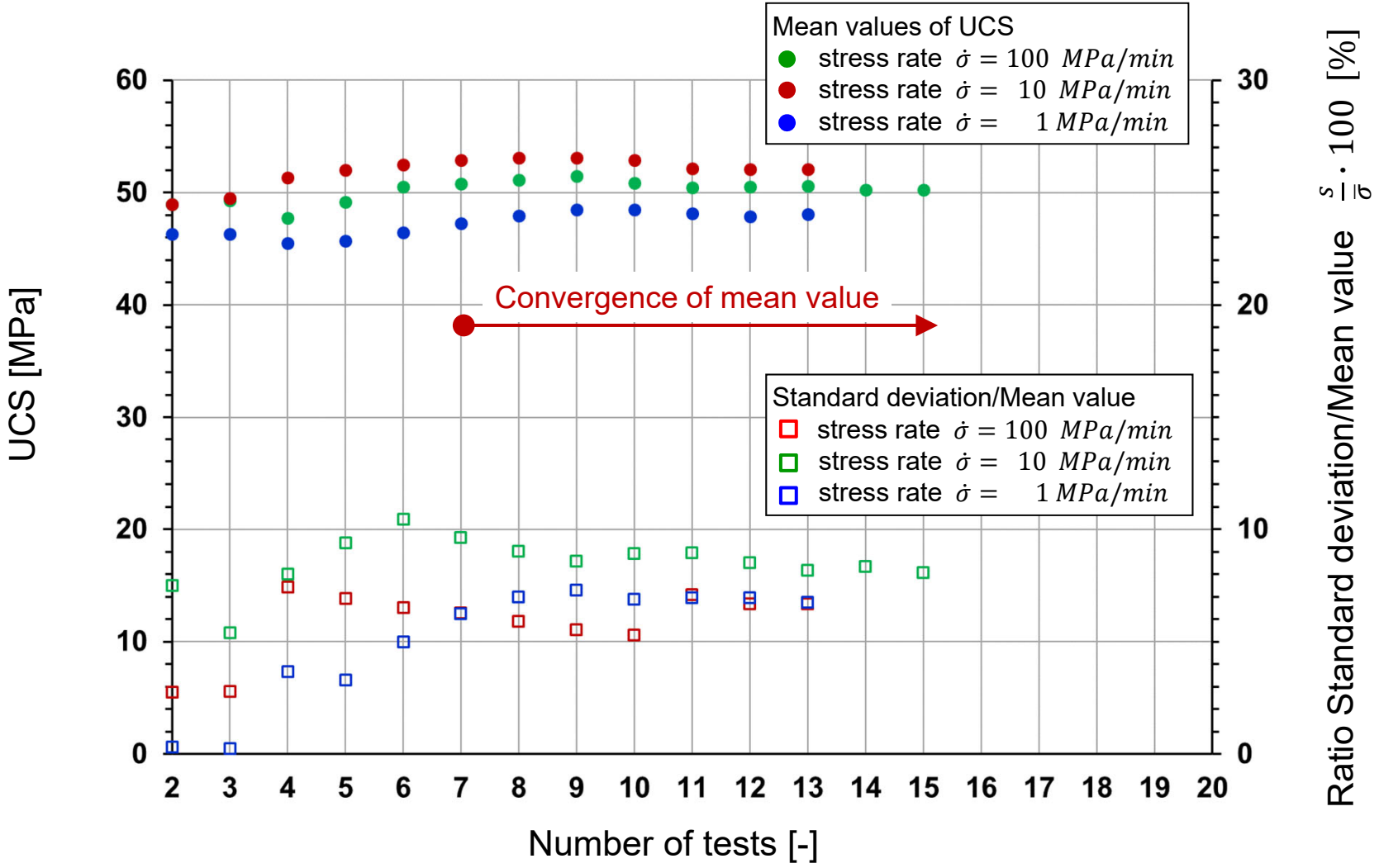

# Visibility of failure modes (Examples Sandstone vs. Basalt)

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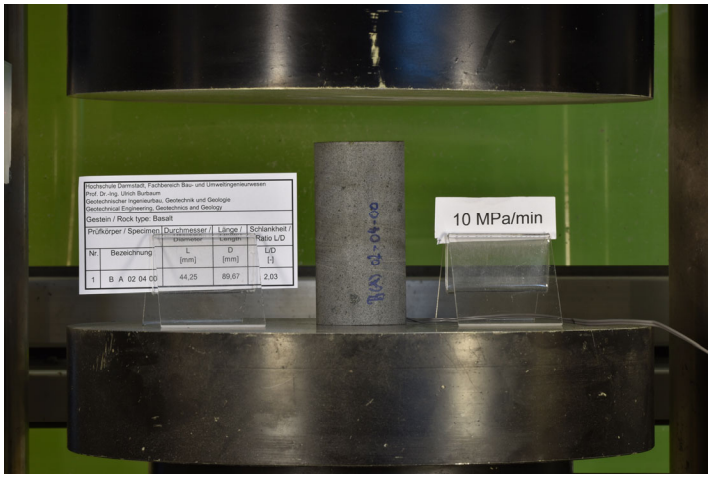


# Explosive-like failure: Basalt

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# Conclusions

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- There is no evidence that the Young‘s modulus depends on the stress rate at static or static-like stress rate levels.
- There is significant evidence that the UCS is depending on the stress-rate even at static or static-like stress rate levels.
- The dependency is in an order that can not be ignored in engineering or research testing.
- The standards should be subject to be reviewed in this topic.
- Testing of hard rock types should stick to a specific stress rate during all project phases, from investigation to execution phase in rock engineering projects.
- The stress rate should be chosen according to the strength level. The less the strength level is the lower the stress rate should be.
- The number of tests required in order to obtain reliable mean values depend on the homogenity/heterogenity of the rocks and should not be inferior to six to ten tests.
- Explosive-like failure of extremely strong hard rock seems revealed to be a buckling failure.

# Outlook – from engineering to science

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- Dependency of the UCS on the stress rate is descriptive research.
- The UCS of rock depends on the binding of the mineral grains, the reason for this is yet not clear.
- The physical/mineralogical reason for the dependency of the strength of hard rock on the stress rate with regard to the binding of mineral grains is therefore subject for future research.
- The petrophysical high-pressure testing system PAX-1600 inaugurated today is expected to enable research on that topic.
- Additional application of Micro-CT while testing strength in order to determine the changes in mineral binding would be big step forward.

# Thank you for your attention

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