Ring-shear test data of quartz sand from the Tectonic Modelling Lab of the University of Bern (CH) (http://doi.org/10.5880/fidgeo.2018.028)

1. Citation

 When using the data please cite:

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Zwaan, F. & Schreurs, G. (2017). How oblique extension and structural inheritance influence rift segment interaction: Insights from 4D analog models. *Interpretation*, *5*(1), SD119-SD138, https://doi.org/10.1190/INT-2016-0063.1

Zwaan, F., Schreurs, G. & Adam, J. (2017). Effects of sedimentation on rift segment evolution and rift interaction in orthogonal and oblique extensional settings: Insights from analogue models analysed with 4D X-ray computed tomography and digital volume correlation techniques. *Global and planetary change*, https://doi.org/10.1016/j.gloplacha.2017.11.002

2. Data Description

This dataset provides internal and basal (wall) friction data from ring-shear tests (RST) on a quartz sand material that has been used in tectonic experiments in Zwaan et al. (2016, 2017), Zwaan and Scheurs (2017) and in the Tectonic Modelling Lab of the University of Bern (CH) as an analogue for brittle layers in the crust or lithosphere. The material has been characterized by means of internal and basal friction coefficients μ and cohesions C as a remote service by the Helmholtz Laboratory for Tectonic Modelling (HelTec) at the GFZ German Research Centre for Geosciences in Potsdam for the Tectonic Modelling Lab of the University of Bern (UB).

According to our analysis the material behaves as a Mohr-Coulomb material characterized by a linear failure envelope. Internal peak, dynamic and reactivation friction coefficients are μ_P = 0.73, μ_D = 0.61, and μ_R = 0.66, respectively. Internal cohesions C are in the range of 10 to 70 Pa. Basal peak, dynamic and reactivation friction coefficients are μ_P = 0.41, μ_D = 0.35, and μ_R = 0.36, respectively, whereas basal cohesions C are in the range of 120 to 150 Pa. The rate dependency of the internal dynamic friction coefficient is insignificant (<1%).

2.1. Materials tested

The material tested is a natural quartz sand sold under the product ID: CAS-No. 14808-60-7, EC-No. 238-878-4 by the company Carlo Bernasconi AG. The grains are angular to poorly rounded and have a low sphericity (Zwaan et al., 2016; Figure 1). The grain size distribution is in the range of 60-250 µm measured in the Tectonic Modelling Lab of the UB (1 kg sample in 4h; Table 1). The bulk density of the sieved material is ρ = ~1560 kg m^{-3} (Zwaan et al., 2016). Further information on the material can be found on the webpage of the company (https://www.carloag.ch/shop/quarzsand-a-0-06-0-22-mm.html#).

For basal (wall) friction, the sand has been sheared against a wooden plate covered with self-adhesive and transparent plastic foil (“Alkor foil”, produced by Alkor-Venilia, article number 120010, named "Gekkofix 11325” see Klinkmüller et al., 2016). Additional information concerning the sand can be found in Zwaan et al. (2016).

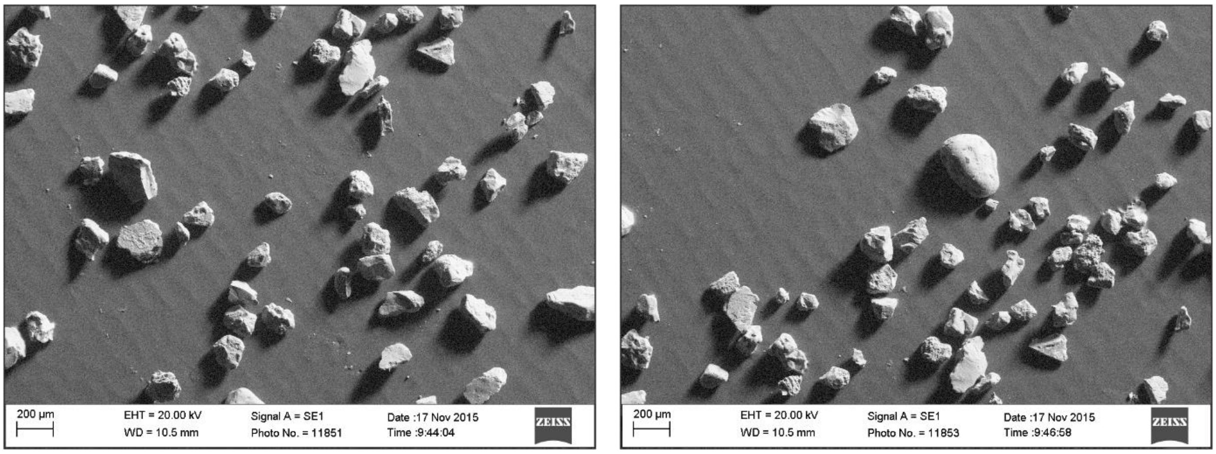

Figure 1: Example of scanning electron microscope (SEM) images *of the tested quartz sand. Additional images can be found in the attached data repository.*

Table 1: Grain size analysis of the quartz sand tested in this study.

Sieve size [µm]	Maximum [µm]	Weight retained [g]	Percentage retained [%]	Percentage passing [%]	Cumulative percentage passing [%]
>630	700	0.00	0.00	100.00	100.00
>400	630	0.00	0.00	100.00	100.00
>355	400	0.70	0.07	99.93	100.00
>224	355	58.20	5.85	94.15	99.93
>125	224	604.90	60.76	39.24	94.08
>63	125	323.10	32.45	67.55	33.33
<63	63	8.70	0.874	99.13	0.87

2.2. Measurement procedures

The data presented here are derived by ring shear testing using a SCHULZE RST-01.pc (Schulze, 1994, 2003, 2008) at the Helmholtz Laboratory for Tectonic Modelling (HelTec) of the GFZ German Research Centre for Geosciences in Potsdam. The RST is specially designed to measure friction coefficients and cohesion in loose granular material accurately at low confining pressures and shear velocities similar to sandbox experiments. In this tester, a sand layer is sheared internally (internal friction) or against a rigid plane (wall or basal friction) at constant normal stress σ_N and shear velocity v while the shear stress τ and volume change ΔV is measured continuously. For more details see Klinkmüller et al. (2016) and Ritter et al. (2016).

2.2.1. Sample preparation and test conditions:

Each sample has been carefully prepared by the same person and measured consistently following the same protocol. The measurements presented here correspond to internal friction, i.e. shearing inside the material, and basal (or wall) friction against Alkor foil. Preparation included sieving (specified in Table 2) from 30 cm height into a shear cell of type No. 1 for internal friction and No. 2 for wall friction. Normal force, shear force, velocity and lid displacement (volume change) were measured at 100 Hz and then down sampled to 5 Hz. Laboratory conditions were air conditioned during all the measurements (Temperature: 23°C, Humidity: 45%).

2.2.2. RST (Ring-shear test) procedure:

Internal and basal (wall) friction tests follow the same test protocol. In a RST a shear velocity of v = 3 mm min^{-1} is imposed. 15 measurements are done at normal stresses of σ_N = 430, 860, 1290, 1720, 2150 Pa (3 repetitions per stress level). During the measurement the material is sheared for initially 3 minutes. During this period the shear stress τ reaches a peak (= peak friction) and then drops to a plateau indicating shear has localized into a shear zone (= dynamic friction). The sample is then unloaded by shortly reversing rotation and immediately re-sheared for 3 minutes during which shear stress τ reaches a second peak (= reactivation friction) simulating reactivation of an existing shear zone. Before RST we verify that internal friction is independent of shear velocity v by carrying out a velocity stepping test (ranging from 0.1 to 30 mm min^{-1}) at σ_N = 2000 Pa. The tested material shows a <1% decrease in the coefficient of the internal dynamic friction μ_D per ten-fold increase in shear velocity v.

Table 2: Sample overview *(UB = University of Bern, GFZ = German Research Centre for Geosciences in Potsdam).*

GFZ-ID	UB-ID	Material	Sieve-ID	Sieving rate [g $min^{-1}cm^{-2}$]	File name
324-01	Quartz Neusand	Quartz sand	Geomod	29	324-01_UB_quartzneusand_internal
327-01	Quartz Neusand	Quartz sand	Geomod	29	327-01_UB_quartzneusand_basal

2.3. Analysis method

2.3.1. RST analysis: Friction coefficients and cohesion

From the resulting shear stress curves (see e.g. Figure 2) three characteristic values (strengths) have been picked manually:

(1) the shear strength τ^* at ***peak friction*** corresponding to the first peak in the shear curve reflecting hardening-weakening during strain localization
(2) the shear strength τ^* at ***dynamic friction*** corresponding to the plateau after localization and representing friction during sliding
(3) the shear strength τ^* at ***reactivation friction*** corresponding to the second peak and representing static friction during reactivation of the shear zone.

We performed regression analysis of these friction data by means of linear regression in two ways:

(1) A linear regression through all data pairs of shear strength τ^* and normal stress σ_N. The slope of the linear regression corresponds to the friction coefficient μ and the y-axis intercept to cohesion C (see e.g. Figure 3). This method assumes that the material behaves strictly as a Mohr-Coulomb material, i.e. has a linear failure envelope.

(2) Calculating all possible two point slopes (friction coefficient μ) and y-axis intercepts (cohesion C) for mutually combined data pairs of shear strength τ^* and normal stress σ_N. These data (i.e. all individual μ and C) are then evaluated by means of univariate statistics by calculating mean and standard deviation and comparing the probability density function (pdf) to that of a normal distribution (see e.g. Figure 4). This method overcomes the limitation of the analysis to Mohr-Coulomb material and allows for non-linear failure envelopes (see Santimano et al., 2015).

In case values for μ and C as derived from the two methods are identical (within standard deviation), the material is properly characterized by a straight Mohr-Coulomb failure envelope.

2.3.2. Python-based analysis

A Python script is provided in the subfolder "Script" allowing analysis and visualization of the data. Python is an open-source, interpreted programming language. A complete Python-distribution is, for instance, provided by the "Anaconda"-platform, which can be downloaded from: https://www.anaconda.com/download/.

For conducting the RST-analysis, the "RSTanalysis.py"- file has to be opened and executed in the "Spyder"-editor (Note: make sure that folders "Data files" and "Script" are stored in the same directory.)

3. File description

For both internal and basal (wall) friction RST there exists

(i) RST shear curve data ("File name_ts.txt"; example Table 3)
(ii) RST shear curve plot ("Filename_ts.pdf"; example Figure 2)
(iii) RST friction data of ring-shear-tests ("File name_peak.txt", "File name_dynamic.txt", "File name_reactivation.txt"; example Table 4)
(iv) RST fiction plots of ring-shear-tests ("File name_linregr.pdf"; example Figure 3)
(v) RST histograms of friction data ("File name_hist.pdf"; example Figure 4),

respectively. Furthermore, 14 SEM images are provided in the subfolder "SEMimages". An overview of all files of the data set is given in the **List of Files.**

3.1. RST shear curve data

Shear curve data are given as (i) time series (ts) data in .txt-format ("File name_ts.txt") and visualized as (ii) shear stress τ versus displacement d plots ("Filename_ts.pdf") (Figure 2).

Table 3: Example of shear curve time series data (324-01). *First line is header. First column is time in seconds. Columns 2-19 are shear forces (in N) for corresponding normal stresses as specified in the header of the respective columns (5 stress levels from 430 to 2150 Pa, three repetitions each stress level).*

Time [s]	Normal stress: 430 [Pa]	860 [Pa]	1290 [Pa]	…
0.0	-0.1962	0.1706939	0.623916	…
0.2	…	…	…	…
…	…	…	…	…

3.2. RST friction data

Friction data are given as (iii) data pairs (normal stress σ_N and shear strength τ^*; Table 4) for peak, dynamic and reactivation friction in txt format ("File name_peak.txt", "File name_dynamic.txt", "File name_reactivation.txt"). They are visualized by (iv) plotting into Mohr Space (normal stress σ_N vs. shear stress τ) including a linear regression (Figure 3) ("File name_linregr.pdf"). The results of the regression analysis (see 2.3) are plotted in (v) histograms for friction coefficients μ and cohesions C (Figure 4) ("File name_hist.pdf").

Table 4: Example of friction data (324-01). *First line is header. First column is normal stress σ_N. Second column is shear strength τ^*. 19 rows in total.*

Normal stress [Pa]	Shear strength [Pa]
430.00	308.95
860.00	625.59
…	…

4. Results

Our analysis reveals that the tested material behaves as a Mohr-Coulomb material characterized by a linear failure envelope. Values of friction coefficients μ and cohesions C are listed in Table 5. Internal peak, dynamic and reactivation friction coefficients are μ_P = 0.73, μ_D = 0.61, and μ_R = 0.66, respectively. Internal cohesions are in the range of 10 to 70 Pa. Basal peak, dynamic and reactivation friction coefficients are μ_P = 0.41, μ_D = 0.35, and μ_R = 0.36, respectively, whereas basal cohesions C are in the range of 120 to 150 Pa. The rate dependency of the internal dynamic friction coefficient μ_D is insignificant (<1%).

Table 5: Summary of RST data (v = shear velocity).

Parameter	Symbol	Unit	Linear least-squares regression method		Mutual two-point regression method	
			Value	Standard deviation	Value	Standard deviation
Internal friction						
Coefficient of peak friction	μ_P	-	0.728	0.012	0.728	0.064
Peak cohesion	C_P	Pa	21.06	17.41	8.84	97.97
Coefficient of dynamic friction	μ_D	-	0.612	0.007	0.613	0.037
Dynamic cohesion	C_D	Pa	52.92	9.75	52.16	54.44
Coefficient of reactivation friction	μ_R	-	0.662	0.007	0.663	0.039
Reactivation cohesion	C_R	Pa	72.30	10.25	65.72	60.17
Rate dependency	$\Delta\mu_D/\Delta logv$	-	0.002	n.a.	n.a.	n.a.
Basal Friction						
Coefficient of peak friction	μ_P	-	0.405	0.009	0.405	0.051
Peak cohesion	C_P	Pa	124.37	12.23	132.29	70.35
Coefficient of dynamic friction	μ_D	-	0.353	0.009	0.353	0.046
Dynamic cohesion	C_D	Pa	140.17	12.82	146.56	65.09
Coefficient of reactivation friction	μ_R	-	0.359	0.008	0.372	0.107
Reactivation cohesion	C_R	Pa	121.27	11.45	121.45	77.1

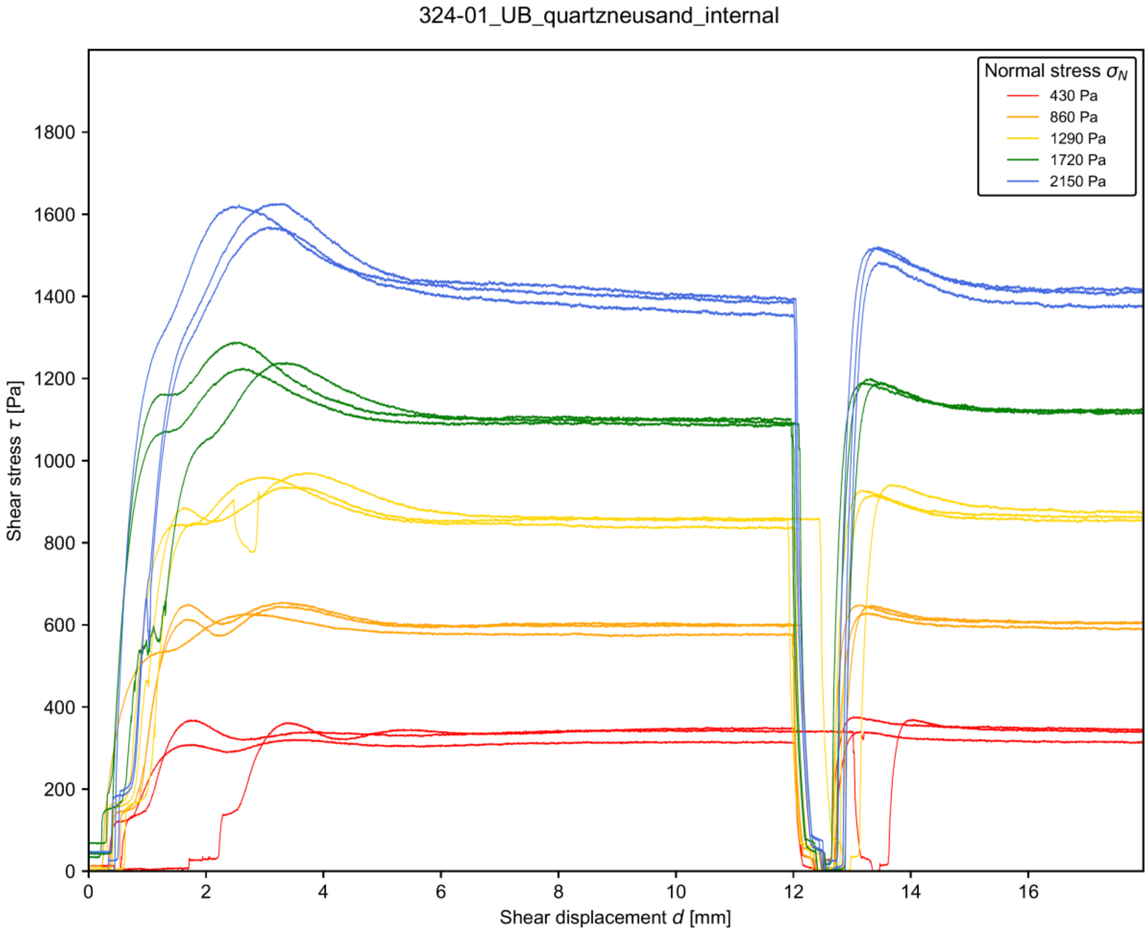

Figure 2: Example of shear curve plot (324-01). *Y-axis is shear stress τ, x-axis is shear displacement d. Each data set consists of 15 shear curves corresponding to 5 levels of normal stress σ_N with 3 repetitions each stress level (UB = University of Bern)*

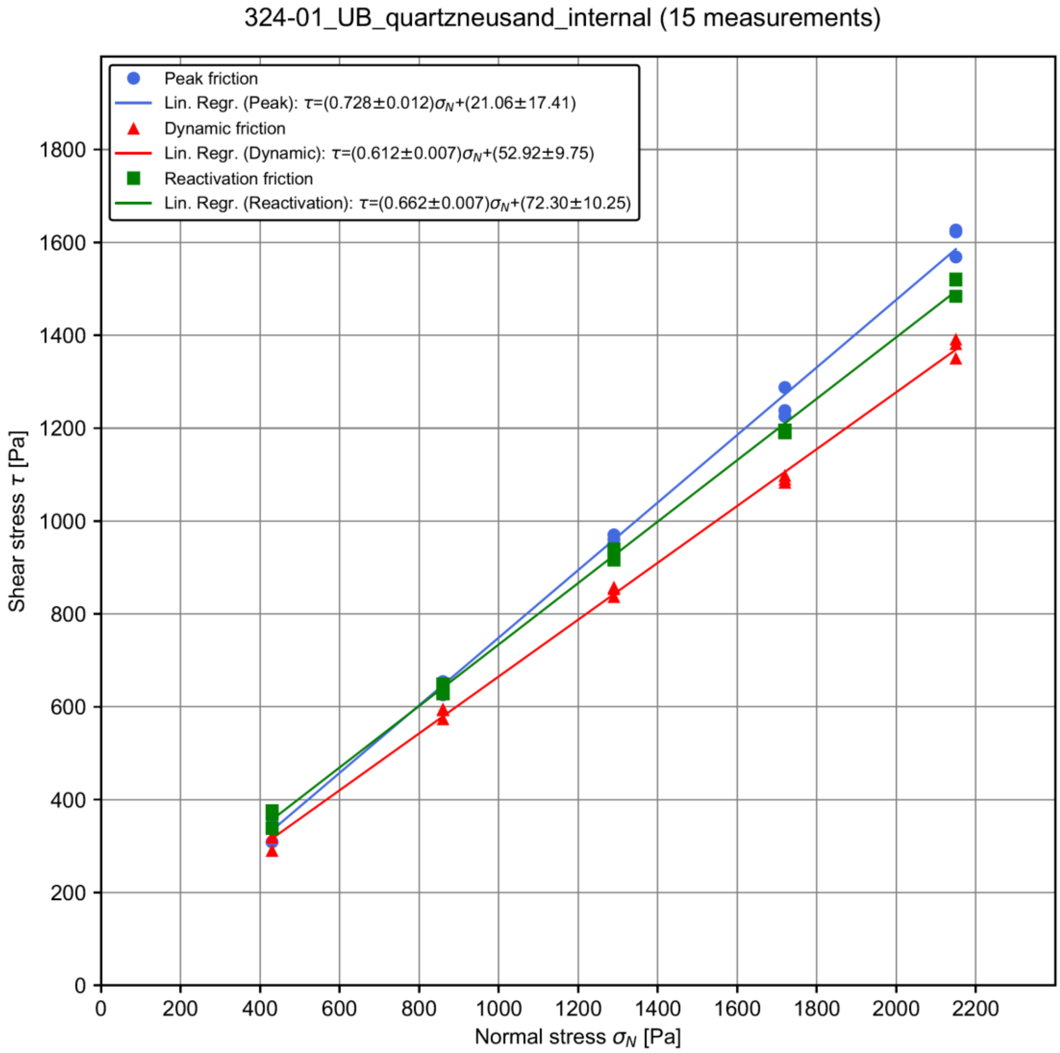

Figure 3: Example of friction plot (324-01). *Plot of all data pairs in the Mohr space (normal stress σ_N vs. shear stress τ) including curves of the corresponding linear least-squares regression (UB = University of Bern).*

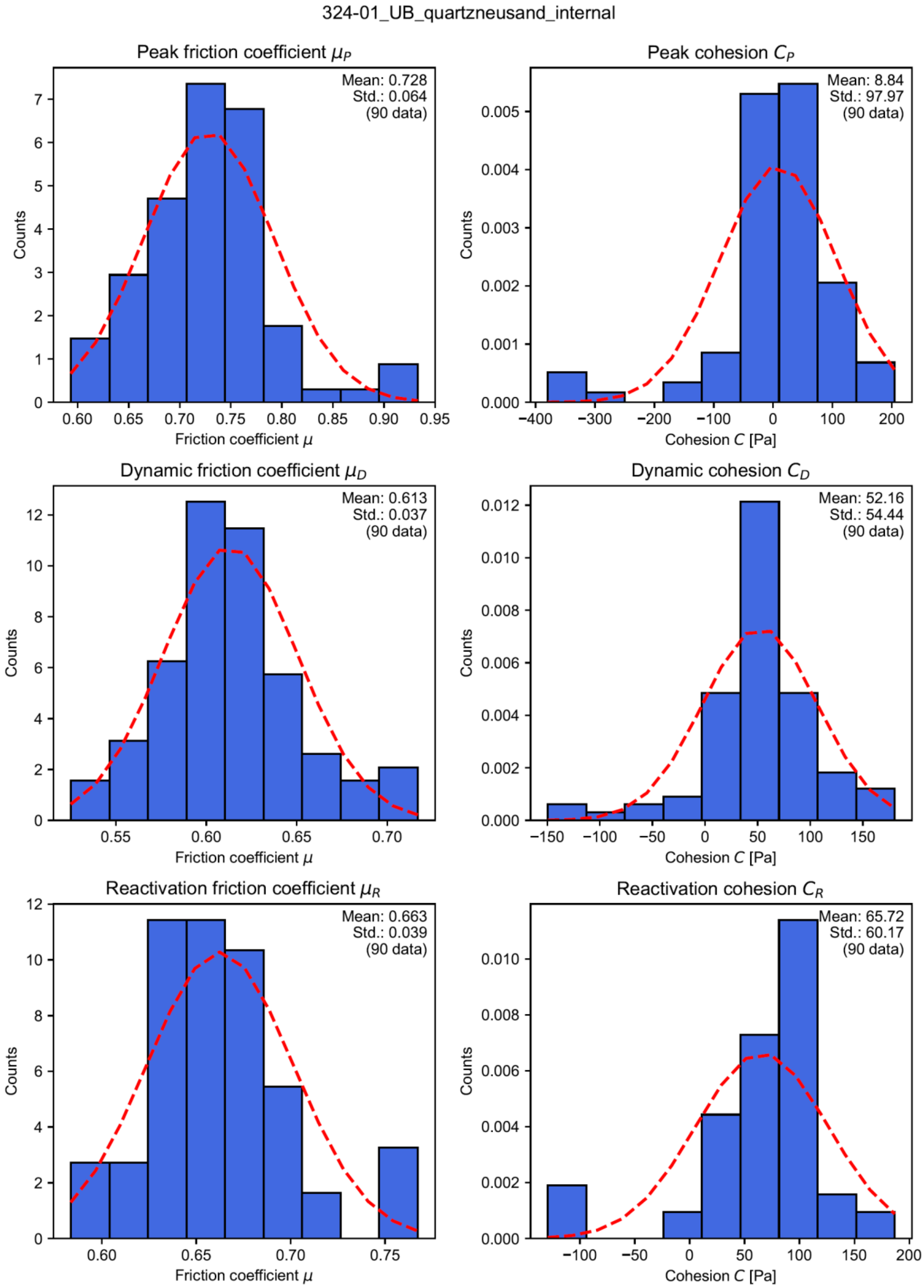

Figure 4: Example of histogram plot (324-01). *Histograms of mutual two-point regression results for slope (friction coefficient μ) and y-axis intercept (cohesion C). Red curves are synthetic normal distributions with the same mean and standard deviation (std.) as the data set for comparison (UB = University of Bern).*

5. References

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