METER

PARIO©

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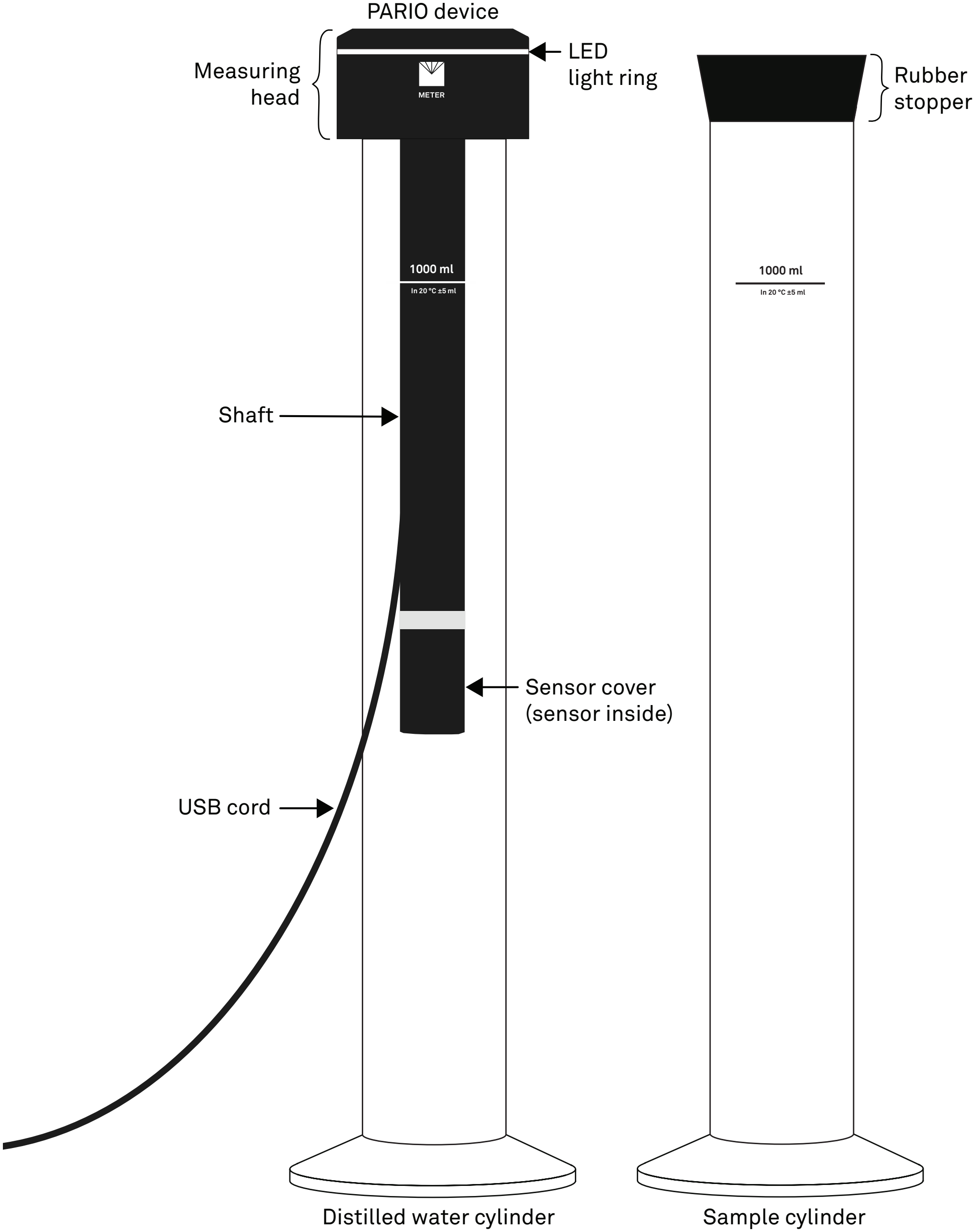
PARIO device
Measuring head
LED light ring
METER
1000 ml
In 20 °C ±5 ml
Rubber stopper
1000 ml
In 20 °C ±5 ml
Shaft
Sensor cover (sensor inside)
USB cord
Distilled water cylinder
Sample cylinder

1. INTRODUCTION

Thank you for choosing the PARIO© Soil Particle Analyzer from METER Group.

This manual includes detailed information about PARIO Control software configuration, advanced settings, postprocessing, and evaluation as well as guidelines for required and research-specific steps of soil sample preparation.

Verify all PARIO components are included and appear in good condition:

- PARIO device
- Two glass cylinders
- Rubber stopper
- USB cable
- Product support information card

2. OPERATION

Please read all instructions before operating the PARIO to ensure it performs to its full potential. Do not apply any other PARIO installation or measurement procedures other than those described in this manual.

Please observe the following considerations carefully.

- Read all applicable safety instructions (e.g., material safety data sheets for used chemicals or soil preparation instructions) and follow recommended safety measures.
- Do not use the device if the electrical wire is damaged.
- Always avoid direct sunlight exposure.
- Dispose of all materials and chemicals according to national legislation and environmental care regulations. Please refer to the respective safety data sheets.

⚠ PRECAUTIONS

METER instruments are built to the highest standards, but misuse, improper protection, or improper installation may damage the sensor and possibly void the manufacturer's warranty. Before integrating PARIO into a system, make sure to follow the recommended installation instructions and have the proper protections in place to safeguard sensors from damage.

2.1 INSTALLATION

Follow the steps listed in Table 1 to set up the PARIO.

Table 1 Installation

Tools Needed	Microsoft® Windows® computer (Windows 7 or newer)
Preparation	**WARNING: The PARIO is not intended for outdoor use.** **Select Clean, Level Location** Place the PARIO on a horizontal, vibration-free, and solid surface where the temperature remains fairly stable (away from air conditioner and heater vents, windows, etc.) **IMPORTANT: Temperature fluctuations or vibrations will strongly affect the accuracy of measurement results.**

Table 1 Installation (continued)

Installation	**Install PARIO Control Software and METER USB Driver** Download the installation package from metergroup.com/downloads/pario. Run the `PARIO CONTROL *.exe` file and go through the PARIO Control Setup Wizard. The wizard will install the PARIO Control software and the METER USB driver. Click on the PARIO Control icon (located where saved in the wizard installation) to open the program (Section 2.2.2). **Connect PARIO** Connect the PARIO USB cable into a computer USB port. The PARIO LED should flash white three times and then turn off. (Section 2.2.2). Multiple PARIO devices can be used simultaneously by connecting them to a powered USB hub. METER recommends a maximum of 15 PARIO devices per computer.

2.2 PARIO MEASUREMENT PROCESS

The PARIO measurement process is divided into four parts:

- Soil sample preparation (Section 2.2.1)
- PARIO measurement (Section 2.2.2)
- Postprocessing (Section 2.2.3)
- Data evaluation and export (Section 2.2.4)

The workflow described in this manual refers primarily to the German standard DIN ISO 11277 2002-08 and *Methods of Soil Analysis Part 4-Physical Methods* (Gee and Or 2002), which are two of the many possible methods. The steps and sequence will vary depending on the standard.

Figure 1 describes all recommended steps for the sample preparation and PARIO measurement. Sieving, destroying organic matter, and dispersing sample particles are necessary to get a valid result of particle size distribution (PSD) (Section 3.4). Figure 1 also includes optional preparation steps of removing soluble salts and plasters and removing iron oxides. These optional steps depend on the user's needs and scope of research.

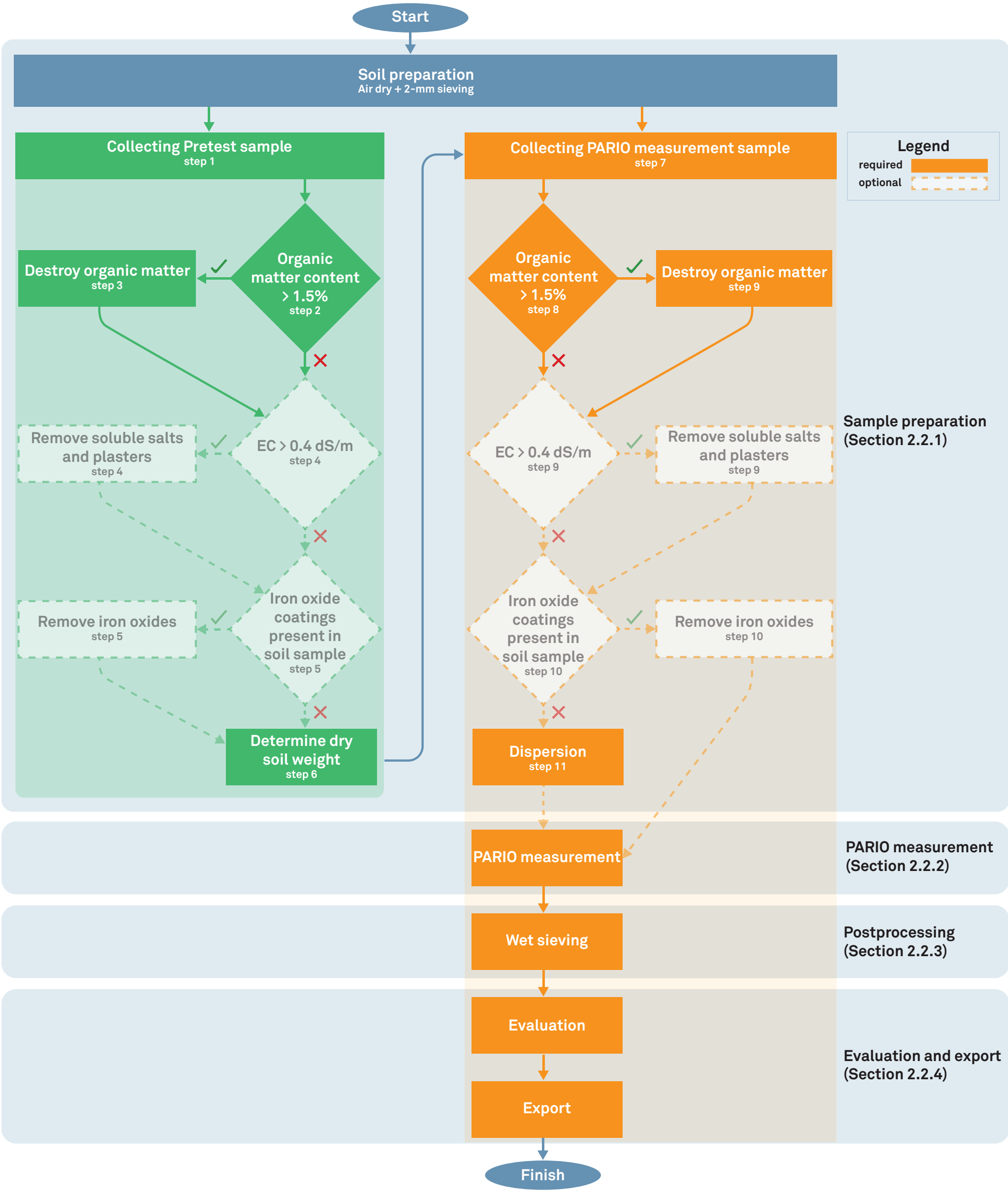

Figure 1 PARIO measurement process flowchart

2.2.1 SOIL SAMPLE PREPARATION

Before any PARIO measurements can be done, the soil needs to go through a preparation stage, described in the following table.

Steps	Equipment Needed
Air dry and sieve the ground sample to gain approximately 150 g sieved material. a. Air dry soil for at least 24 h. b. Grind soil with mortar and pestle or mechanical grinder. c. Pass ground sample through 2-mm sieve to remove gravel. d. Let the ground sample air dry for an additional 24 h (recommended).	2-mm sieve mortar pan for soil

METER recommends using two separate soil samples from the prepared soil.

- The Pretest soil sample will be used to characterize the organic matter content of the soil, calculate the sample dry mass, and perform any other pretreatment steps that may be needed, such as soluble salts and plasters removal or iron oxides removal (Section 2.2.1.1).

  If no pretreatment is required (i.e., no organic matter or other matter needs to be removed), proceed to step 6 to determine the water content of the sample before running a PARIO measurement.

- The PARIO measurement soil sample will be used for the actual PARIO measurement process and will go through the same pretreatment steps (Section 2.2.1.2) plus some additional steps before the actual PARIO measurement begins (Section 2.2.2).

2.2.1.1 PRETEST SOIL SAMPLE

A Pretest soil sample will be used to determine the following soil characteristics of the PARIO measurement sample:

- Organic matter content
- Amount of soluble salts and plasters (optional)
- Amount of iron oxides (optional)
- Sample dry mass

It is important to follow the same steps on both sets of samples (Pretest soil sample and PARIO measurement soil sample) to ensure an accurate determination of soil weight.

NOTE: Carefully follow the following sequence of steps and be sure to perform the same steps for both the Pretest soil sample and the PARIO measurement soil sample because this will affect the calculation of the dry soil weight, which is necessary for evaluation.

Performing the following steps to determine the soil sample properties and the dry soil weight. Knowing the soil sample properties ensures that the correct pretreatment steps are performed on the PARIO measurement sample.

Steps	Equipment Needed
1. Collect the Pretest Sample **NOTE: Be precise with the soil dry weight (within ±0.1 g) or the analysis will not be accurate.** a. Weigh out approximately 50 g of soil from the 2-mm sieved, ground soil sample (Section 2.2.1). This will be referred to as the Pretest soil sample. b. Document the exact collected soil sample weight (m_{wet}).	precision balance (±0.01 g)
2. Determine Organic Matter Content a. Determine the percent of organic matter in the soil sample. If the organic matter of the soil is unknown, use the most appropriate procedure for the circumstances (e.g., by following step 3 [see note below], using the brown coloring method, or by using an annealing method). **NOTE: The weight of the sample after organic matter is destroyed can be used to calculate percent of organic matter.** **NOTE: Some procedures for determining organic matter are destructive and destroy the soil sample. If using one of these procedures, use a sample separate from the Pretest soil sample. In this situation, the separate soil sample will need to be discarded.** b. If the organic matter content is >1.5% of the total dry mass, destroy the organic matter in the Pretest soil sample as described in step 3. c. If the organic matter is <1.5%, proceed to step 4.	
3. Destroy Organic Matter If the organic matter content is >1.5%, destroy the organic matter in the Pretest soil sample. **WARNING: Read the respective safety data sheets for solids and chemicals carefully and follow them strictly. The following steps must be carried out with great care. Hydrogen peroxide (H_2O_2) can decompose violently with some organic substances that may be present in the soil. Never observe the reaction by looking into the glass beaker from above. Do not accelerate apparently slow reactions by heating or by adding any further H_2O_2.** These steps follow DIN ISO 11277 (2002) and Gee and Or (2002). a. Place the 50 g of Pretest soil sample from step 1 in a 1-L glass beaker. b. Document the exact sample mass for subsequent evaluations. c. Add 30 mL of distilled water to the beaker and stir with a glass rod until the soil and water are well mixed. d. Add 30 mL of 30% H_2O_2 and stir with a glass rod until well mixed.	1-L glass beaker distilled water glass rod 30% hydrogen peroxide (H_2O_2) heating plate fume hood centrifuge

Steps	Equipment Needed
e. Cover the open beaker and let the sample soak overnight. Remove the cover. Put the glass beaker on a heating plate under a fume hood. f. Heat the solution at 40 °C, stirring the solution regularly. The solution will begin to foam. Watch the solution carefully because the foaming can occur suddenly and intensely. g. Add distilled water if the foaming gets too high. h. Continue heating until the foaming due to decomposition of the organic matter has stopped, and existing bubbles have dissipated. This can take up to 4 h. i. Remove the beaker from the heating plate and let the sample cool down. If the soil has a high organic matter content (>5% organic matter), the process of removing organic matter may need to be repeated 2 or 3 times. If the soil does not have a high organic matter content, proceed to step j. **NOTE: Before adding more H_2O_2, add distilled water to the soil sample, then remove residue by using a centrifuge, decanting, or by filtrating.** j. When all organic matter is destroyed, add distilled water and remove residue by using a centrifuge, decanting, or by filtrating. **4. Remove Soluable Salts and Plasters** In some cases it may be necessary to remove soluble salts and plasters. If the soil has saturated extract electric conductivity (EC) greater than 0.4 dS/m follow the steps in Appendix B to remove the soluble salts and plasters. If soluble salts and plasters are not removed, proceed to step 5. **5. Remove Iron Oxide** In some cases it may be necessary to remove iron oxides. If iron oxide coatings are present in the soil sample, follow the steps in Appendix B to remove iron oxides. If iron oxides are not removed, proceed to step 6.	

Steps	Equipment Needed
6. Determine Dry Soil Weight The dry soil weight needs to be measured to account for the residual water content and the destruction of any organics, solubles salts and plasters, and iron oxides. This weight will be used to determine the true soil weight of the PARIO measurement sample. a. Record the sample weight plus the drying pan weight if it has not been recorded in previous steps. b. Transfer the Pretest sample into a preweighed drying pan. c. Place the Pretest soil sample and drying pan into a drying oven at 105 °C for 24 h. d. Weigh the dry sample plus the drying pan. e. Subtract the drying pan weight from the total Pretest soil sample dry mass to determine the exact soil mass (m_{dry}). **NOTE: Be precise with the dry weight of the Pretest sample (within ±0.1 g) or the analysis will not be accurate.**	precision balance (±0.01 g) drying pan drying oven

Example:

Pretest Sample Weight + Drying Pan Weight	–	Pan Weight	=	M_{dry}
54.6 g	–	7.8 g	=	46.8 g

2.2.1.2 PARIO MEASUREMENT SAMPLE

The following steps describe the recommended procedure for pretreating the PARIO measurement sample prior to running the sedimentation experiment in the PARIO. Some of the pretreatment steps are critical where others are optional:

- Organic Matter Removal (optional depending on organic matter content)
- Soluble Salts and Plasters Removal (optional)
- Iron Oxide Removal (optional)
- Chemical Dispersion (required)
- Physical Dispersion (required)

NOTE: Any pretreatment steps done on the Pretest sample need to be done on the PARIO measurement sample.

Steps	Equipment Needed
7. Collecting the PARIO Measurement Sample	precision balance (±0.01 g)
8. Organic Matter Removal	same as in step 3

7. Collecting the PARIO Measurement Sample

The amount of soil needed in a PARIO experiment should be between

25 g dry weight (soils with a lower sand content), and
50 g dry weight (soils with a higher sand content).

If the soil texture is unknown, METER recommends using 30 g of dry soil.

Because material is lost during sample preparation (e.g., destroyed organic matter, water content), the actual soil weight of the PARIO measurement sample has to be calculated by multiplying the initial soil weight of the PARIO measurement sample and the percent of the Pretest soil sample dry soil weight (step 4). For more information, see Section 3.4.

NOTE: Be precise with the dry soil weight of the sample (within ±0.1 g) or the anaysis will not be accurate.

NOTE: Depending on the amount of organic matter, less material is used in the analysis than initially weighed, because the amount of material will decrease through pretreatment process. For example, if the initial dry mass is 30.0 g and the organic matter content is 10%, the reduced mineral mass after destruction of organic matter will be 27.0 g.

Example calculation:

	Weight	% Total Mass
Initial weight of Pretest soil sample (m_{wet})	50 g	100%
Dry weight of Pretest soil sample (m_{dry})	47.5 g	95%
Weight of everything removed from Pretest soil sample (water, organic matter, soluble salts & plasters, iron oxides)	2.5 g	5%

Actual weight for PARIO measurement sample:

PARIO measurement sample weight	×	% dry mass of Pretest soil sample	=	Total dry soil weight of PARIO measurement sample
30 g	×	0.95	=	28.5 g

NOTE: Ensure that the total dry soil weight of the PARIO measurement sample is greater than 25 g.

8. Organic Matter Removal

If the PARIO measurement soil sample has >1.5% organic matter, destroy the organic matter following the process in step 3. If the soil has <1.5% organic matter, proceed to step 9.

Steps	Equipment Needed
9. Soluble Salts and Plasters Removal In some cases it may be necessary to remove soluble salts and plasters. If the PARIO measurement soil sample has saturated extract t greater than 0.4 dS/m, follow the steps in Appendix B to remove the soluble salts and plasters. If soluble salts and plaster are not removed, proceed to step 10.	
10. Iron Oxide Removal In some cases it may be necessary to remove iron oxides. If iron oxide coatings are present in the PARIO measurement soil sample, follow the steps in Appendix B to remove iron oxides. If iron oxides are not removed, proceed to step 11.	
11. Sample Dispersion Below are two different options for chemical dispersion of soil and two options for physical dispersion of soil (Section 3.4). Choose a method based on the available lab equipment and preferred standards. a. **CHEMICAL DISPERSION** Perform chemical dispersion prior to physical dispersion. **WARNING: Read the respective safety data sheets for solids and chemicals carefully and follow them strictly.** **OPTION 1 (DIN 2002)** **Prepare a 40 g/L solution of $Na_4P_2O_7$ dispersing agent.** i. Add 40 g of $Na_4P_2O_7$ to a 1-L Erlenmeyer flask. ii. Add enough distilled water to the flask to fill it to the 1-L mark. iii. Place the flask on a stir plate and let it stir until the $Na_4P_2O_7$ is dissolved. iv. Refill the lost volume with distilled water. v. Pour the solution into a sealable 1-L bottle or dispenser. **NOTE: The solution will lose its effectiveness after about 1 month.**	distilled water sodium pyrophosphate ($Na_4P_2O_7$) stir bar sealable 1-L bottle shaker table

Steps	Equipment Needed
Disperse the PARIO measurement sample. vi. Place the PARIO measurement sample into either – a sealable 1-L bottle (for physical dispersion option 1), or – a 600-mL beaker (for physical dispersion option 2). vii. Add 200 mL of distilled water to the bottle/beaker. viii. Add 1 mL of dispersing agent per gram of soil sample to the bottle/beaker.	
OPTION 2 (Gee and Or 2002) **Prepare a 50 g solution of** $Na_6O_{18}P_6$ **dispersing agent.** i. Add 50 g of $Na_6O_{18}P_6$ to a 1-L Erlenmeyer flask. ii. Add enough distilled water to the flask to fill it to the 1-L mark. iii. Place the flask on a stir plate and let it stir until the $Na_4P_2O_7$ is dissolved. iv. Refill the lost volume with distilled water. v. Pour the solution into a sealable 1-L bottle or dispenser. **NOTE: The solution will lose its effectiveness after about 1 month.** **Disperse the PARIO measurement sample.** vi. Place the PARIO measurement sample into either – a sealable 1-L bottle (for physical dispersion option 1) or – a 600-mL beaker (for physical dispersion option 2). vii. Add 250 mL of distilled water to the bottle/beaker. viii. Add 100 mL of dispersing agent to the bottle/beaker. b. **PHYSICAL DISPERSION** Physical dispersion should occur after chemical dispersion steps.	distilled water sodium hexameta-phosphate ($Na_6O_{18}P_6$) stir bar sealable 1-L bottle

Steps	Equipment Needed
OPTION 1 (DIN 2002) i. Seal the 1-L shaker bottle. ii. Place sample on a reciprocating shaker and run for 6 to 12 h. METER recommends running this step overnight.	shaker table
OPTION 2 (Gee and Or 2002) iii. Allow sample to sit in covered 600-mL beaker overnight. iv. Transfer sample from 600-mL beaker to mixer cup for dispersing with a wash bottle filled with deionized water. v. Place mixer cup in electric mixer (milkshake or ASTM mixer with soil-specific paddles) and run for 5 min.	mixer cup electrical mixer

The sample is now prepared for the PARIO to measure (Section 2.2.2). If the sample needs to be stored, leave it in the used, sealable bottle.

NOTE: The effectivness of dispersion will diminish over time. The sooner the sample is measured after these steps, the better the results.

2.2.2 PARIO MEASUREMENT

The PARIO measures the PSD of soil samples in suspension in a PARIO glass cylinder. The method is primarily based on the German standard DIN ISO 11277 (DIN 2002) and *Methods of Soil Analysis Part 4-Physical Methods* (Gee and Or 2002), which are based on Stokes's law. The computation equations are only valid for a laminar settling of the particles as this is assumed for Stokes's law.

The samples, device, and suspension fluid must be equilibrated at room temperature. Room temperature should be constant within ±1.5 °C during the entire measurement. If possible, use a temperature-controlled room or place PARIO cylinders in a temperature-controlled water bath.

NOTE: Before starting the PARIO measurement, deactivate the computer standby mode and automatic updates to avoid interrupting tests.

After preparing the sample properly (Section 2.2.1), use the following steps to perform the PARIO measurement.

1. Place the PARIO cylinders on a level surface.
2. Transfer the dispersed soil sample into one of the PARIO cylinders.

   Using a wash bottle with distilled water to ensure the whole sample is transferred. This cylinder will be referred to as the sample cylinder.

3. Fill the sample cylinder with room-temperature distilled water to bring the level of liquid to the 1,000-mL mark (Figure 2), ensuring the meniscus touches the upper line of the mark.

   NOTE: It may be necessary to let the sample sit for 1 h to come to room temperature.

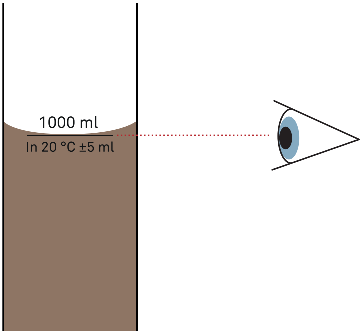

Figure 2 Fill the sample cylinder to the 1,000-mL mark

4. Place the rubber stopper on the dispersed sample cylinder to avoid evaporation (Figure 3).
5. Fill the distilled water cylinder up to the 1,000-mL mark with room-temperature distilled water (Figure 2 and Figure 3).
6. Place the PARIO inside the distilled water cylinder for at least 10 min for temperature equilibration (Figure 3).

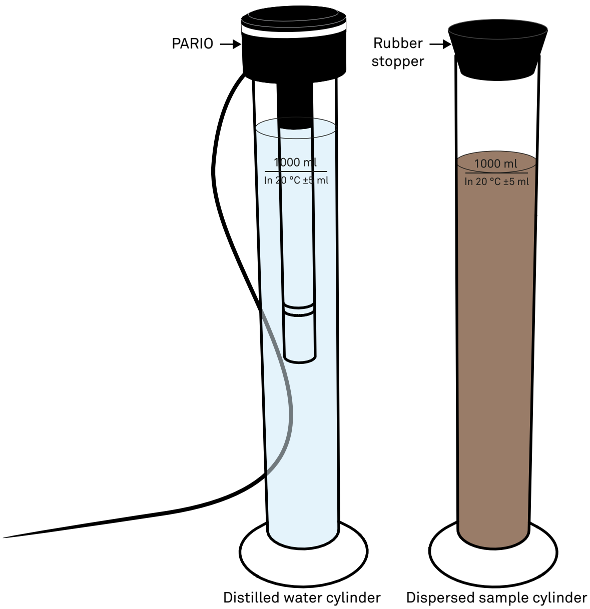

Figure 3 PARIO device and PARIO measurement sample equilibrating to room temperature

7. Connect the PARIO to a computer using the USB port.
8. Start PARIO Control software.

   The LED ring should flash white three times and then remain solid white if the PARIO device is recognized by the PARIO Control software.

   If this sequence does not happen, disconnect and reconnect.
9. Click `New Measurement` on the PARIO Control main screen (Figure 4).

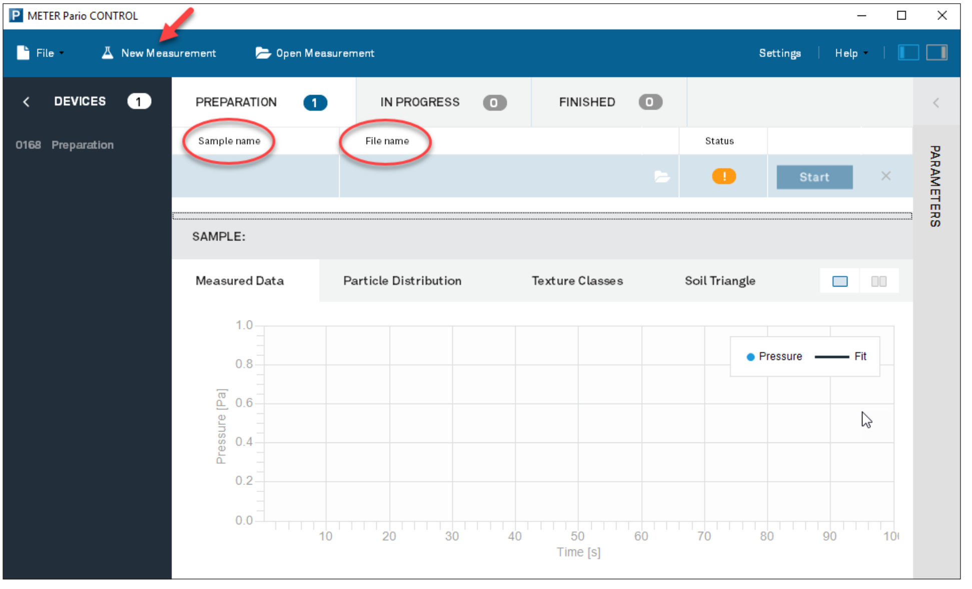

Figure 4 New Measurement at the top of PARIO Control main screen

10. Enter `Sample name` parameter.
11. Change the automatically generated `File name` parameter, if desired.
12. Enter `Duration` parameter (the default is 8 h) (Figure 5).

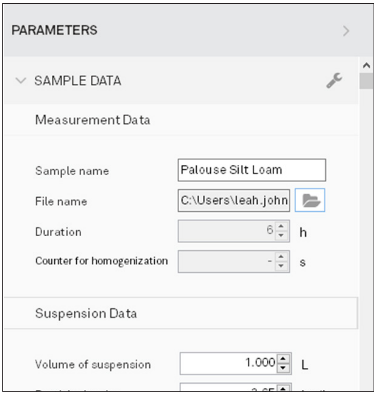

Figure 5 Parameters

13. Enter `Timer for homogenization` parameter (recommended minimum time is 60 s) (Figure 5).

    The time for homogenization has to be adapted to the respective circumstances. A complete homogenization of the suspension has to be ensured.

    NOTE: If the particles in the suspension settled completely, use vigorous shaking and stirring to remove slurry from the base of the cylinder before starting the countdown.

    When all necessary parameters are entered, the test will appear in the Preparation tab with a green checkmark in the Status column.

    The `Start` button will become selectable, and the LED ring will flash white three times and then remain solid white.

14. Click `Start` for the desired sample.

    This initializes the Time for homogenization countdown (Figure 6).

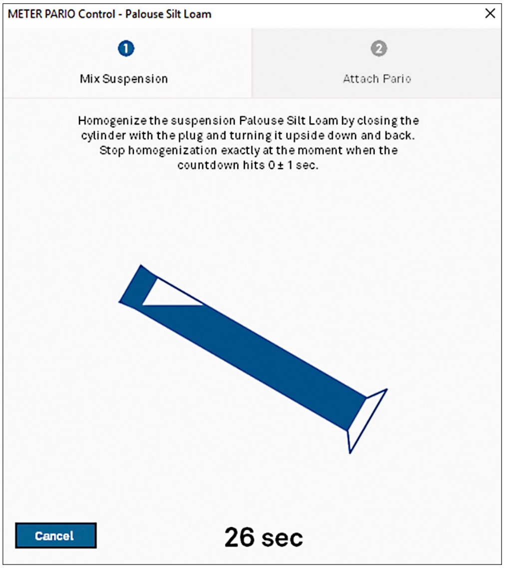

Figure 6 PARIO Control homogenization countdown with mixing instructions

15. Mix the suspension in the sample cylinder thoroughly during the countdown using one of the following methods:
    - Continually turning the cylinder with the rubber stopper in place (Figure 7)
    - Vigorous vertical stirring with a suitable stirrer (typically a plate with openings at the end of a bar)

IMPORTANT: Be absolutely sure to prepare a homogeneous suspension. Any error in the homogenization will propagate through the analysis and return wrong values.

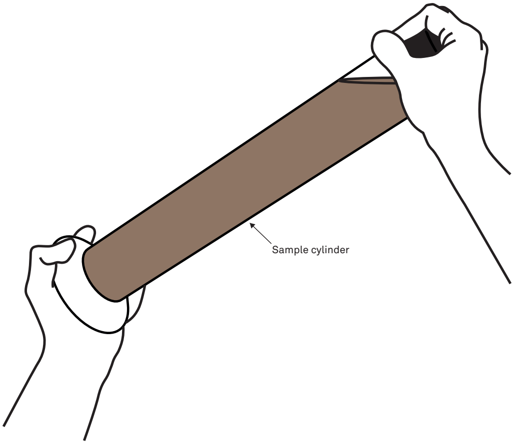

Figure 7 Mix soil sample

16. Place the sample cylinder on the level surface when the countdown reaches 0 s and remove stopper.

    The PARIO Control window will update to show instructions for placing the PARIO on the sample cylinder (Figure 8).

    NOTE: It is important that the cylinder is on a level surface when the countdown reaches 0 s (±1 s). The 0 s of the countdown initializes the start of the measurement. At this point the sedimentation has to start.

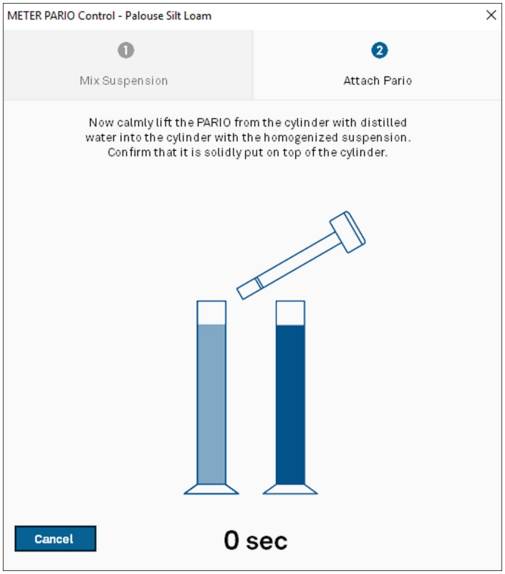

Figure 8 Completed PARIO Control countdown with instructions to insert PARIO into sample cylindar

17. Remove the PARIO from the cylinder with distilled water.
18. Momentarily bring the PARIO to a horizontal orientation of approximately 45° to activate the automatic device detection in PARIO Control (Figure 9).

    NOTE: Make sure the computer standby mode and automatic updates are deactivated to avoid interrupting the PARIO measurement.

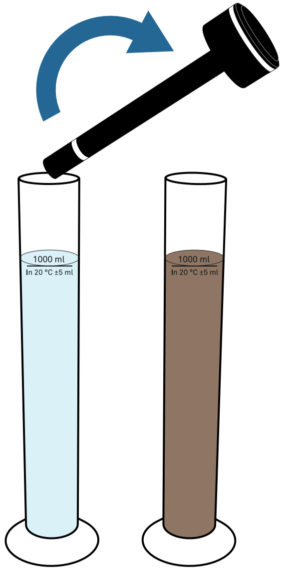

Figure 9 Insert PARIO device into cylinder with soil suspension

19. Insert the PARIO into the sample cylinder, carefully fitting the groove of the PARIO on the rim of the sample cylinder.

    The amount of time from the end of the mixing until the insertion of the PARIO should not exceed 20 s.

    The status line of the running measurement shown in PARIO Control is moved automatically from the Preparation tab to the In Progress tab (Figure 10).

    The LED ring changes to slow pulsing blue.

Figure 10 PARIO Control during test

20. Leave the PARIO undisturbed for the duration of the measurement time (Figure 11).

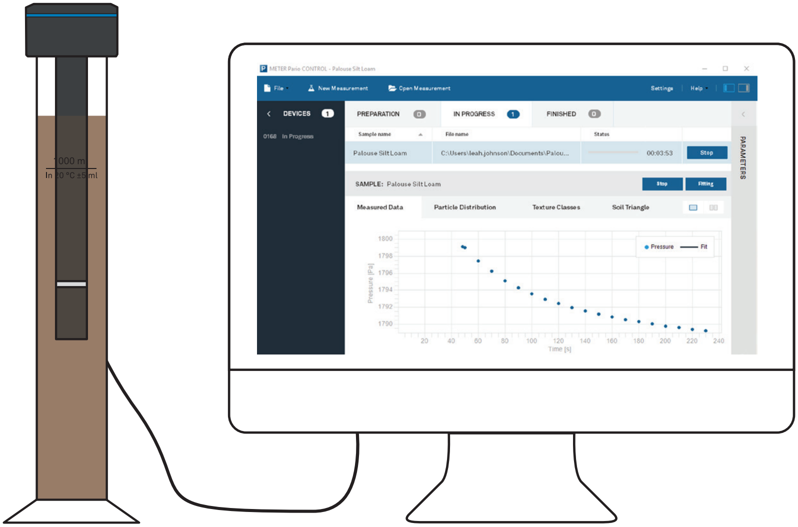

Figure 11 PARIO device and PARIO Control software during test

A measurement finishes automatically when the preentered measurement time has ended. Alternatively, a user can stop a measurement any time by clicking `Stop` in PARIO Control.

PARIO Control will record three parameters (time, pressure, and temperature) every 10 s and depict the recorded data graphically.

If multiple PARIO devices are used, the operator can now proceed with mixing the next suspension. Switching windows in PARIO Control will not affect the running measurements.

The PARIO LED will change to permanent blue when the measurement is complete. The measurement moves to the Finished tab (Figure 12).

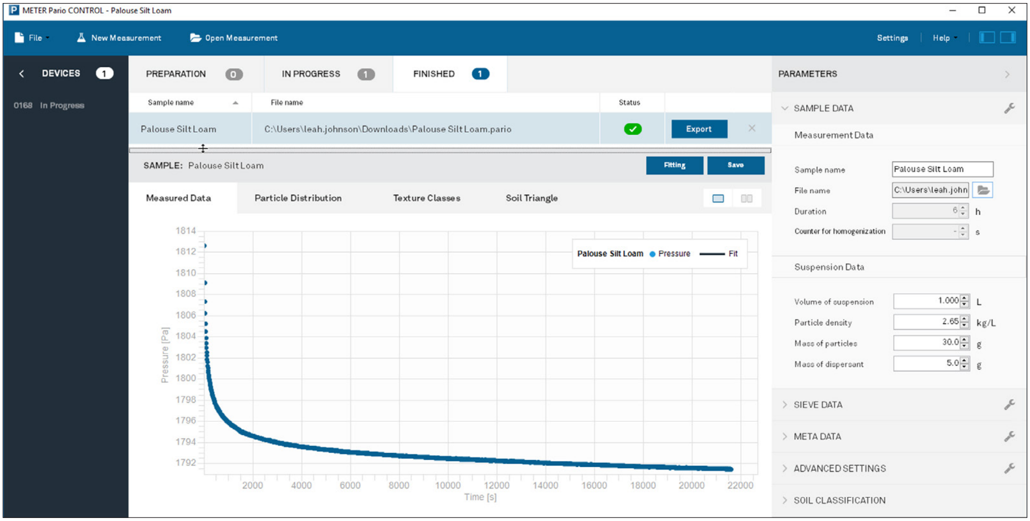

Figure 12 PARIO Control after test

21. For short-term storage (e.g., the next measurement will be within a couple days), remove the PARIO from the suspension and place it again in the cylinder with distilled water (Figure 13).

    If necessary, rinse the shaft of the PARIO with a soft jet of water and clean the shaft with a soft cloth. For long-term storage, see Section 4.2.

    IMPORTANT: Never touch the pressure sensor, which is shielded by the sensor cover. Spray only a soft stream of water in the area of the sensor protector to avoid damaging the pressure sensor.

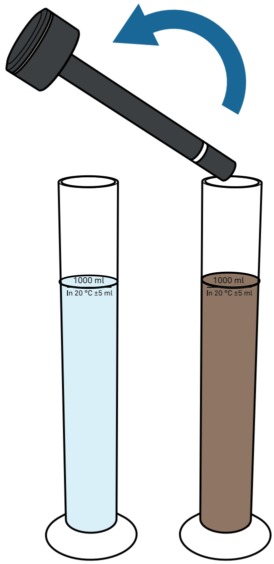

Figure 13 Replace PARIO in distilled water after test

2.2.3 POSTPROCESSING

Once the PARIO measurement is complete, the PARIO measurement sample needs to go through one final postprocessing step to determine the sand and clay content. This is typically achieved by wet sieving the PARIO measurement sample.

Wet sieving of the soil sample has to be done to determine the sand fractions (2,000 to 63 or 50 µm) for the sample (Table 2). This can be done either with a homogenous parallel sample before or during the PARIO measurement or right after the measurement using the same sample measured with the PARIO.

Table 2 Recommended mesh openings

Germany (µm)	USA (µm)
63	53
112	106
200	250
630	500
2,000	1,000

METER recommends doing the wet sieving right after the PARIO measurement using the same sample. This guarantees conformity of results from wet sieving (sand) to the PARIO results (silt) and, therefore, the correct identification of the clay fraction.

METER also recommends doing the sieve analysis with a three-dimensional working screening machine, combining throw pulse and angular momentum. This guarantees an optimal movement of the screenings.

The sieves are mounted downward with the largest mesh opening on top. Depending on the screening machine, the duration and type of movement have to be defined. Please refer to the appropriate screening machine manual.

Use the following steps to sieve the PARIO measurement sample (DIN 2002; DIN 2011).

1. Transfer the contents of the PARIO sample cylinder into the first mesh of the screening tower.
2. Use a spray bottle to transfer all particles of the soil sample into the sieve.
3. Continue the screening until the water coming out of the drain hose is clear.
4. Place the residues of the sieves in labelled glass beakers.
5. Put the glass beakers in the oven for 24 h at 105 °C.
6. Calculate and document the dry soil weights to evaluate the wet sieving.

2.2.4 DATA EVALUATION AND EXPORT

Data evaluation is based on the integral suspension pressure (ISP) method (Section 3.4) and PARIO Control software. All generated data can be exported into one Microsoft Excel® spreadsheet file, including visual illustration.

DATA EVALUATION

These data evaluation steps can be performed in PARIO Control at any time during or after the PARIO measurement.

1. In the Suspension Data subsection, enter the `Volume of suspension` value (default is 1 L) (Figure 14).

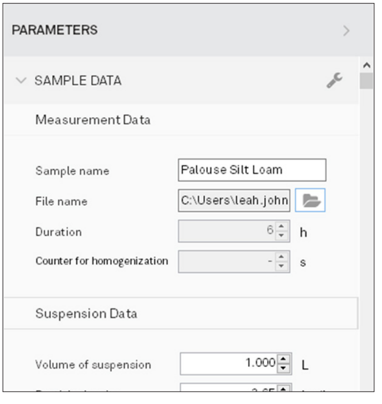

Figure 14 Example of evaluating data parameters

2. Enter `Particle density` value (default is 2.65 g/cm^3).
3. Enter `Total dry soil weight` value.

   The total dry soil weight is the total oven dry sample mass (24 h for 105 °C) including sand, silt, and clay.

   The mass of particles entered for evaluation can be calculated by

   - determining the water content with a Pretest sample (step 6, Section 2.2.1.1) and
   - calculating the oven dry weight of the PARIO measurement sample (step 7, Section 2.2.1.2).

4. Enter `Mass of dispersant` value (the mass of dispersant in the 1-L suspension).

   The dispersion mass is determined by adding a certain volume of dispersants solution to the soil. For example, if the dispersant solution = 40 g/L and the added dispersant volume = 25 mL, then the total dispersant in suspension = 40 g/L × 0.025 L = 1.0 g.

   For more information about these parameters, refer to Section 3.3.6.

5. In the Sieve Data subsection, enter sieve data (Section 2.2.3).

   Enter the values in percent for the defined particle size classes (Figure 15).

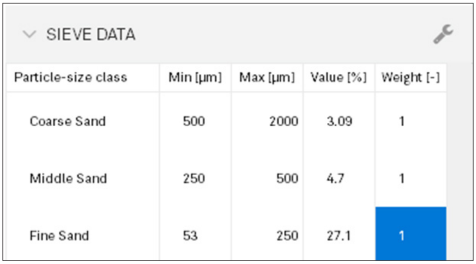

Figure 15 Enter sieve data

6. In the Soil Classification subsection, select either US Soil Taxonomy or German Classification (KA 5) (Figure 16).

   The texture classes as well as the soil triangle will be adapted to the selected classification setting.

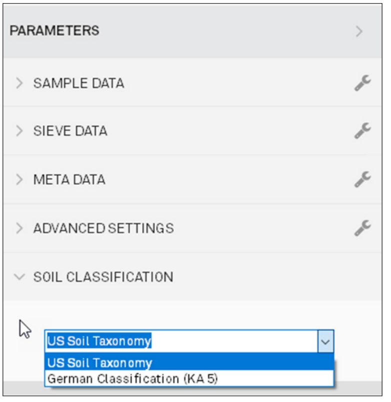

Figure 16 Soil Classification options

7. Click the `Fitting` button above the completed test (Figure 17).

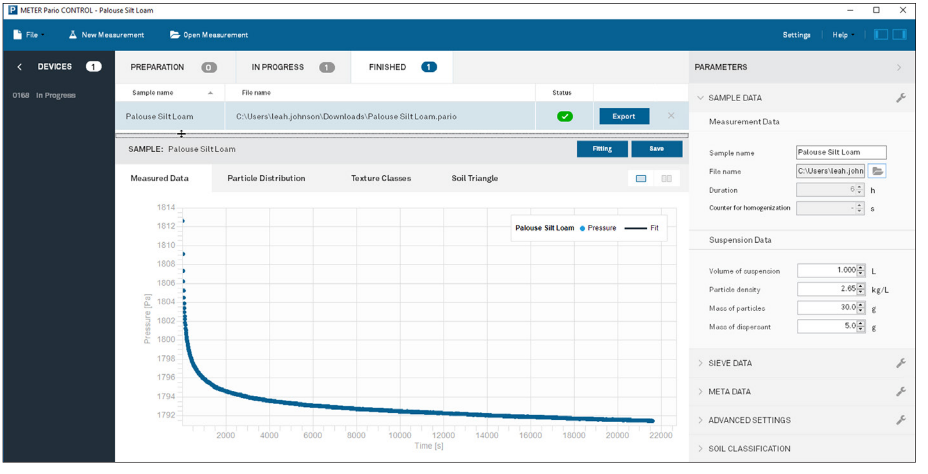

Figure 17 `Fitting` button above completed test

PARIO Control executes the fitting of the measured data. The fitting process can take several seconds and cannot be interrupted. The mouse icon will become an hourglass (or other icon) that indicates the computer is busy.

As documented in Durner, Iden, and von Unold (2016), the sedimentation process is simulated numerically, and the parameters that determine the cumulative PSD function are determined by nonlinear regression to achieve a best possible accordance between model and measurements (time series of pressure data by PARIO and independently measured sand fractions).

Notes:

- The result of the fitting depends on having the right settings, most importantly (1) the correct dry mass of mineral particles and (2) the correct sand fractions that stems from the independent sieving of the material.
- Any error in the sand fractions will propagate into a complementary error of the clay fraction, since the pressure data is restricted to silt particles. Sand particles settle so quickly that their behavior is not described by Stokes's law, and clay particles settle so slowly that most are still in suspension after 8 h.
- Fitting is possible without entering sand fractions. However, in order to get accurate clay, sand, and silt calculations, the sand fraction data needs to be entered before fitting.
- If the initial pressure data do not show a decrease (due to the formation and disappearance of foam or other unexpected processes), PARIO automatically disregards these initial data. PARIO Control will shade the respective data gray.

As a result of the fitting, the parameters of the PSD are identified and interpolated by a Hermitian spline. The corresponding function is shown by PARIO Control and can be exported into an Excel spreadsheet file. By default, the depicted range of particle sizes extends from 2 μm to 2 mm. However, the PSD identification goes down to 0.1 μm and the respective data for the sub-clay range is given in the exported file.

8. Click `Save` to save the fitting in the location indicated in the `File name` column.

EXPORT

To export the measurement results, click `Export` from the Finished tab (Figure 18).

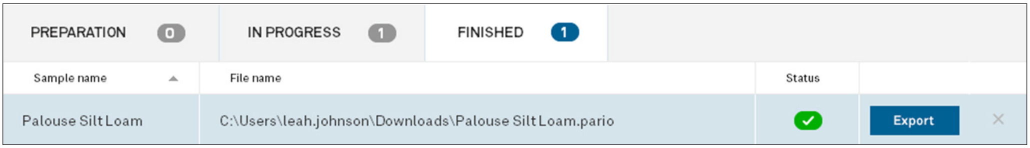

Figure 18 Export in the Finished tab

The file is subdivided in five tabs (Figure 19).

Settings & Parameters	Shows all entered parameters.
Sieve Data	Gives the sieve data values.
Measured Data	Displays measured data points (runtime, measured and fitted pressure, temperature) and a chart showing runtime versus pressure versus temperature.
Particle Distribution	Shows the calculated cumulative PSD referring to particle diameter (in micrometers) versus cumulative relative mass.
Texture Classes	Gives final result of texture classes.
Soil Triangle	Displays the soil triangle with the soil type marked with a red point.

	A	B	C	D	E	F	G	H
3		METER PARIO						
4		**PARTICLE-SIZE DISTRIBUTION | Palouse Silt Loam**						
5								
6								
7		PARAMETERS						
8								
9		Sample Data						
10								
11		Sample Name	Palouse Silt Loam					
12		File Name	C:\Users\leah.johnson\Desktop\Palouse Silt Loam Sample Data.xlsx					
13		Duration	6					
14		Counter for Homogenizatio	-					
15								
16		Volume of suspension	1					
17		Particle Density	2.65					
18		Mass of Particles	30					
19		Mass of Dispersant	5					
20								
21								
22		Sieve Data						
23								
24		**Particle-size class**	**Min [µm]**	**Max [µm]**	**Value [%]**	**cum. Value [-]**	**Weight [-]**	
25		Coarse Sand	500	2000	3.1	1.0	1	
26		Middle Sand	250	500	4.7	0.9	1	
27		Fine Sand	53	250	27.1	0.7	1	
28								
29								
30		Meta Data						
31								
32		Serial Number	168					
33		Firmware Version	1.4					
34		Software Version	0.7.4					
35		PSDFIT Version	1.19					
36		Start of measurement	3/8/2018 14:43					
37		Stop of measurement	3/8/2018 20:43					
38		Duration of measurement	5:59:00					
39		Temperature Range	0.7 °C					
40		Temperature Mean	22.4 °C					
41								
42		Advanced Settings						
43								
44		rel. WeightP	1					
45		rel. WeightF	1					
46		TCRIT	20					
47		Liquid Expansion	1.3					

Figure 19 Example of exported test data

3. SYSTEM

This section describes the specifications, components, and theory of the PARIO.

3.1 SPECIFICATIONS

MEASUREMENT SPECIFICATIONS

Particle Size Range

2-63 µm

Approximate Error in Mass Fraction Detection

±3%

Accuracy of Pressure Measurement

±1 Pa

Typical Particle Mass

25–50 g per 1-L suspension

Typical Duration of Measurement

8 h

Measurement Interval

10 s

COMMUNICATION SPECIFICATIONS

Power Requirements

USB 5 V/100 mA

Computer Compatibility

Microsoft Windows 7 or newer

PHYSICAL SPECIFICATIONS

Glass Cylinder

Height	450.0 mm (17.7 in)
Diameter Inner Outer	 59.0 mm (2.3 in) 67.5 mm (2.7 in)
Volume	1,000 cm^3 (61.0 in^3)
Material	Borosilicate glass 3.3

PARIO Device	
Height	293.0 mm (9.1 in)
Diameter	80.0 mm (3.2 in)
Material	Polyoxymethylene plastic (POM) and stainless steel
Volume of Suspension	
1,000 mL	
Operating Temperature	
Minimum	15 °C
Typical	20 °C
Maximum	35 °C
Maximum Tolerable Temperature Change During Measurement	
±1.5 °C	
Required External Measurements	
Content of organic matter Wet sieving	
Cable Type	
USB 2.0; 500 mA for receiving port	

COMPLIANCE

Manufactured under ISO 9001:2015
EM ISO/IEC 17050:2010 (CE Mark)

3.2 PARIO HARDWARE

The PARIO measuring system consists of

- the PARIO device,
- two glass cylinders,
- rubber stopper, and

The PARIO device consists of a pressure sensor at the tip of a shaft, which is connected to a measuring head (Figure 20). A temperature sensor is located at the side of the pressure transducer. The pressure and temperature signals are processed in the measuring head on top of the sample cylinder. The signals are transferred to a computer via a USB connection.

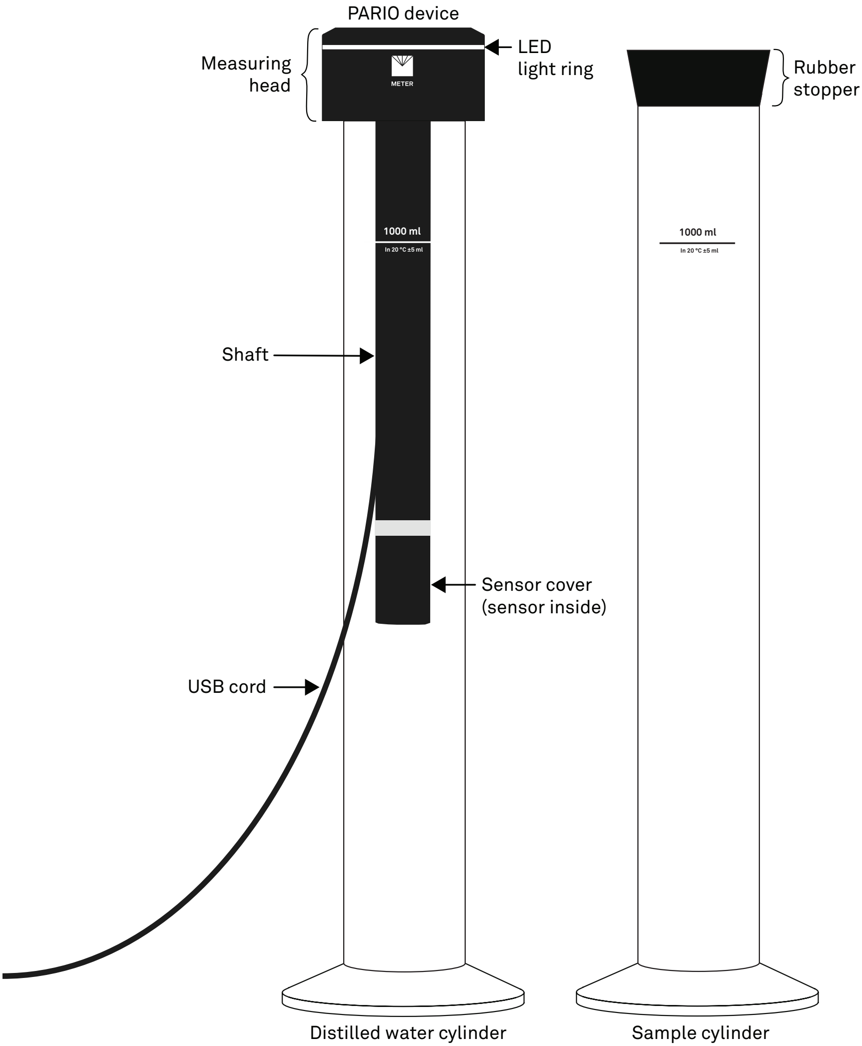

Figure 20 PARIO device

The status of the instrument is indicated by the LED ring on the measuring head.

White flashing three times	PARIO has been detected by the computer.
White permanent	PARIO has been detected by PARIO Control and can be configured for measurement.
White flashing	PARIO is ready for measurement.
Blue slow pulsing	Measurement is in progress.

Blue permanent	Measurement is finished.
Red permanent	Firmware is being updated.
Red flashing	Cylinder or PARIO was bumped or moved. This can also indicate a hardware error. Please contact Customer Support.
No light	PARIO is not connected to or recognized by a computer.

3.3 PARIO CONTROL SOFTWARE

The PARIO Control software is needed for configuration, measurement, and data manipulation. This section describes PARIO Control in detail.

The PARIO Control main screen is divided into five main parts (Figure 21):

- Main menu toolbar (Section 3.3.1)
- Device menu (Section 3.3.2)
- Test status tabs (Section 3.3.3)
- Parameters menu (Section 3.3.4)
- Test output windows (Section 3.3.5)

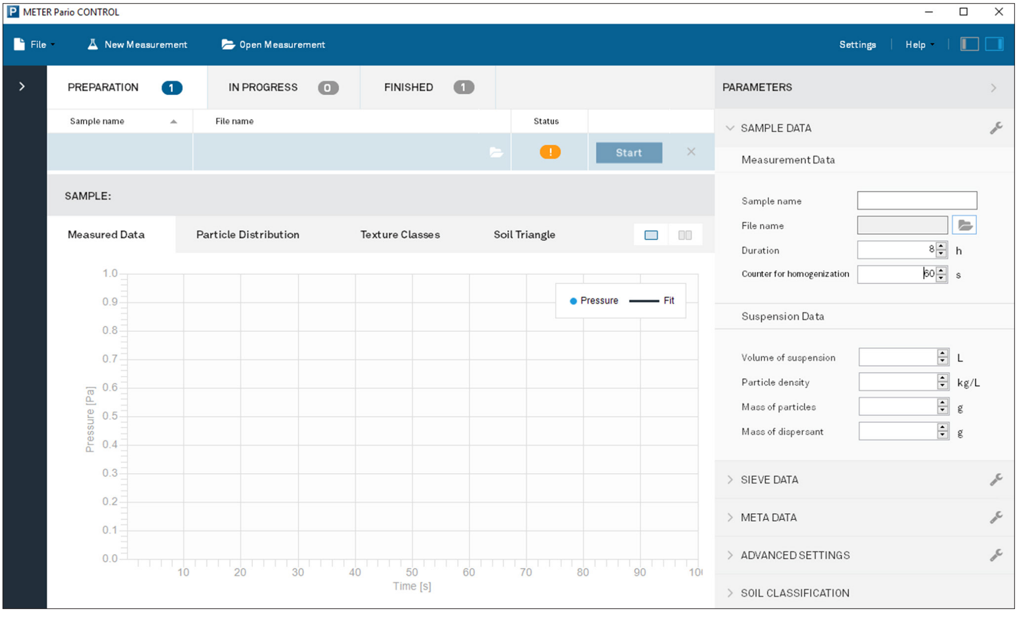

Figure 21 PARIO Control main screen

The main screen also provides access to the Settings window (Section 3.3.6).

3.3.1 MAIN MENU TOOLBAR

The Main menu toolbar contains main actions in the software (Figure 22).

File	Select menu for options to Save, Save All, Save as..., Export selected..., or Quit.
New Measurement	Click to begin a new PARIO measurement. It will populate in the Preparation tab to be configured.
Open Measurement	Click to open a finished measurement file (`.pario`). It will populate in the Finished tab after opening.
Settings	Click to open Settings window (Section 3.3.6).
Help	Click to open the PARIO User Manual or information about the software.
Device menu collapse icon	Collapses the Device menu on the left.
Parameters menu collapse icon	Collapses the Parameters menu on the right.

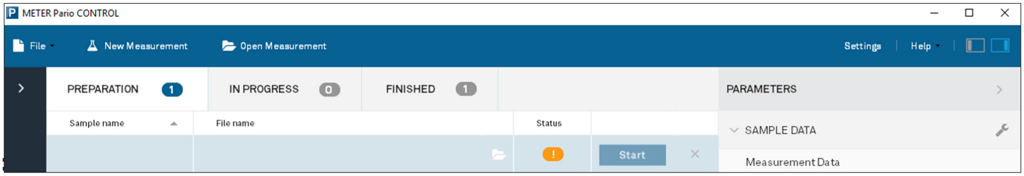

Figure 22 Main menu toolbar

3.3.2 DEVICE MENU

The device menu shows all connected PARIO device serial numbers and their current status (Figure 23). The Device menu can be collapsed or expanded by clicking on the arrow.

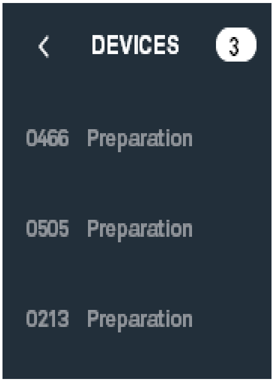

Figure 23 Device menu

3.3.3 TEST STATUS TABS

The test status tabs show all tests for all connected PARIO devices (Figure 24).

Preparation tab	New measurements
Progress tab	Running measurements
Finished tab	Completed measurements

The measurements are automatically moved from tab to tab as the software receives information from PARIO.

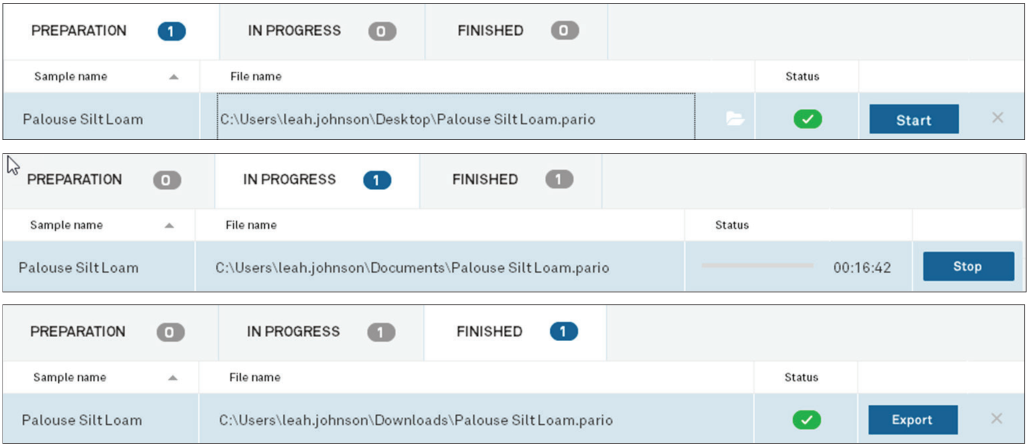

Figure 24 Test status tabs

Right clicking in the Test Status tab also allows the user to close, begin, or open measurements (Figure 25).

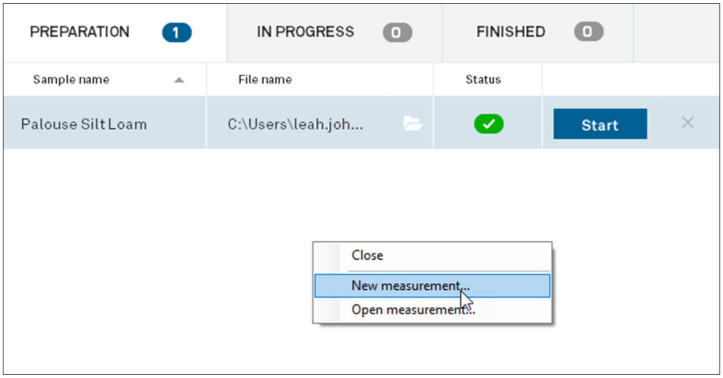

Figure 25 Right click menu in test status area

3.3.4 PARAMETERS MENU

The Parameters menu contains the following subsections (Figure 26):

- Sample Data
- Sieve Data
- Metadata
- Advanced Settings
- Soil Classification

The menu can be collapsed and expanded by clicking on it.

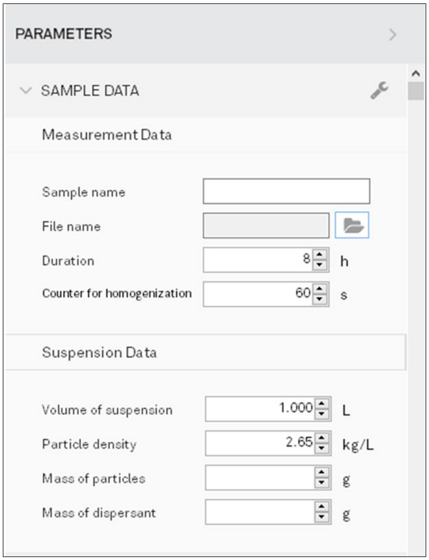

Figure 26 Parameters menu

SAMPLE DATA

The Sample Data subsection will be altered when setting up a new measurement (Section 2.2.2). More in-depth explanations of the fields and the respective defaults are in Section 3.3.6.

Sample name	Name can be anything the user chooses.
File name	Field will be autopopulated.
Duration	Default is 8 h.
Timer for homogenization	Minimum recommendation is 60 s.
Volume of suspension	Default is 1 L.
Particle density	Default is 2.65 g/cm^3.
Mass of particles	The mass of particles is the total oven dry sample mass (24 h at 105 °C) including sand, silt, and clay.
Mass of dispersent	The mass of dispersant in the 1-L suspension.

Clicking on the tool icon in the Sample Data header brings up three options:

Apply default settings	Resets fields to defaults.
Save as default settings	Saves field inputs as new defaults.
Copy to clipboard	Copies data to the computer clipboard.

SIEVE DATA

The Sieve Data subsection is to enter sample sieve data (Section 2.2.3). The values should be entered in percents for the particle size classes. Clicking on the tool icon in the Sieve Data header brings up two options:

Example Sieve Data	Autofills subsection with default example sieve data.
Copy to clipboard	Copies data to the computer clipboard.

METADATA

The Metadata subsection displays the following information:

- Hardware serial number and firmware version
- Software version
- PSDFIT version
- Start of measurement
- Stop of measurement
- Duration of measurement
- Temperature range
- Temperature mean

Edits cannot be made to the information in this section. Clicking on the tool icon in the Metadata header gives the option to copy the information to the clipboard.

ADVANCED SETTINGS

The Advanced Settings subsection allows for changes to PARIO data evaluation and compensation parameters (Figure 27).

IMPORTANT: These settings should only be changed by experienced users.

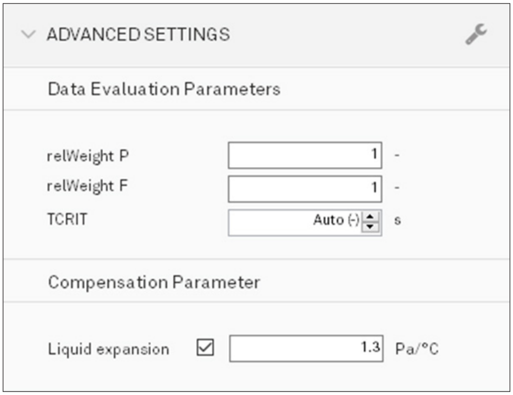

Figure 27 Advanced Settings subsection

relWeight P

Default value is 1.

Relative weight of pressure data class in object function. Values can be arbitrarily increased or decreased, from 0 to 100. Entering 0 means that the pressure data are completely disregarded in the fitting process.

relWeight F

Default value is 1.

Relative weight of sieve data class in object function. Values can be arbitrarily increased or decreased, from 0 to 100. Entering 0 means that the data class is completely disregarded in the fitting process.

In determining the PSD by inverse modeling, deviations between measured and simulated pressure data and between measured and simulated sand fraction data must be simultaneously minimized. The resulting object function that is to be minimized contains this data with different units, magnitude, and number. PARIO uses an internal weighing scheme. The user can modify this default weighing by increasing the importance of pressure data (relWeight P > 1) or the importance of the sand fraction data from sieving (relWeight F > 1). Increasing the weight of one data type may improve the fit to the respective data, but possibly worsen the fit to the other data type.

TCRIT

Default is AUTO.

Time of first data point to be used in the evaluation of the pressure time series.

Normally, PARIO records data beginning at about 20 s. This early pressure decrease is affected by particles of all sizes, including sand particles, which fall very quickly and possibly in a turbulent manner that cannot be described by Stokes's law. Thus, if the sample contains a considerable amount of sand, the very first pressure data should not be used in the PARIO analysis.

Liquid expansion Default is 1.3 Pa/°C.

The temperature during a sedimentation analysis should be kept as constant as possible. However, under some circumstances, moderate temperature drift might occur, which will be recorded by the PARIO. The PARIO pressure sensor is temperature compensated, but different thermal expansion of liquid and solid parts of the experimental setup will cause a temperature drift of the pressure signals. To compensate for thermal expansion, PARIO uses an experimentally determined value of 1.3 Pa/°C (i.e., pressure head change of 0.13 mm/°C).

Clicking on the tool icon in the Advanced Settings header brings up three options:

Apply default settings	Resets fields to defaults.
Save as default settings	Saves field inputs as new defaults.
Copy to clipboard	Copies data to the computer clipboard.

SOIL CLASSIFICATION

The Soil Classification subsection is used to select either the German soil classification KA 5 or USDA classification system.

3.3.5 TEST OUTPUT WINDOWS

PARIO Control provides four test output windows (Figure 28), which can be shown in four tabs or in two side-by-side displays. Double clicking in the data graphs opens the data table. The measurement window can be printed, maximized, or exported.

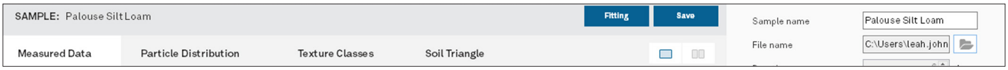

Figure 28 Test output windows

MEASURED DATA

The Measured Data window shows the recorded data of pressure versus time (Figure 29). The pressure axis can be toggled to show temperature axis. The time axis can be switched between linear and logarithmic. Data can be shown either all or in a reduced amount. After fitting the pressure decrease, the fitted line is shown in superposition to the data.

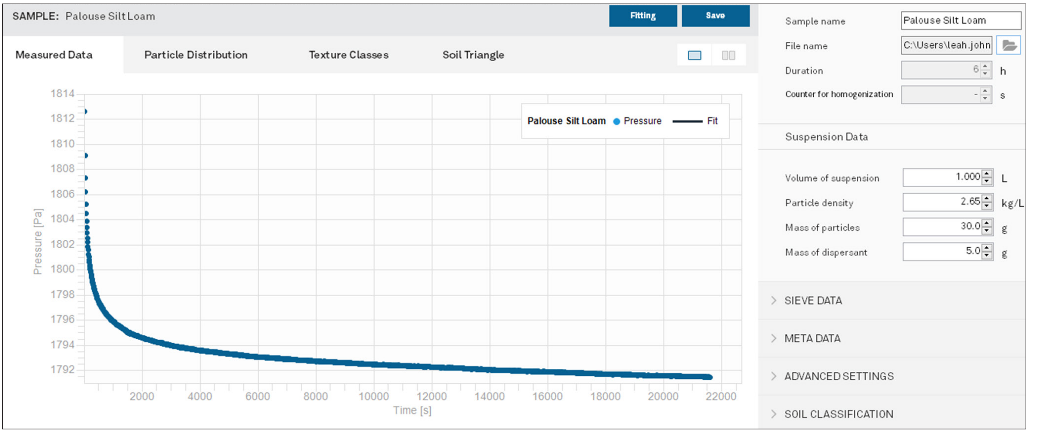

Figure 29 Example Measured Data window

PARTICLE DISTRIBUTION

The Particle Distribution window shows the result of the analysis as cumulative PSD, which is available after fitting the data (Figure 30). This result is dependent on the chosen soil classification.

IMPORTANT: The total cumulative PSD is correct only if the proper sieve fractions were inserted to the respective data window ahead of the fitting and if the inserted mass of dry mineral particles is correct.

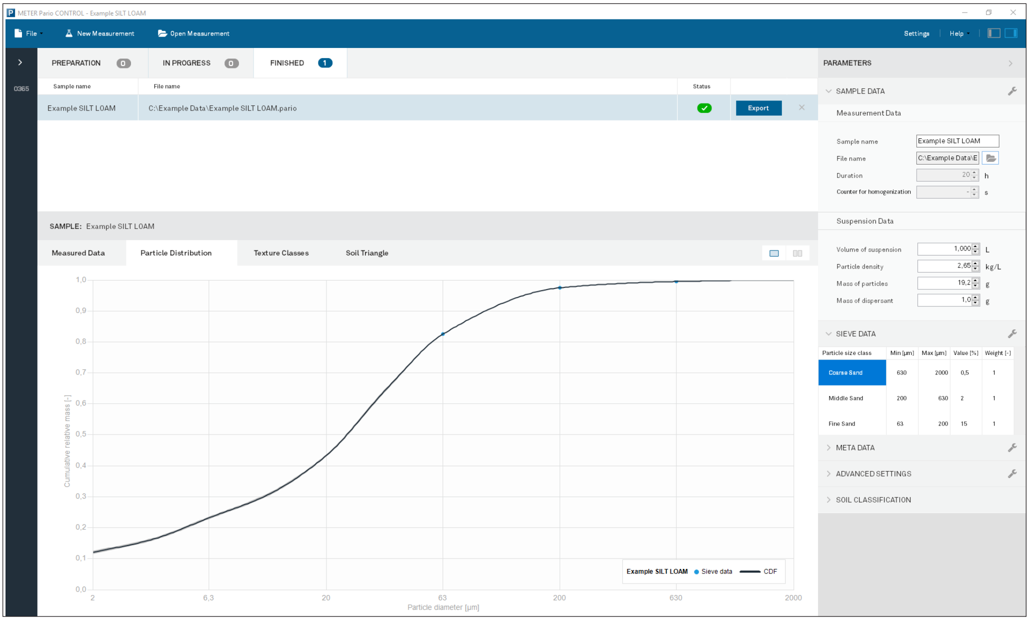

Figure 30 Example PSD window

TEXTURE CLASSES

The Texture Classes window shows the mass fractions as a bar graph with subcategories of clay, fine silt, middle silt, coarse silt, and the entered sand fractions (Figure 31). The last three bars show the added fractions for clay, silt, and sand. The data will depend on the selected classification scheme (Section 3.3.4). This result is dependent on the chosen soil classification.

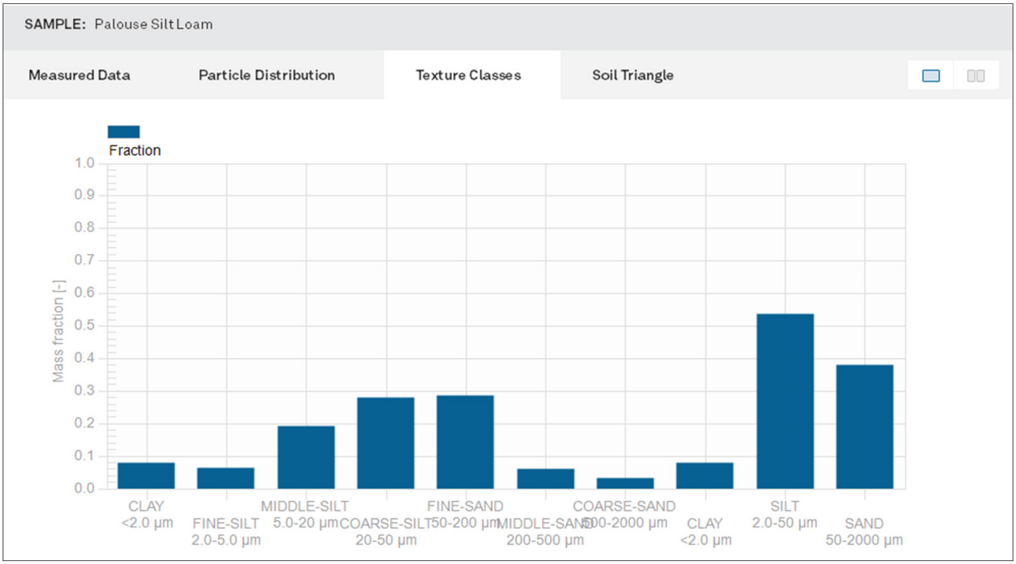

Figure 31 Example Texture Classes window

SOIL TRIANGLE

The Soil Triangle window shows the soil triangle and indicates the resulting soil type by a red dot (Figure 32). The user can switch between the German classification KA 5 (Boden, 2005) and the USDA classification system (Section 3.3.4).

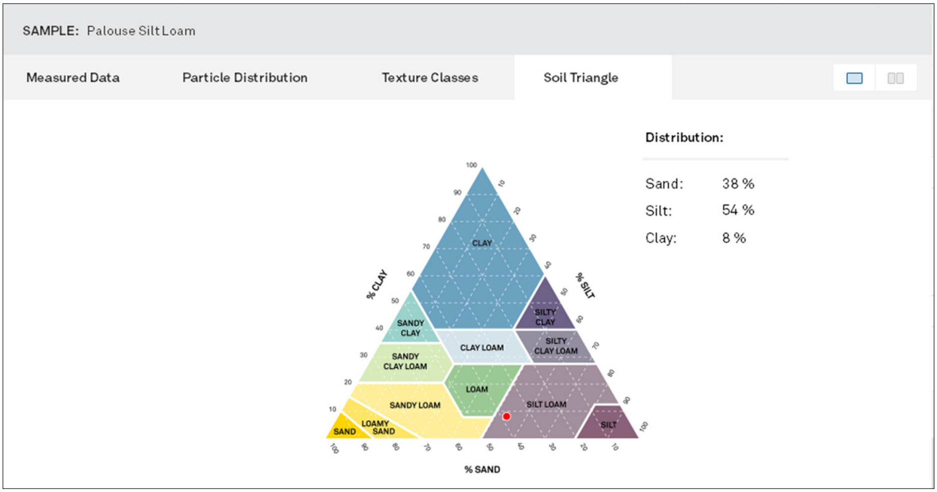

Figure 32 Example Soil Triangle window

3.3.6 SETTINGS WINDOW

The Settings window can be used to set various parameters. The updated parameters will be available for all subsequent individual measurements or can be selected to become defaults.

The settings window is categorized into three sections:

- General
- Default Parameters
- Sieve Data

GENERAL

The General settings are subdivided into Reports and Files (Figure 33).

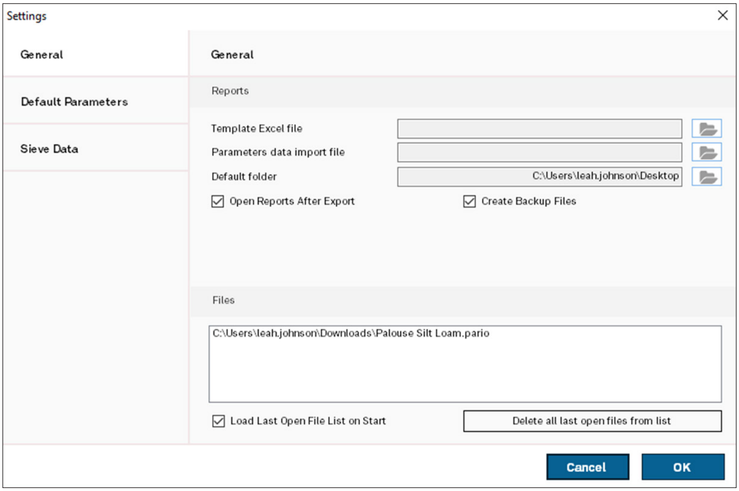

Figure 33 General settings

Template Excel file	Import a custom Excel file (`.xlsx`). The PARIO data and evaluation will then be exported in the selected template. **NOTE: Expert use only.**
Parameters data import file	Import a user-generated Excel file (`.xlsx`) including the sieve data. **NOTE: Expert use only.**
Default Folder	Select the saving location of the `.pario` file.
Open Reports After Export	Click the checkbox to automatically open reports in Microsoft Excel.

Create Backup Files — Click the checkbox to generate a backup file. The backup file will be saved in the same folder as the measurement file.

Load Last Open File List on Start — Click the checkbox to reopen all measurements that were last open when starting the software.

Delete all last open files from list — Click to delete the listed files.

DEFAULT PARAMETERS

The Default Parameters settings (Figure 34) allow the user to create new defaults for the Parameters menu (Section 3.3.4).

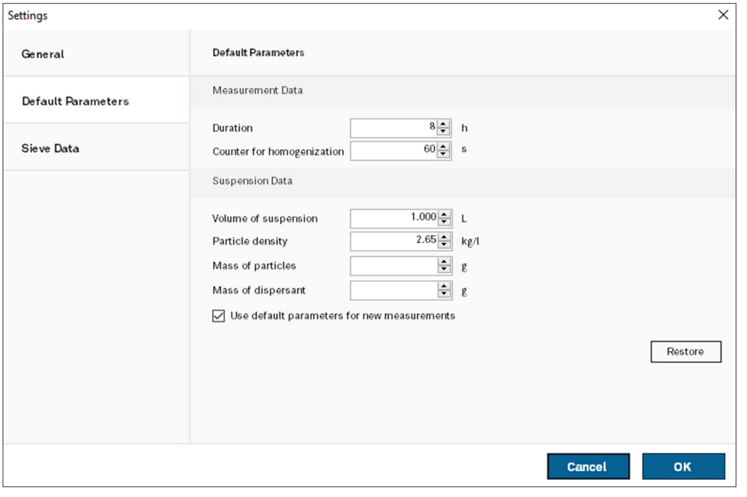

Figure 34 Default Parameters settings

Duration

Default is 8 h.

The identified PSD depends on the duration of the experiment. The uncertainty of the PSD is very small (down to approximately D = 2 μm) for a duration of 8 h. At that time, particles of 2 μm have reached a settling depth of about 10 cm and can be measured with the ISP method.

The influence of measurement time on the identification of the small particles is illustrated in Figure 35. As expected from the quadratic relationship between particle diameter and settling velocity, a shortening of the duration of the experiment down to 2 h (reduction by a factor of 3), shifts the lower limit of identification by a factor of √3 toward larger particles.

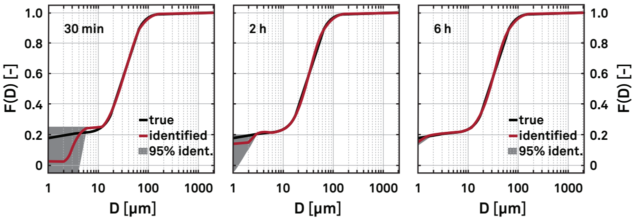

Figure 35 Uncertainties in the identification of the PSD due to reduced measurement times after 30 min, 2 h, and 6 h, respectively (Durner, Iden, and von Unold 2016)

The same holds for further shortening the duration to 30 min. In addition to the uncertainties of the identified cumulative PSD distribution functions, the error in the estimated silt fraction caused by a shortening of the experiment can be considered. An experiment with a settling time of 30 min leads to a mean identification error of 8.5% and a maximum error of 18.7%, which is not acceptable. However, after 2 h, the mean deviation (MD) and root-mean square deviation (RMSD) are quite moderate (0.4% and 1.4%, respectively).

Running the experiment for 8 h reduces the mean error to a value close to 0, and the RMSD to 0.6%. These values are comparable to the reference scenario with a sedimentation time of 24 h and show that the experiment can, in practice, be finished within 8 h, or within a regular lab day (Durner, Iden, and von Unold 2016).

The measuring time can be increased to 12 h if a second start of the measurement is not needed.

Timer for homogenization

Recommended time is 60 s.

The time for homogenization has to be adapted to the respective circumstances. A complete homogenization of the suspension must be ensured.

When the suspension is left to rest in the cylinder for a long period of time, some of the particles will settle completely and may stick to the bottom of the cylinder. In that case, the soil has to be removed completely from the bottom of the cylinder before starting the timer.

Volume of suspension

Recommended option is 1 L.

A 1-L suspension volume is recommended (DIN 2002; DIN 2011; ASTM 2007; ASTM 2017; ÖNORM 2002).

Particle density

Default is 2.65 g/cm³.

The default value refers to the particle density of quartz. Quartz is a dominant mineral in many soils and its density does not deviate considerably from other common minerals in soils. For nontypical soils (for example, soils with allophane as the dominant mineral), a different value for particle density can be entered.

Total dry weight

This value will be filled in per test. A default can be created by the user.

The mass of particles refers to the total oven dry sample mass (24 h at 105 °C), including sand, silt, and clay.

The mass of particles entered for evaluation can be calculated by

- determining the water content with a Pretest sample (step 6, Section 2.2.1.1) and
- calculating the oven dry weight of the PARIO measurement sample (step 7, Section 2.2.1.2).

Mass of dispersant

This value will be filled in per test. A default can be created by the user.

The mass of dispersant in the 1-L suspension, depending on the manufacturing process, has to be entered. The dispersion mass is coming from adding a certain volume of dispersants solution to the soil. For example, if the dispersant solution = 40 g/L and the added dispersant volume = 25 ml, then the total dispersant in suspension = 40 g/L × 0.025 L = 1.0 g. Typical values are 0.7 to 1.4 g.

Use default parameters for new measurements

Click the checkbox to override defaults with new values.

Restore

Remove all manually entered values and reset the default values.

SIEVE DATA

The Sieve Data settings allow the user to edit, create, or import a sieve data template (Figure 36).

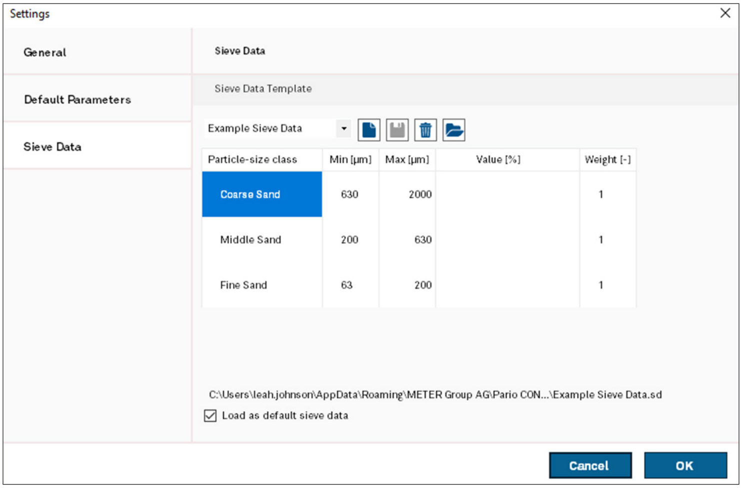

Figure 36 Sieve Data settings

The Example Sieve Data option sets the particle size classes in Table 4.

Table 4 Particle size classes

Sand Type	German Soil Mapping Guideline KA 5	USDA Classification System
Fine	63–200	50–250
Middle	200–630	250–500
Coarse	630–2,000	500–2,000

Particle size classes can also be added or deleted, and the minimum and maximum diameters of the chosen particle size classes can be defined. These changes can be saved as a new sieve data template.

METER recommends using at least three sand subclasses (coarse, middle, and fine). If it is desired, other classes can be added by the user (e.g., splitting the fine sand fraction or lowering the limit of the finest sieved particles to 50 µm). Also, the determined values in percent can be entered here and used as default for other measurements. The weights of sieve data class can be arbitrarily increased or decreased, from 0 to 100. Entering 0 means that the data class is completely disregarded in the fitting process. Increasing the weight of one data type may improve the fit to the respective data, but possibly worsen the fit to the other data type.

3.4 THEORY

PARIO is an automated system for PSA of soils. Soil is subdivided into fine soil (<2,000 µm) and gravel (>2,000 µm). Fine soil is further subdivided into sand, silt, and loam. The limits of the particle fractions are defined by equivalent diameters of the particles, which vary depending on national classification systems (Hartge and Horn 2014). PARIO Control uses the German soil mapping guideline KA 5 or the USDA classification system for the analysis (Table 5).

Table 5 Soil particle classification systems (Hartge and Horn 2014)

Particle Fraction	German Soil Mapping Guideline KA 5	USDA Classification System
Sand	63–2,000	50–2,000
Silt	2–63	2–50
Clay	<2	<2

The PSD of silt fraction (2 to 63/50 µm) is obtained by the sedimentation method, which identifies silt fractions with hydrodynamic diameters between 63/50 µm (upper size limit) and 2 µm (lower size limit) (Section 3.4.1). The PSD for sand fractions is provided by external wet sieve analysis (Section 2.2.3). The clay fraction is calculated by PARIO Control, subtracting the externally measured sand and silt fractions from the total amount of material used in the analysis.

3.4.1 MEASUREMENT PRINCIPLE

PARIO uses the ISP method to derive the PSD from the pressure decrease at a measuring depth in a suspension. The theory of the method is published by Durner, Iden, and von Unold (2016) and is based on Stokes's law. Stokes's law indicates that particles of spherical shape settle in a suspension with a characteristic velocity, which is determined by the fluid viscosity, the density difference between the particle material and the suspension fluid, and the diameter of the particle. The computation equations are only valid for a laminar settling of the particles, as this is assumed for Stokes´s law. The sedimentation methodology follows the requirements of DIN ISO 11277 (DIN 2002), ISO 13317 (ISO 2001), and ASTM D422-63 (ASTM 2007).

The preparation of the suspension involves destruction of organic matter and binding agents as well as dispersion of the material (Section 2.2.1). Users should refer to the respective operation protocols that are described in textbooks (e.g., Tan 2005), methods monographs (e.g., Gee and Or 2002), or normative documents (e.g., ISO 2001; ASTM 2007).

3.4.2 EFFECTS OF TEMPERATURE

The viscosity of water is highly temperature dependent. Dynamic viscosity can be approximated by the function $y = 0.0007T^2 - 0.0531T + 1.764$ ($r^2 = 0.9996$), where T is given in degrees Celsius. Table 6 lists some characteristic values of the viscosity at various temperatures.

Table 6 Characteristic values of water viscosity at various temperatures

Temperature (°C)	5	10	15	20	25
Dynamic viscosity of water (mPa·s) at 1 bar	1.518	1.306	1.137	1.001	0.894

PARIO Control records the temperature during a run and calculates the mean temperature from it. Settling velocity is calculated for a constant particle density of 2.65 g/cm³ and a viscosity and density of water that is temperature-dependent.

3.4.3 EFFECTS OF GAS BUBBLES

Gas bubbles may occur when the water in the suspension is not equilibrated with the ambient air temperature. Gas bubbles at the pressure transducer will affect its reading, and air bubbles that stick to liquid–solid interfaces may lead to bias in the weight of the water column above the measuring depth.

To avoid gas bubble formation, use slightly degassed water (e.g., by heating the deionized water prior to its use in preparing the suspension).

3.4.4 SAMPLE PRETREATMENT AND DISPERSION CONSIDERATIONS

For the measurements from the PARIO to be accurate, pretreatment of the soil samples is required. Pretreatment enhances the separation or dispersion of aggregates and is key for any particle-size analysis (PSA) measurement. Soils typically contain organic matter and, in some cases, iron oxides that cause the soil particles to bind together.

The methods presented in this manual refer primarily to the German standard DIN ISO 11277 (DIN 2002) and *Methods of Soil Analysis Part 4—Physical Methods* (Gee and Or 2002). There are many other common and valid standards that can also be used (e.g., ASTM D7928) as well as chemical and physical pretreatment methods. For more details on the outlined steps, refer to the individual methods.

Sample preparation requires the same steps as the preparation for the hydrometer or the pipette method. Generally, it is the user's decision how to disperse soil samples, destroy binding materials, and remove organic matter. Typical procedures are described in the respective steps in Section 2.2 and may differ from discipline to discipline and country to country.

For more details on the outlined steps as well as the METER recommended sequence of the single steps, visualized in a flow chart, refer to Section 2.2.

3.4.4.1 ORGANIC MATTER REMOVAL

Removing organic matter from a soil sample is often one of the first pretreatment steps. The decision to remove the organic matter from the sample depends on the intended use of the analytical results of the PSA. A good rule of thumb is to remove organic matter if the organic matter is >1.5% of the total sample.

If the organic matter will be destroyed for the measurement sample, refer to Section 2.2.1.1.

3.4.4.2 SOLUBLE SALTS AND PLASTERS REMOVAL

A variety of soluble salts is commonly found in alkaline soils. Alkaline salts decrease the effectiveness of soil organic removal by decomposing hydrogen peroxide (H_2O_2), decreasing its effectiveness as a decomposing agent. Typically, if the extract electrical conductivity (EC) is >0.4 dS/m, METER recommends removing the salts. However, the decision to remove soluble salts and plaster is optional and up to the user (DIN 2002; Gee and Or 2002).

If soluble salts and plasters are to be removed from the measurement sample, refer to Appendix B.

3.4.4.3 IRON OXIDE REMOVAL

Iron oxide coatings often act as cementing and binding agents in soils. To properly disperse the silicate portion of soil, it may be necessary to remove these cementing agents. The decision to remove iron oxides is optional and up to the user (DIN 2002; Gee and Or 2002).

If iron oxides will be removed from the measurement sample, refer to Appendix B.

3.4.4.4 SAMPLE DISPERSION

There are many methods for dispersing soil aggregates. Chemical dispersion is achieved through the process of particle repulsion through the elevation of the particle electrokinetic potential (Soil Science Society of America, 1996). This process is typically achieved by saturating the exchange complex with sodium (Na). Physical dispersion involves the separation of the individual soil particles by a mechanical or physical process. Sample dispersion is the last step done on a sample prior to PSA. Soil samples should be chemically and physically dispersed.

Please refer to step 11, Section 2.2.1.1 for recommended working steps (Option 1 [DIN 2002] and Option 2 [Gee and Or 2002]).

4. SERVICE

This section describes the calibration and maintenance of the PARIO. Troubleshooting solutions and customer service information are also provided.

4.1 CALIBRATION

Each PARIO device is temperature and pressure calibrated after manufacturing. METER recommends sending the device for calibration verification every 2 years. In case of conspicuous errors, PARIO Control will give a warning message to send the PARIO back for an inspection by METER.

4.2 MAINTENANCE AND STORAGE

To clean the exterior of the PARIO, wipe it with a damp cloth. Avoid leaving pools of water on the device as this will lead to salt precipitates. If fine soil and sand grains are deposited in the socket and settle into the base at the end of a measurement, clean the entire base under a gentle spray of water. The pressure transducer of PARIO is ultra-sensitive, so avoid contact with hard, sharp objects or a strong water jet.

For short-term storage, METER strongly recommends placing the PARIO device in a PARIO cylinder that contains 1 L of degassed distilled water, equilibrated to the room temperature at all times.

For long-term storage, METER recommends rinsing all parts of the device with distilled water to remove soil particles and prevent the formation of algae. Store the device in a dry state.

IMPORTANT: Never touch the pressure sensor, which is shielded at the tip of the shaft.

4.3 TROUBLESHOOTING

Table 7 lists common problems and their solutions. If the problem is not listed or these solutions do not solve the issue, contact Accessory Part Numbers.

Table 7 Troubleshooting the PARIO

Problem	Possible Solutions
PARIO does not flash three times when connected or Computer does not recognize the device	Disconnect and reconnect the USB. Check the computer Device Manager to see if the PARIO USB driver is installed correctly. Reinstall the PARIO USB driver, if necessary. Restart the PARIO Control software. Check that the USB hub has sufficient power.

Table 4 Troubleshooting the PARIO (continued)

Problem	Possible Solutions
Start of measurement was not recognized automatically by inserting PARIO into the cylinder	Close the countdown window. Place the device back into the distilled water cylinder. Unplug and replug the USB into the computer. Press `Start` and homogenize the sample again.
Computer goes into standby mode and interrupts measurement	Deactivate the standby mode in the computer settings and start measurement again.

4.4 ACCESSORY PART NUMBERS

Accessory	Part Number
PARIO plug	020651
PARIO glass sample cylinder	020650

4.5 CUSTOMER SUPPORT

NORTH AMERICA

Customer service representatives are available for questions, problems, or feedback Monday through Friday, 7:00 am to 5:00 pm Pacific time.

Email: support.environment@metergroup.com
sales.environment@metergroup.com

Phone: +1.509.332.5600

Fax: +1.509.332.5158

Website: metergroup.com

EUROPE

Customer service representatives are available for questions, problems, or feedback Monday through Friday, 8:00 to 17:00 Central European time.

Email: support@metergroup.de
sales@metergroup.de

Phone: +49 89 12 66 52 47

Fax: +49 89 12 66 52 36

Website: metergroup.de

If contacting METER by email, please include the following information:

Name	Email address
Address	Instrument serial number
Phone	Description of the problem

NOTE: For products purchased through a distributor, please contact the distributor directly for assistance.

4.6 TERMS AND CONDITIONS

By using METER instruments and documentation, you agree to abide by the METER Group, Inc. USA Terms and Conditions. Please refer to metergroup.com/terms-conditions for details.

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APPENDIX A. EXAMPLE MEASUREMENT RESULTS

A.1 EXAMPLE SILT LOAM

Figure A.1 through Figure A.4 show a typical measurement of silt loam sedimentation.

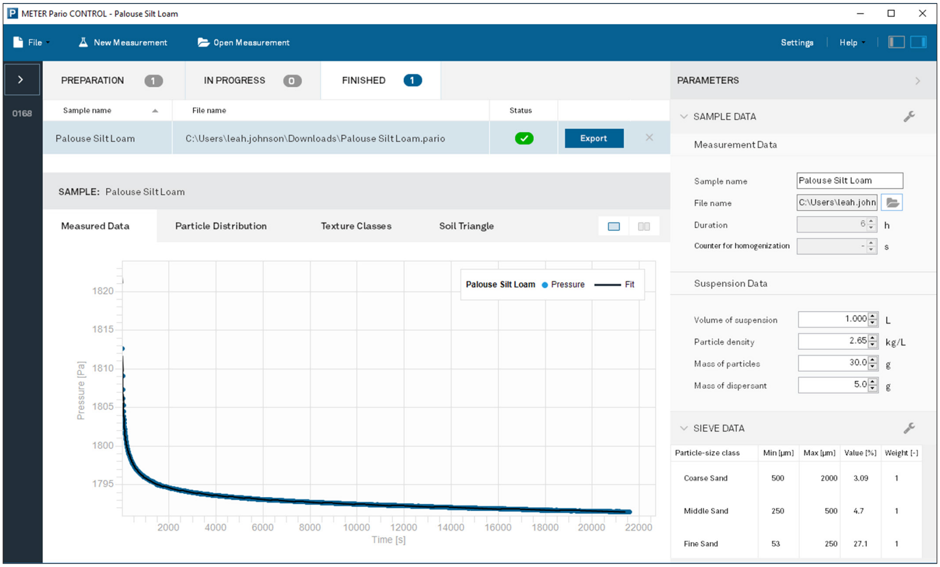

Figure A.1 Example silt loam measured data results

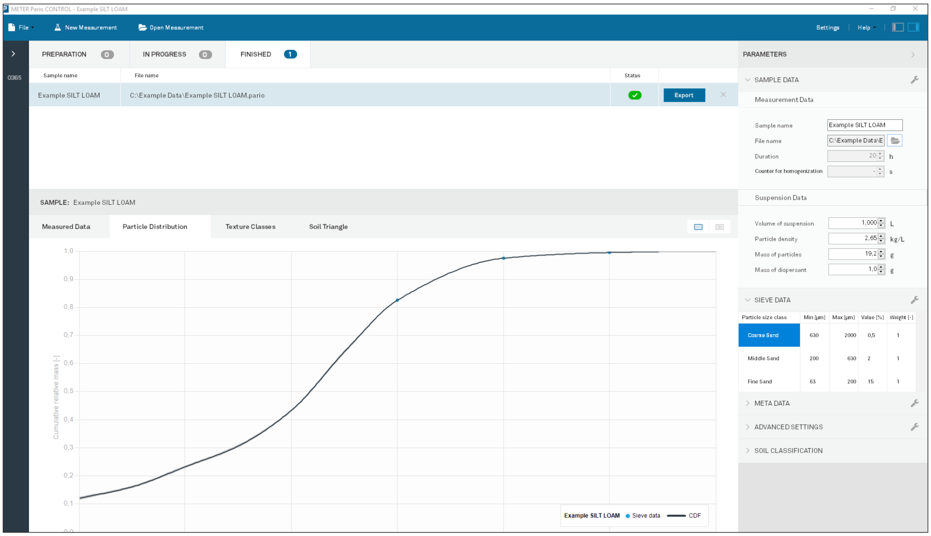

Figure A.2 Example silt loam particle distribution results

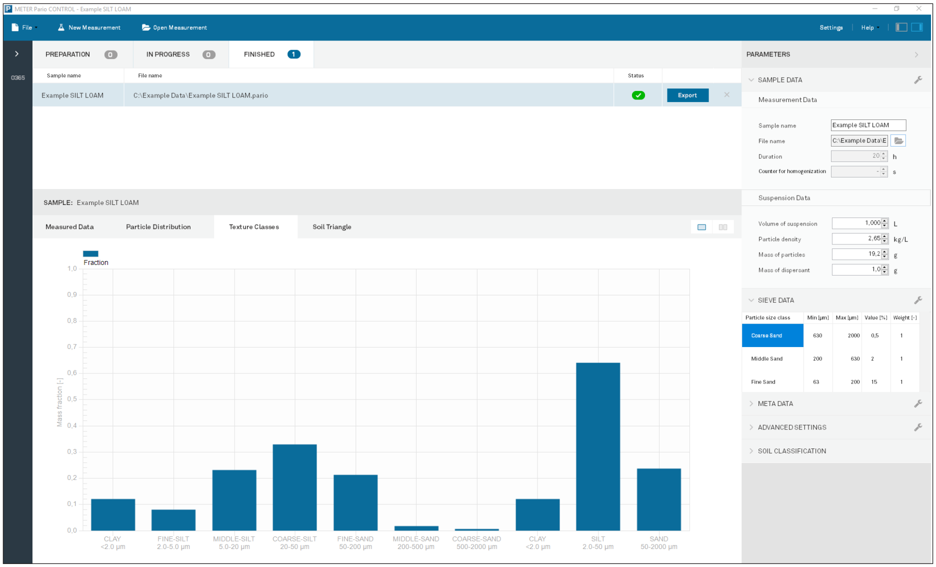

Figure A.3 Example silt loam texture classes results

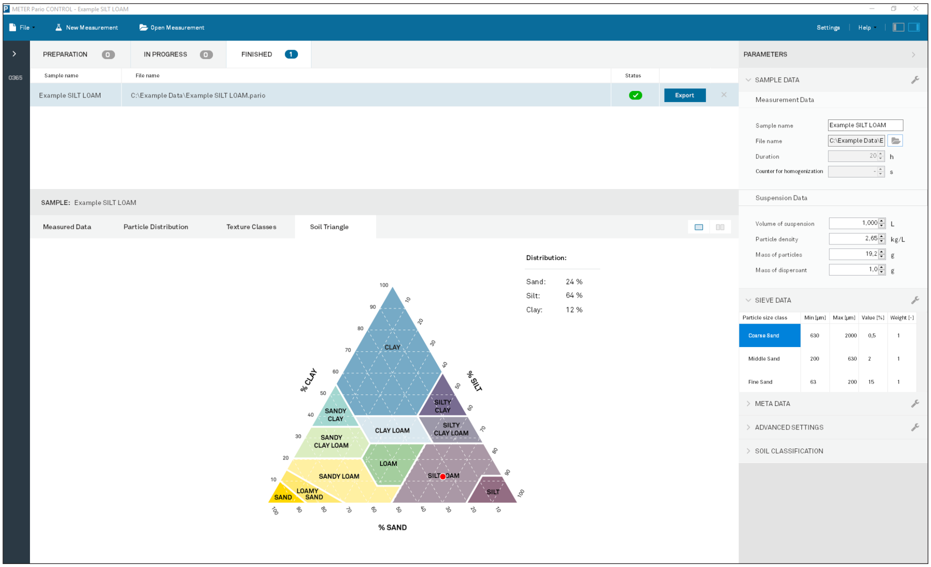

Figure A.4 Example silt loam soil triangle results

A.2 EXAMPLE LOAM

Figure A.5 through Figure A.8 show a typical measurement of silt loam sedimentation.

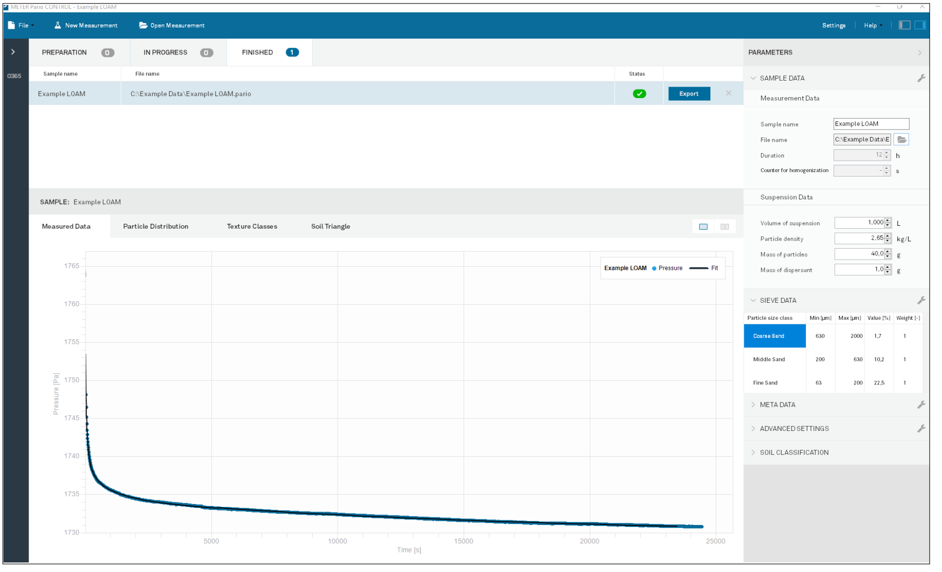

Figure A.5 Example loam measured data results

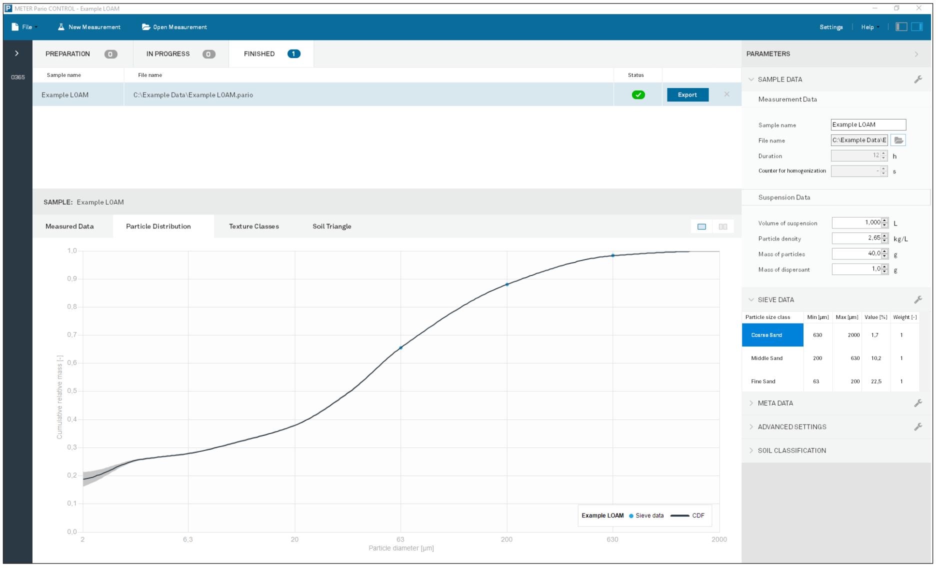

Figure A.6 Example loam particle distribution results

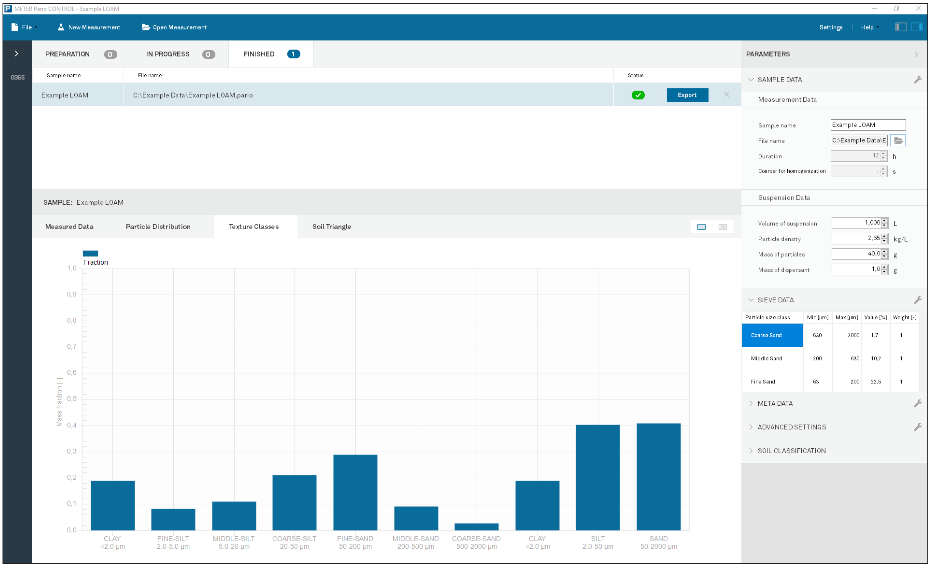

Figure A.7 Example loam texture classes results

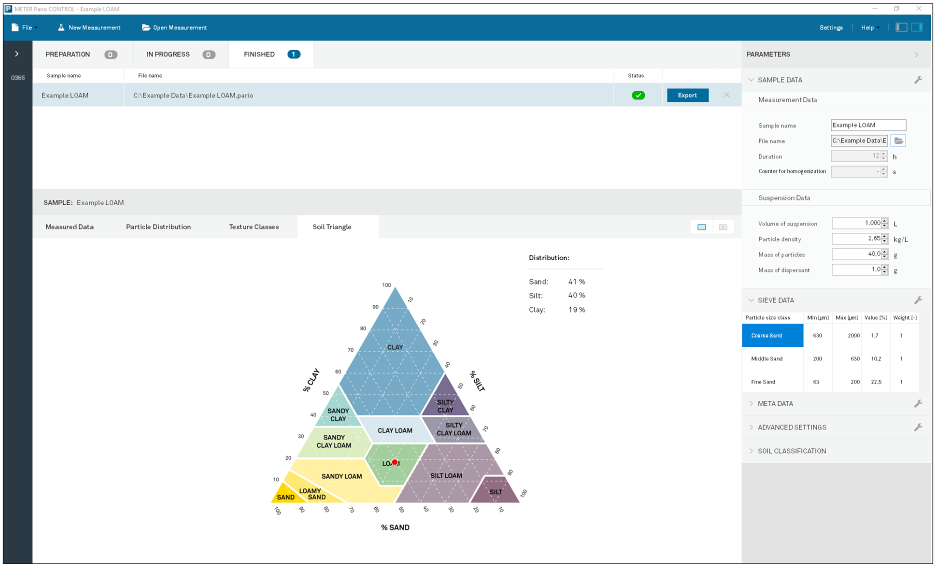

Figure A.8 Example loam soil triangle results

A.3 EXAMPLE SILTY CLAY

Figure A.9 through Figure A.12 how a typical measurement of silty clay sedimentation.

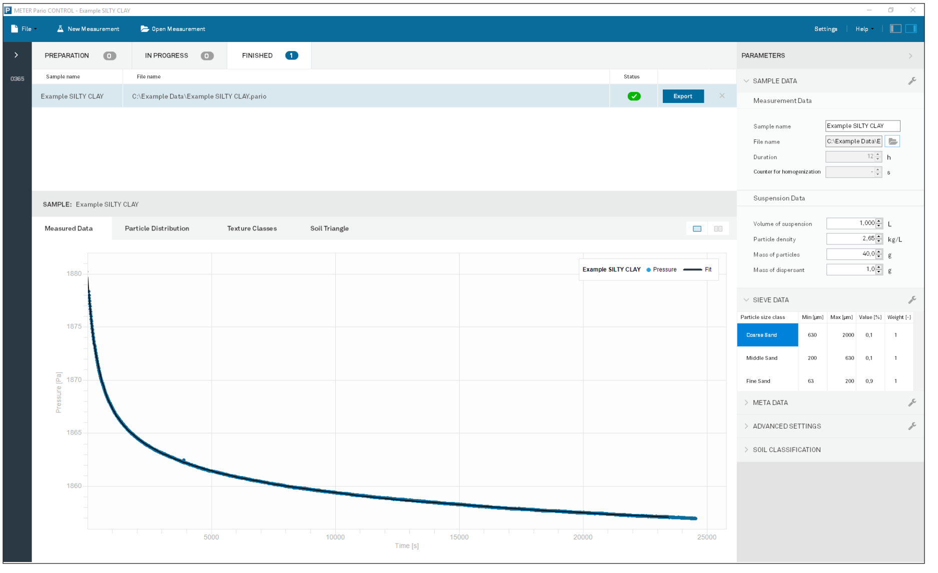

Figure A.9 Example silty clay measured data results

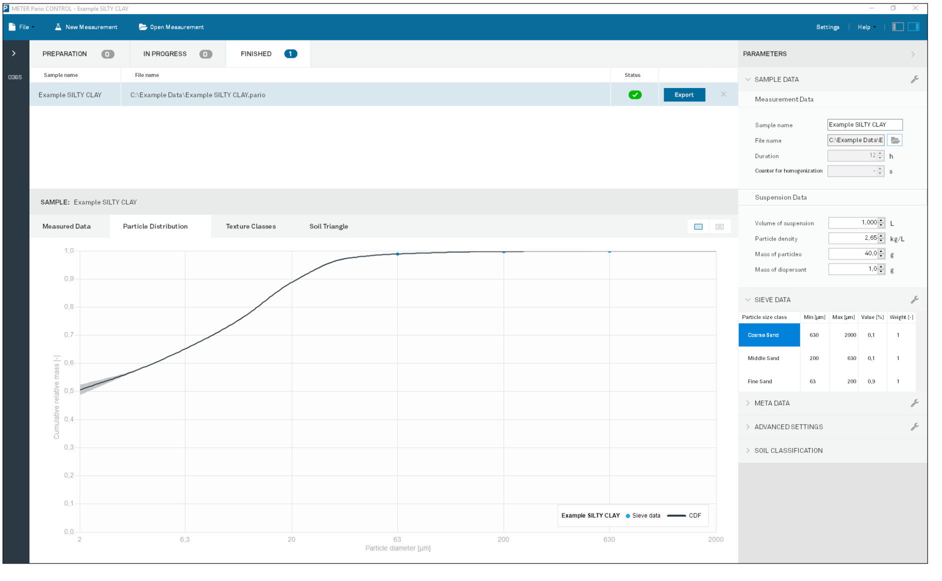

Figure A.10 Example silty clay particle distribution results

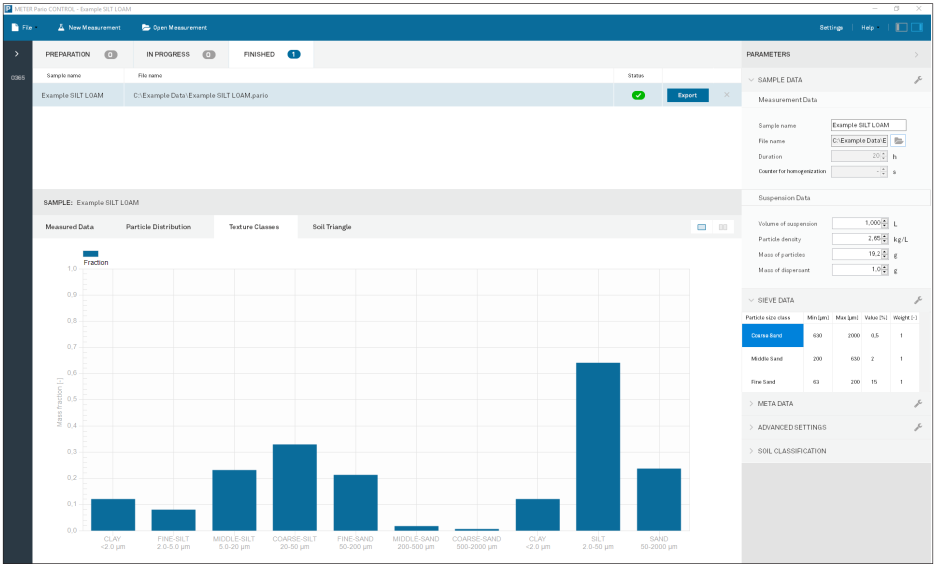

Figure A.11 Example silty clay texture classes results

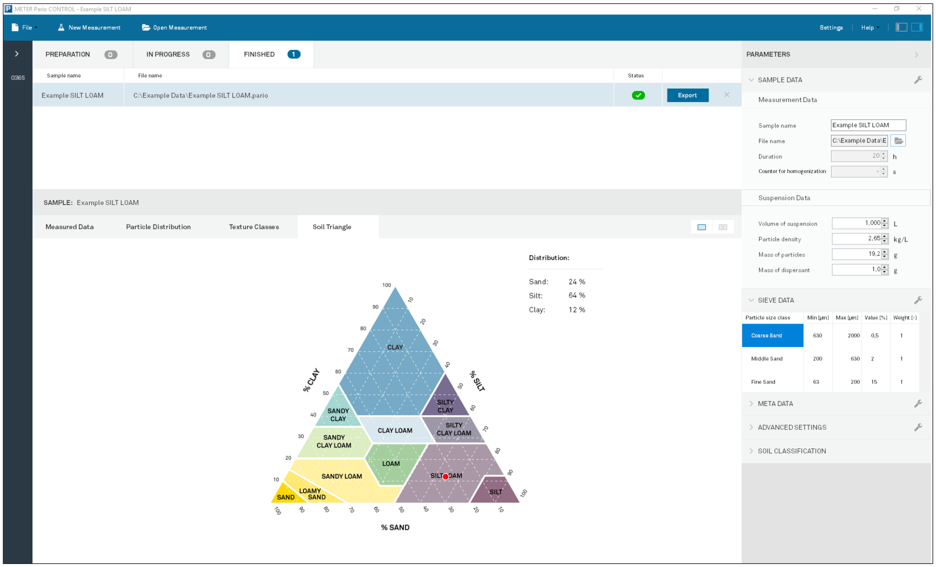

Figure A.12 Example silty clay soil triangle results

A.4 EXAMPLE SAND

Figure A.13 through Figure A.16 show a typical measurement of sand sedimentation.

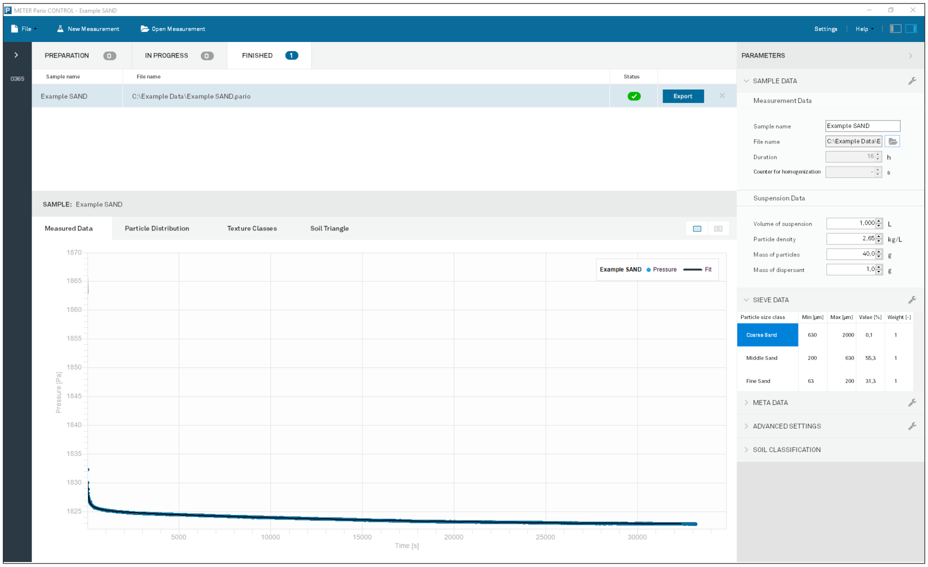

Figure A.13 Example sand measured data results

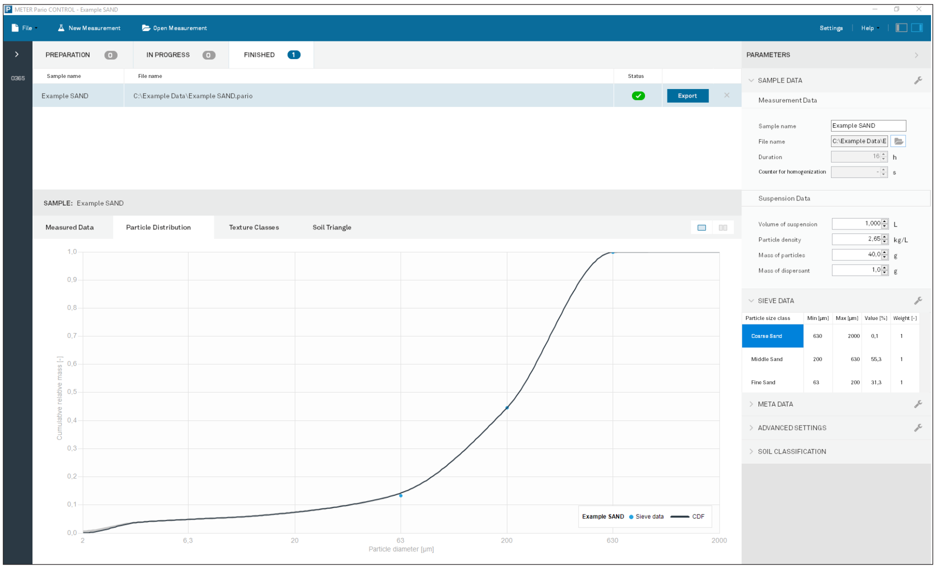

Figure A.14 Example sand particle distribution results

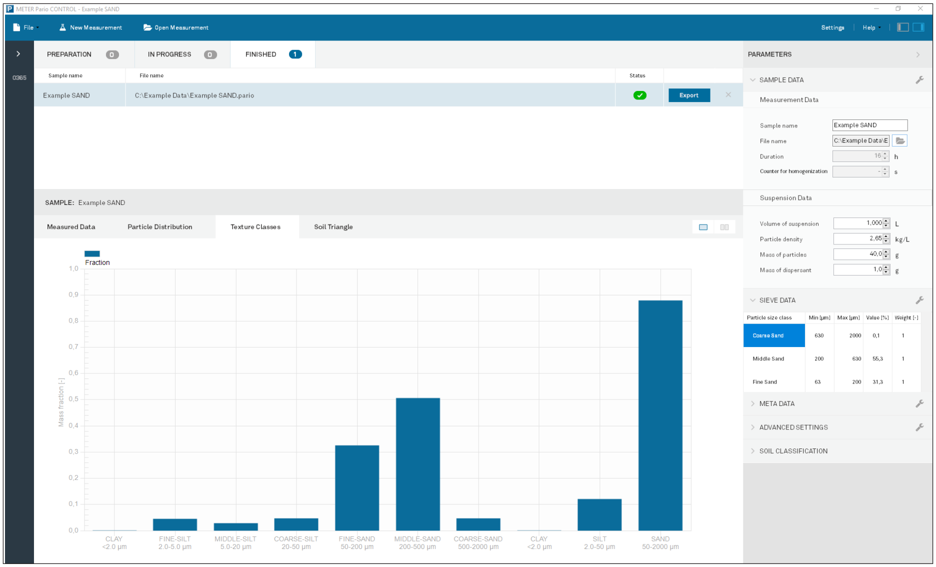

Figure A.15 Example sand texture classes results

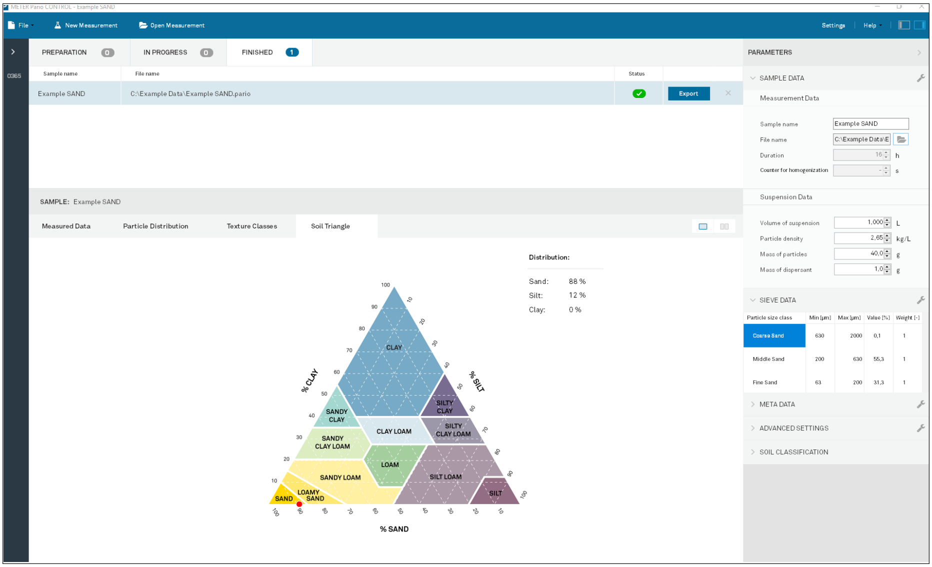

Figure A.16 Example sand soil triangle results

APPENDIX B. NONTYPICAL SOIL PRETREATMENTS

In some cases, additional pretreatment of the soil prior to analysis with the PARIO may be required.

B.1 SOLUBLE SALTS AND PLASTERS REMOVAL

It is typically recommended to remove soluble salts and plasters if the saturated soil sample extract electrical conductivity (EC) is >0.4 dS/m. There are multiple methods available for measuring the EC of the sample. A saturated extract EC is one of the simple approaches to determining the sample EC (Rhoades 1996).

If the EC is >0.4 dS/m, proceed to step 1 below and remove soluble salts and plasters in the Pretest soil sample and PARIO measurement sample using either OPTION 1 (DIN 2002) or OPTION 2 (Gee and Or 2002).

If the EC is less than 0.4 dS/m, no removal is necessary.

Step	Equipment Needed
1. Determine if EC is > or < 0.4 dS/m.	device for measuring EC
2. Remove Soluble Salts and Plasters Below are two different options for removing soluble salts and plasters from soil. The methods chosen may vary depending on the equipment available in the lab and the standards followed. **OPTION 1 (DIN 2002)** a. Transfer sample after organic matter removal (step 8, Section 2.2.1.2) to a 1.5-L bottle. b. Add distilled water to the bottle until the ratio of soil to water is 1:4 or 1:6, according to the percentage of soluble components. c. Close the bottle and shake until everything is in suspension. d. Place on an overend shaker or alternative piece of equipment and shake the bottle for another hour. **NOTE: Use a vibration blade agitator if no overend shaker is available. Mixing agitators should not be used as they could crush the primary particles.** e. Put the closed bottle on a centrifuge for 1 h until the supernatant is clear. f. Measure the EC of the clear supernatant. If the EC is >0.4 dS/m, decant the supernatant liquid. g. Open the bottle, add 250 mL of distilled water, and close the bottle.	centrifuge device for measuring EC

Step	Equipment Needed
h. Put the closed bottle on an overend shaker or alternative equipment and shake for 1 h. i. Remove the bottle from the shaker. j. Put the bottle on a centrifuge and run until the supernatant is clear. k. Repeat this procedure (step e through step j) until the EC of the liquid is <0.4 dS/m. l. Finally decant the supernatant liquid.	
OPTION 2 (Gee and Or 2002) a. Place filter paper (e.g., Whatman #4) in a Büchner funnel or standard funnel large enough to hold the sample and water. b. Transfer the soil sample after organic matter removal (step 8, Section 2.2.1.2) to the filter paper using a wash bottle with deionized water. c. Fill the funnel with deionized water and let drain. Do not let the water rise above the filter paper. Repeat 3 or 4 times. d. Check the EC of the extracted water. Repeat step c until the EC is <0.4 dS/m.	distilled water filter paper funnel

B.2 IRON OXIDE REMOVAL

Iron oxide coatings often act as cementing and binding agents in soils. To properly disperse the silicate portion of soil, it may be necessary to remove these cementing agents. The decision to remove iron oxides is optional and up to the user (DIN 2002; Gee and Or 2002).

Steps	Equipment Needed
Below are recommended steps for removing iron oxides from the soil sample. **WARNING: Read the respective safety data sheets for solids and chemicals carefully and follow them strictly.** a. Use approximately 0.3 mol/L sodium acetate (NaOAc) solution, buffered with acetic acid (AcOH) to pH 3.8. b. Add 40 g/L $Na_2S_2O_4$ to the buffered solution. c. Add the mixture to the sample until the ratio of soil to solution is 1:40. d. Place sample in 1.5-L/1-L shaker bottle. Place 1.5-L/1-L shaker bottle on reciprocating shaker.	sodium acetate solution (NaOAc) acetic acid (AcOH) sodium dithionite ($Na_2S_2O_4$) centrifuge

Steps	Equipment Needed
e. Shake the soil overnight.	
f. The following day, shake the suspension on a centrifuge until the supernatant is clear.	
g. Decant the clear liquid.	
h. Collect waste separately.	
i. Add distilled water, stir and allow the sample to settle again.	
j. Discard the supernatant again.	
k. Repeat these steps until the supernatant is clear.	

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