DANMARKS OG GRØNLANDS GEOLOGISKE UNDERSØGELSE RAPPORT 2012/26

# Completion report Billegrav-2 well (DGU 248.61) southern Bornholm

## Part 5: Fracture descriptions and mineralogical analysis

Peter Roll Jakobsen & Niels H. Schovsbo

GEOLOGICAL SURVEY OF DENMARK AND GREENLAND
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GEUS

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# 1. Introduction

The well 'DGU 248.61' (informally referred to as the Billegrav-2 well) was drilled as part of a shallow drilling campaign conducted by GEUS on southern Bornholm in August 2010 (Figure 1). The aim was to obtain fresh core material for stratigraphical and geochemical studies of the Lower Palaeozoic shales (Schovsbo et al. 2011).

This report is part of a study program on the Billegrav-2 well and summarizes the description of fractures and the mineralogical screening made on the core. Other reports related to the Billegrav-2 well are: 'Results of down hole logs and core scanning' (Schovsbo 2011a), 'Review of the Billegrav-1 and Skelbro-1 wells' (Schovsbo 2011b), 'Results of core plug analysis' (Schovsbo 2012) and 'Lithological and stratigraphical description including geochemical analysis' (Nielsen & Schovsbo 2012).

The data in this report includes: fracture analysis and description, fracture intensity log, quantitative quartz measurements and XRD based semi-quantitative mineralogical screening. All data is included on the attached CD.

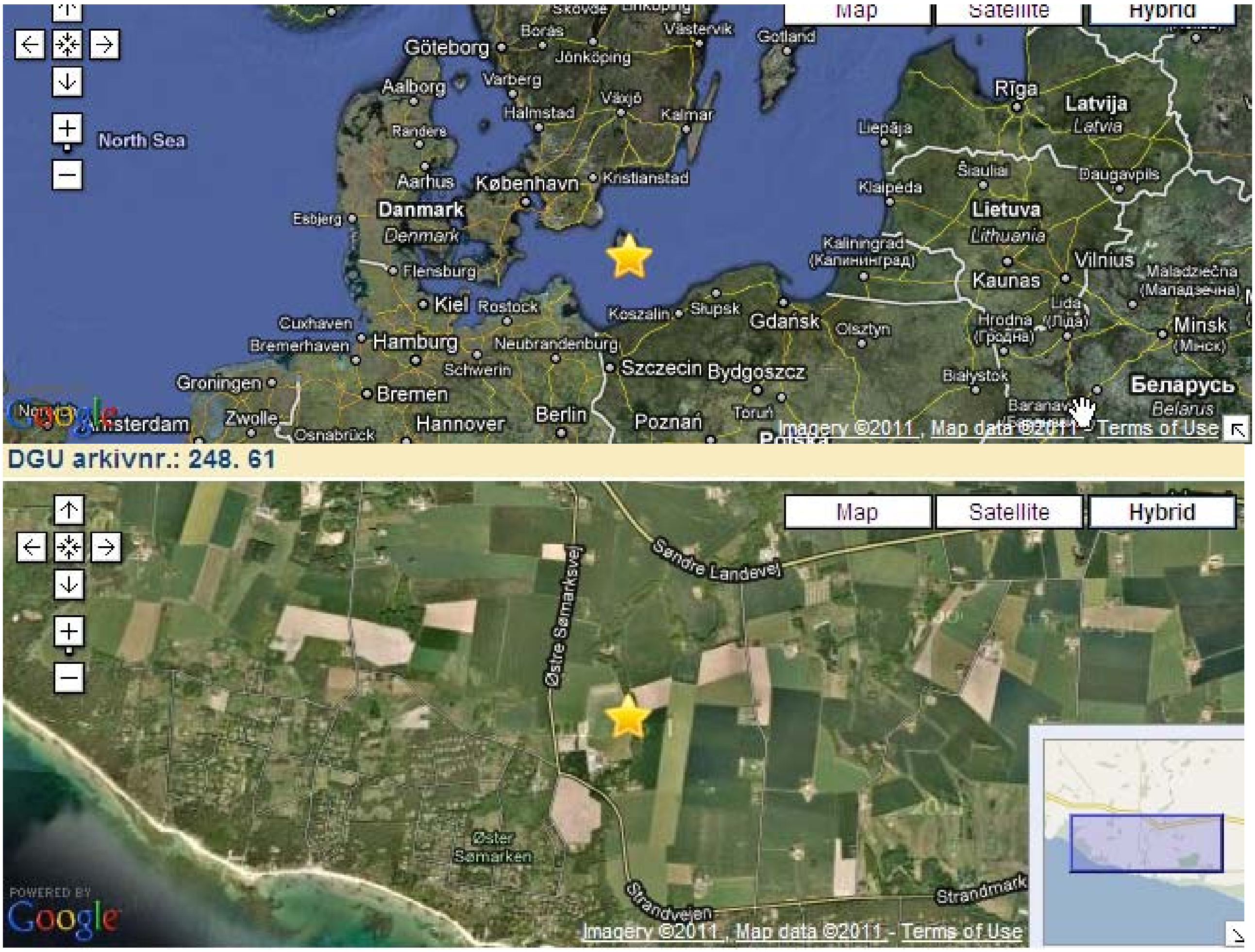


**Figure 1**. Location of the Billegrav-2 well, southern Bornholm, Denmark.

# 2. Fractures

## 2.1. Fracture description method

The parameters used to describe and characterise the fractures are: fracture length, fracture orientation, fracture system, fracture intensity, surface character and fracture filling. The full fracture analysis is presented in Appendix A.

Fracture length
The fracture length was measured and the fracture trace is drawn on the fracture description of the individual core boxes (Appendix A).

The fracture orientation
The fracture orientation is usually described by the strike and dip of the fracture plane. The orientation of the core is not known and only the inclination of the fractures was measured, as the core is vertical. Fractures are grouped as follows: horizontal, weakly inclined (20˚-30˚), moderately inclined (60˚) and vertical or nearly vertical fractures (>80˚).

Fracture system
A fracture system is a set of co-genetic and parallel oriented fractures. As the true orientation of the fractures is not known it is difficult to differentiate between fracture systems. However, if several fracture systems are present together in the core, a minimum of systems can be found, and fractures with different inclination may also be grouped into fracture systems.

Fracture intensity
The fracture intensity is the number of fractures per meter of core. It is indicated on the core box fracture description (Appendix A) and summarised in the fracture intensity log (Appendix B) shown on Figure 16.

Fracture surface
The fracture surface is described on a cm scale as: planar, undulating or irregular. On a mm scale the fracture surface is described as: smooth, rough or with slickenside. Breccias are zones of crushed rock with or without a fine-grained matrix.

Fracture staining and filling
The fracture staining and filling is described as: no filling, clayey/silty/sandy filling (clay), iron staining (Fe), calcite staining (Ca), pyrite staining (p) or healed/cemented (ce).

## 2.2. Fracture descriptions

**Fracture systems**

The strike of the fracture plane cannot be used to differentiate fracture systems as the orientation of the core is not known. Instead the fractures may be subdivided into horizontal, weakly inclined (20˚-30˚), moderately inclined (60˚) and steep (>80˚) fractures. In some cases two fractures with different orientation are present in the same part of the core (Figure 2) and in many cases conjugated fractures are present, representing 2 fracture systems. A conservative estimate gives 6 fracture systems within the core; 2 (nearly) vertical set, 2 moderately inclined set, 1 weakly inclined set and 1 horizontal set.

**Figure 2.** Two set of fractures represented in the same piece of core.

The horizontal fractures are parallel to the layering of the shale and are most likely the result of relaxation due to unloading of overburden, as younger sediments have been eroded as a consequence of tectonic uplift. The inclined and vertical fractures are related to tectonic deformations.

**Fracture intensity**

The fracture intensity varies a great deal in the core (Figure 16). There are some intervals with a relative stable intensity level separated by peaks of high fracture intensity. Apart from the uppermost 2 m of the core intervals with highest fracture intensities are seen in connection with faults and fault zones. In the most intensely fractured parts of the core the actual number is difficult to obtain, and the intensity is set to 25 fractures per m at 59 m and 64 to 66 m.

The uppermost 2 m of the core is intensely fractured, and almost crushed at the top. The intensity gradually decreases and gets more stable from 13 m. This is due to Quaternary sub-glacial impact from advancing glaciers on the shale.

The average level of the intensity between the peaks varies from a little less than 1 to about 5 fractures per m (Figure 16).

### Fracture surface and filling

The fractures are planar (Figures 6 and 7), undulating or irregular (Figures 5 and 8) on a cm scale and they might have a smooth, rough or with slickenside surface on a mm scale.

In connection with faults the shale may be crushed or brecciated (Figure 3). The chaotic fracture pattern in a breccia may be filled with calcite or with a matrix of silt and clay, which is formed during the process of faulting. Slickenside indicates movement along the fracture (Figure 4).

Clay filling of the fractures occurs in the upper part of the core possibly formed as clay-injection from the soil above by a high water pressures under the glaciers in Quaternary time.

At greater depth in the core clay has in some cases been injected into fractures from bentonite rich layers interbedded with shale (Figure 5).

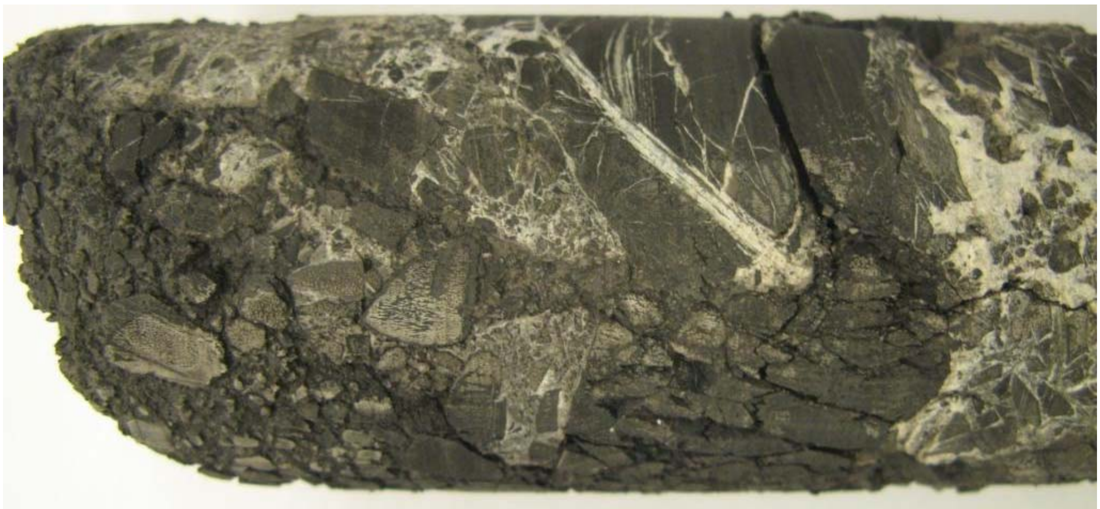


**Figure 3.** Fault breccia with a silt/clay matrix and calcite cement. At 60 m.

**Figure 4.** Slickenside on a fracture surface.

**Figure 5.** Clay injected into a fracture from a bentonite rich layer in the shale at 49.6 m.

Iron oxide precipitation is observed on fracture surfaces in the upper part of the core. The iron is precipitated as reduced iron-bearing water is oxidised in the fractures in the surface near part of the shale.

**Figure 6**. Iron oxide precipitated on planar fracture surfaces (Fe on the fracture description chart in Appendix A).

Calcite has been precipitated in various degree on the fracture surfaces (Figures 5, 7, 8) and the fractures have been partly to fully cemented and thereby ‘closed’. This is particular the case in Unit F3 (between 33 m to 46 m, Figure 16). Here the fracture log indicates a low intensity and all fractures are healed with calcite that probably was mobilised from the carbonate rich matrix.

Pyrite precipitation is also seen on the fracture surfaces (Figure 9).

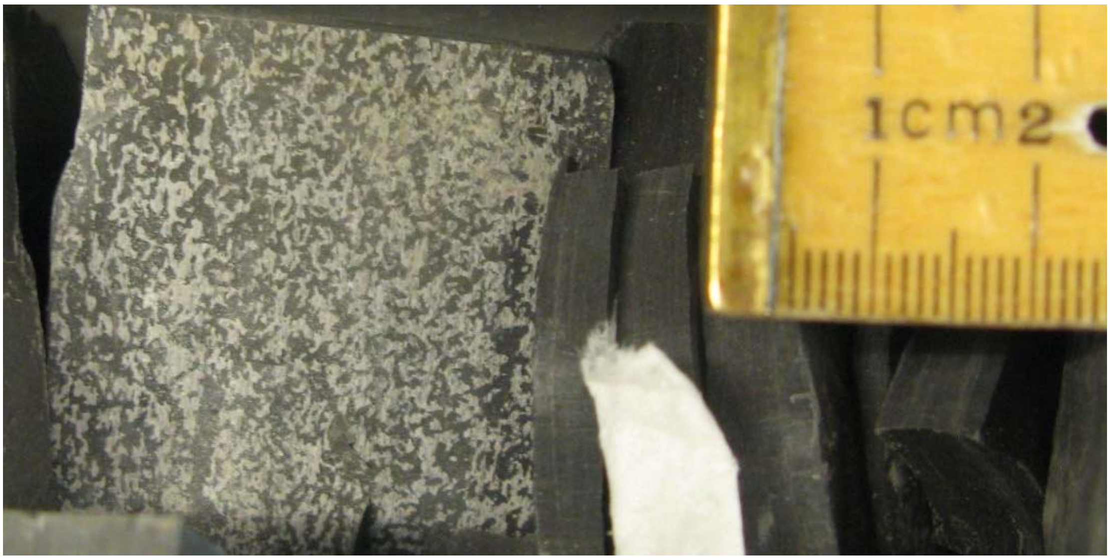


**Figure 7**. Calcite precipitated on a straight and smooth fracture surface at 23.4 m.

**Figure 8**.  Calcite filled straight and irregular fractures at 45.5 m.

**Figure 9**. Pyrite precipitation on a fracture surface.

## 2.3. Faults, fault zones and deformation phases

In the Billegrav 2 well, 7 faults and fault zones are recognized at about 30 m, 54 m, 60 m, 65 m, 74 m, 92 m and 103 m. The faults at 30, 60 and 65 m have resulted in loss of section (Nielsen & Schovsbo 2012), indicating that the faults are normal faults caused by extensional deformation.

The fault zone at about 30 m depth is delimited by two fault breccias at 28.3 m and 32.2 m depth (Figure 10). The breccia at 28.3 m is 5 cm thick and has an inclination of 30˚ compared to the core, and the breccia at 32.2 m is 15 cm thick matrix supported breccia and has an inclination of 45˚ compared to the core. The fracture intensity in the fault zone is much higher than above or below the two breccias. There are also zones with densely spaced fractures with slicken side on the fracture surfaces.

**Figure 10**. Fault breccias delineating the fault zone at about 30 m. A: fault breccia at 28.3 m. B: fault breccia at 32.2 m

**Figure 11**. Steep fault at 55 m.

**Figure 12**. Fault breccia at 60 m.

At 55 m there is a small steep fault with a 1 cm brecciated zone and related fractures (Figure 11). The fractures are open, and there is no filling in the fractures associated with the fault.

The fault zone from 59.7 m to 60.5 m consists of several fault breccias and intense fracturing. The breccias are delineated with straight fractures with slickenside and are either filled with calcite or a silty-clayey matrix (Figure 12). 3 generation of deformation can be detected. There are two generations of faulting/fracturing which have been calcite cemented and one younger faulting/brecciating event cutting the calcite cemented fractures (Figure 12).

The fault zone from 64.30 m to 66.70 m is a brecciated zone with one generation of calcite filled fractures and a younger generation with a fracture matrix of silt/clay (Figure 13).

The fault at 73.25 m is a 5 cm thick breccia, with a high intensity of steep calcite cemented fractures.

The fault at 91.5 to 92 m is a breccia with clay filling (Figure 14). There is a relatively high intensity of fracturing in the underlying 3 m of the core.

The fault zone, from 103.3 m to 104.2 m consists of many closely spaced low angel fractures with slickenside on all the fracture surfaces.

**Figure 13**. Breccia at 64.60 m, Box 18.

**Figure 14**. Clay filled breccia, Box 26, 92 m.

### Deformation phases

In several intervals in the core, up to three generations of fracture formation are distinguished; e.g. 28.35 m, 45,8 m and 59 m.

At 28.35 m a fracture was cemented with calcite. Subsequently open fractures related to the fault were generated (see Appendix A, Box 8).

At 45.8 m the first generated fracture was cemented with calcite. Subsequently a fracture was formed in which clay was injected from a clay layer (see Appendix A, Box 12).

At 59 m three generations of deformations can be differentiated. There are two generations of faulting/fracturing which have been calcite cemented and one younger faulting/brecciating event cutting the calcite cemented fractures (see Figure 12 and Appendix A, Box 16)

## 2.4. Relationship between fracture intensity and down hole logs

**Fracture intensity and sonic velocity**
There seems to be a relationship between fracture intensity and sonic velocity (Figure 16). The shale characterised by high fracture intensities are also characterised by low sonic velocity.

**Fracture distribution and water flow log**
On the flow log a total of 12 inflow zones have been identified (Figure 16).

The largest inflow in the well has been identified to be at about 51 m. At this level there are no faults, and the inflow seems to be related to some irregular fractures, partly with clay filling (Figure 15).

**Figure 15**. Irregular fractures at 51.3 m from which the largest inflow of water (33% of the total inflow) occur.

The uppermost inflow zone is at about 20 m and it is the second largest inflow zone (11 %), Between 19 and 20 m in the core the fracture intensity increases a little and the fractures are conjugated sets, representing 2 fracture set.

The inflow at 31 m is within the uppermost fault zone. It is situated in the highly fractured part between the breccias that delineates this fault zone.

At 38 m an inflow zone has been identified (Figure 16). However no particular fracture occurrence has been identified in the core to explain this inflow.

At 48 m there is a long calcite cemented fracture that may have been at least partly open.

At about 55 m there is a narrow but open fault breccia (Figure 11).

The inflow at about 61 m is in the fractured part just below a fault zone.

At 66 m the inflow zone is located in a fracture zone, and at 68 m it is just below the fracture zone.

At the inflow zone at about 77 m there are a couple of cutting open fractures.

The inflow zone at 90 m is just above a fault zone, with slightly higher fracture intensity.

The inflow zone at 96 m is a highly fractured (9 fractures per m) part of the well.

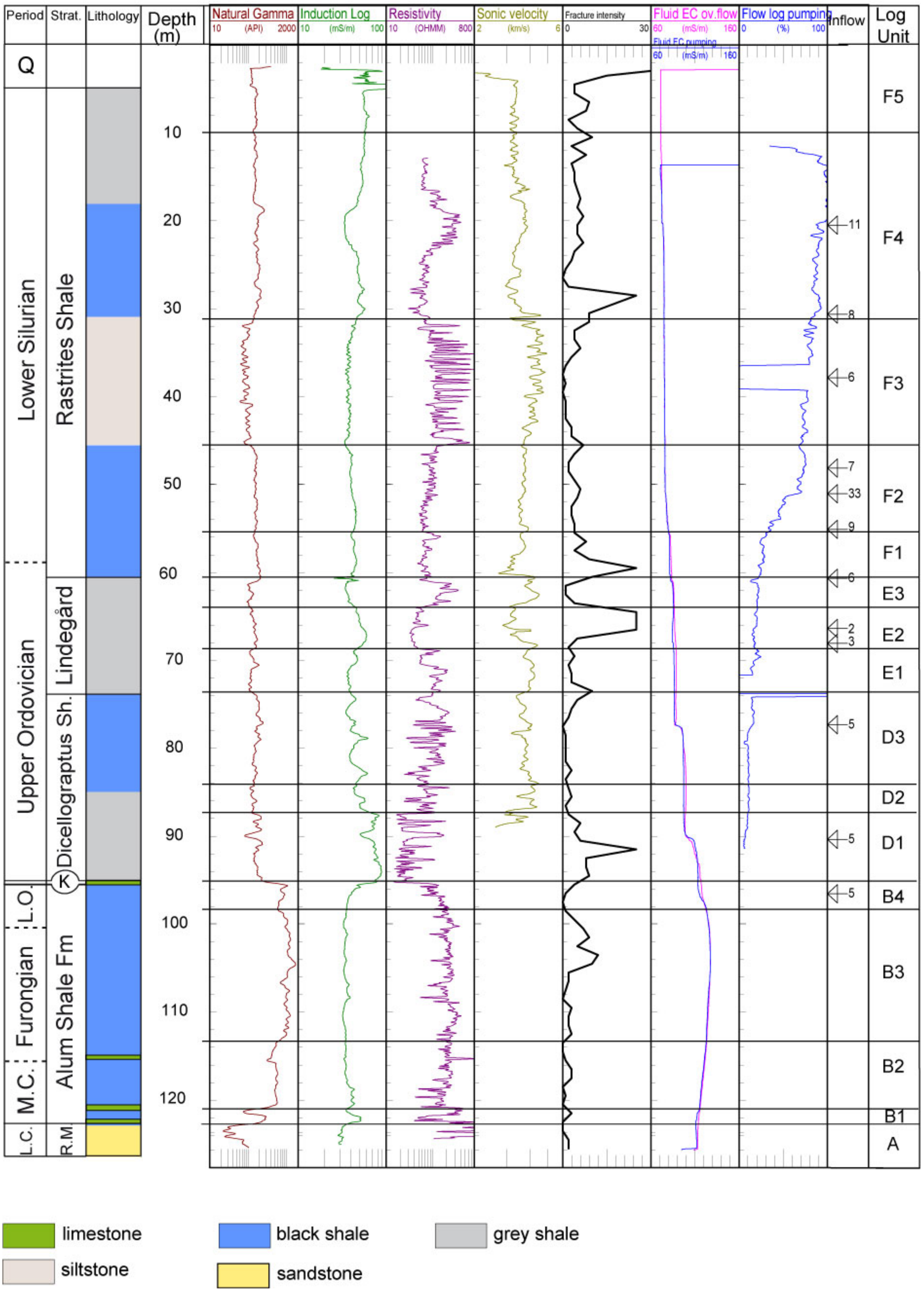


**Figure 16.** Down hole logs and water flow logs measured in the Billegrav-2 well. The fracture density log is shown in panel 5. Lithology and log stratigraphy are based on Schovsbo et al. (2011).

# 3. Mineralogical determinations

The mineralogical composition was measured on 60 samples from the core. 30 samples have previously been included in Schovsbo (2012) as part of the core plug analysis report.

## 3.1. Methods

Quartz and XRD screening

The XRD powder diffraction patterns were obtained on randomly oriented powder using CoKα-radiation. The quartz content was measured by X-ray diffraction by comparing peak heights between the sample and a standard composed of Merck quartz 1.07536 ground dawn to <0.063 micron is used. The analysis was made at the GEUS clay laboratory.

The XRD spectra were investigated for the main mineral groups present. Identified mineral groups include kaolinite, mica, clay, quartz, calcite, dolomite/ankerite and pyrite/marcasite. Barite and feldspar was not identified.

The results of the mineralogical screening of the samples areas presented in Table 2. In the table the reflection areas of the minerals are presented.

TOC, carbonate and soulphur

The total carbon (TC) and total sulphur (TS) contents were measured on a LECO CS-200 carbon/sulphur analyser. Approximately 0.05 g of dried rock powder was placed together with iron accelerator material in an oven and heated to 1300°C, the evolved gasses were measured by infrared absorption. The carbonate content was measured on sample splits by titration and the carbonate content (TCC) was used to correct the TC to TOC using the formula:

$$\text{TOC (wt.\%)} = \text{TC (wt.\%)} - \text{TCC (wt.\%)}$$

Total sulphur (TS) content was measured by combustion of the samples in a LECO-type oven. All measurements were made at the Institute of Geography and Geology, University of Copenhagen.

## 3.2. Quantitative mineralogy

In order to quantify the main mineralogical components in the samples the following components have been calculated (Tables 1 and 3):

Carbonate content: Measured directly on the sample by titration technique.

Pyrite ($FeS_2$) content: Calculated from total sulphur (TS) content assuming that all sulphur is present in pyrite.

Organic matter content: Calculated directly from the TOC content.

<u>Quartz content:</u> Measured by X-ray diffraction by comparing peak heights between the sample and a standard.

<u>% unresolved:</u> Proportion of the sample that is not accounted for by the analysis of the above mentioned phases. Calculated from the formula: 100% – (%Quartz + %TOC + %Pyrite + %Carbonate).

<u>The Q/(total clay) ratio:</u> Calculated from the quantitative measurement of quartz and the semi quantitative concentration of total clays.

## 3.3. Semi-quantitative mineralogy

The content of the mineral phases identified during the bulk XRD screening of the samples are measured in area of reflectivity (Table 2). This scale is proportional with concentration as can be seen in Figure 17. The pyrite content measured by combustion technique compares directly with the pyrite/marcasite reflection area (Figure 17A). Also the sum of the peak area of carbonate phases (calcite, dolomite/ankerite) compares directly with the carbonate content measured by titration technique (Figure 17B).

In the same manner the reflectivity area for kaolinite, mica, and clay has been scaled to the proportion of the sample that is not accounted for by the quantitative mineralogical analysis. In this manner a semi-quantitative measurement of these phases have been established (Table 3).

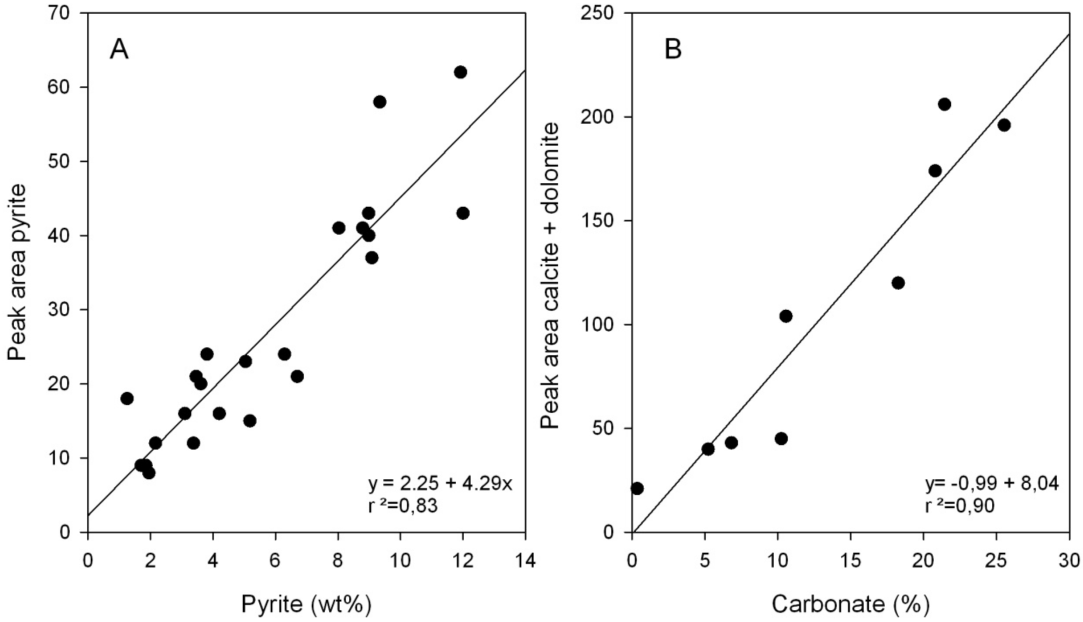


**Figure 17.** Comparison between reflectivity area of (A) pyrite/marcasite and (B) carbonate with the measured quantity in the Billegrav-2 well (from Schovsbo 2012).

## 3.4. Variation of quartz and carbonate content

Quartz content (Figures 18, 19)
The quartz content in the Alum Shale range between 9–54%. Highest quartz content occur in the B4 unit with correspond roughly to the Ordovician part of the formation.

The quartz content in the Dicellograptus Shale range between 32–60%. Highest concentrations are measured in the basal part of the shale (unit D1) where the shale is interbedded with bentonites and in the topmost part of the organic rich D3 unit.

The quartz content in the Rastrites shale range between 23–63%. Highest concentrations are measured in the organic rich F4 unit between 21-23.5 m.

Carbonate content (Figures 18, 19)
The carbonate content in the Alum Shale range between 0.0–6.8%. Highest content are measured in the B3 unit.

The Dicellograptus Shale has low carbonate content that range between 2.1–6.4% (Figures 18, 19).

The carbonate content in the Lindegård Formation range between 3.7–31.6%. The highest content is measured in the E3 unit.

The carbonate content in the Rastrites shale range between 0.0–23.7%. Concentrations above 15% are measured in the F3 unit. This unit contains abundant carbonate cemented beds (Nielsen and Schovsbo 2012).

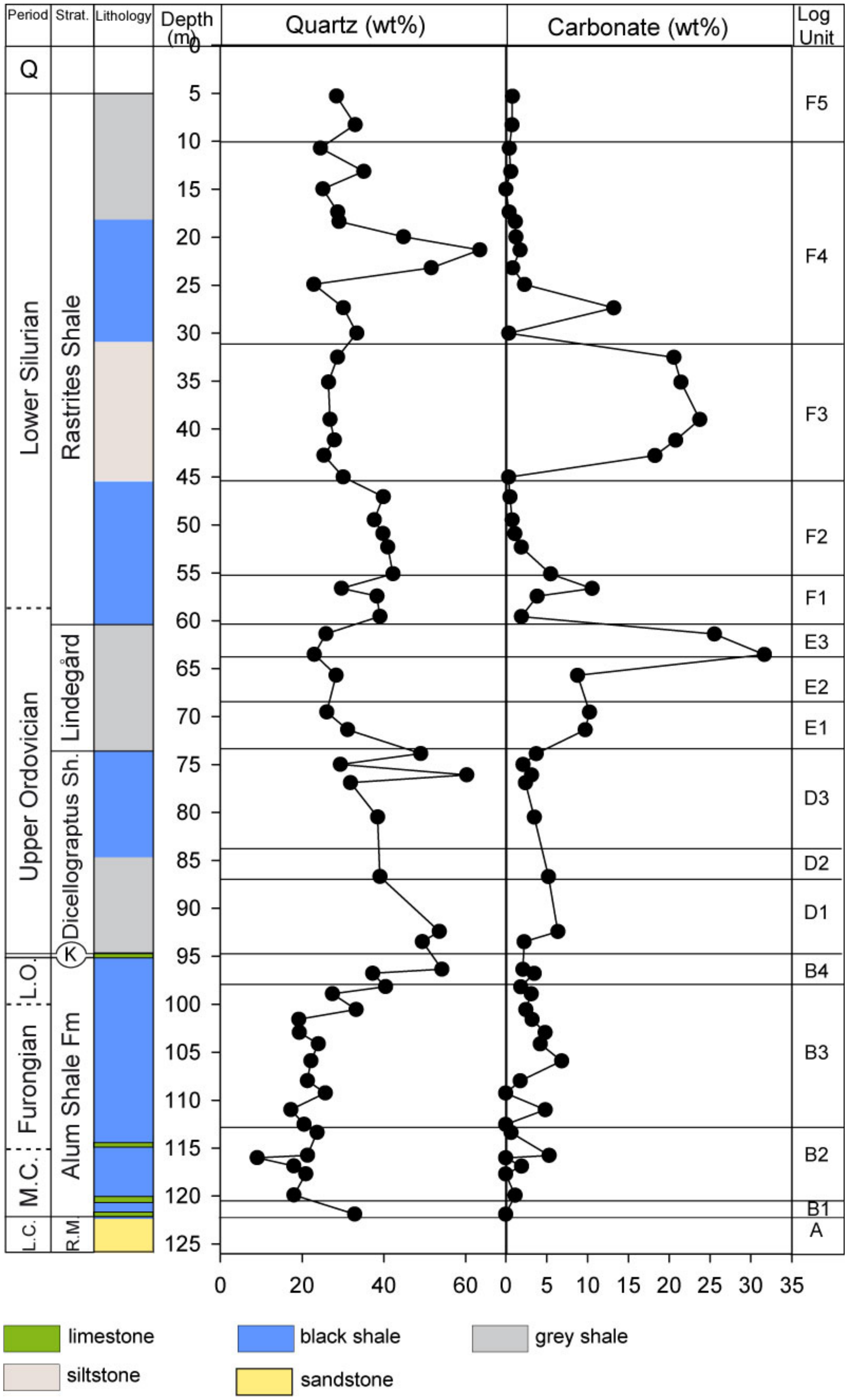


**Figure 18.** Variation in quartz and carbonate content in the Billegrav-2 well. The lithology and log units are after Schovsbo et al. (2011).

**Table 1.** Results of the quantitative mineralogical analysis of the samples.

| | | | | | Quantitative | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **this report** | **Sample** | **Formation** | **Unit** | **Base (m)** | **TOC %** | **TC %** | **TS %** | **Carb. %** | **Pyrite %** | **Q %** | **Unre-solved %** |
| | 1 | Rastrites | F5 | 5.28 | 1.0 | 1.1 | 2.0 | 0.8 | 3.8 | 28 | 66 |
| 1 | 1007 | Rastrites | F5 | 8.27 | 0.3 | 0.4 | 0.1 | 0.8 | 0.1 | 33 | 66 |
| | 2 | Rastrites | F4 | 10.70 | 0.5 | 0.6 | 1.9 | 0.4 | 3.6 | 24 | 71 |
| 1 | 1012 | Rastrites | F4 | 13.13 | 0.5 | 0.6 | 0.7 | 0.6 | 1.3 | 35 | 63 |
| | 3 | Rastrites | F4 | 14.97 | 0.5 | 0.5 | 1.7 | 0.0 | 3.1 | 25 | 71 |
| 1 | 1017 | Rastrites | F4 | 17.36 | 0.3 | 0.4 | 0.0 | 0.4 | 0.0 | 29 | 71 |
| 1 | 1020 | Rastrites | F4 | 18.37 | 1.4 | 1.6 | 1.0 | 1.2 | 1.8 | 29 | 67 |
| | 4 | Rastrites | F4 | 19.95 | 3.9 | 4.0 | 2.2 | 1.2 | 4.2 | 45 | 46 |
| 1 | 1027 | Rastrites | F4 | 21.31 | 2.4 | 2.6 | 1.5 | 1.8 | 2.8 | 63 | 30 |
| | 5 | Rastrites | F4 | 23.18 | 2.3 | 2.4 | 2.7 | 0.8 | 5.0 | 52 | 40 |
| | 6 | Rastrites | F4 | 24.90 | 3.1 | 3.4 | 3.4 | 2.3 | 6.3 | 23 | 65 |
| 1 | 1035 | Rastrites | F4 | 27.35 | 1.3 | 2.9 | 1.6 | 13.2 | 3.0 | 30 | 52 |
| | 7 | Rastrites | F4 | 29.99 | 1.2 | 1.2 | 0.7 | 0.4 | 1.3 | 33 | 64 |
| 1 | 1041 | Rastrites | F3 | 32.52 | 0.4 | 2.9 | 1.1 | 20.6 | 2.1 | 29 | 48 |
| | 8 | Rastrites | F3 | 35.10 | 0.6 | 3.1 | 1.2 | 21.4 | 2.2 | 26 | 49 |
| 1 | 1046 | Rastrites | F3 | 38.99 | 0.6 | 3.4 | 1.0 | 23.7 | 1.8 | 27 | 47 |
| | 9 | Rastrites | F3 | 41.15 | 0.9 | 3.4 | 1.0 | 20.8 | 1.8 | 28 | 49 |
| | 10 | Rastrites | F3 | 42.74 | 1.0 | 3.2 | 1.0 | 18.3 | 1.9 | 25 | 53 |
| | 11 | Rastrites | F3 | 45.00 | 0.8 | 0.9 | 1.9 | 0.4 | 3.5 | 30 | 65 |
| 1 | 1053 | Rastrites | F2 | 47.07 | 1.3 | 1.4 | 1.7 | 0.5 | 3.2 | 40 | 55 |
| 1 | 1057 | Rastrites | F2 | 49.48 | 1.6 | 1.7 | 2.2 | 0.8 | 4.1 | 38 | 56 |
| | 12 | Rastrites | F2 | 50.90 | 1.1 | 1.3 | 1.5 | 1.1 | 2.7 | 40 | 55 |
| 1 | 1062 | Rastrites | F2 | 52.30 | 0.7 | 1.0 | 1.3 | 1.9 | 2.4 | 41 | 54 |
| 1 | 1066 | Rastrites | F2 | 55.10 | 0.6 | 1.3 | 1.3 | 5.5 | 2.5 | 42 | 49 |
| | 13 | Rastrites | F1 | 56.60 | 0.4 | 1.7 | 0.7 | 10.6 | 1.3 | 30 | 58 |
| 1 | 1069 | Rastrites | F1 | 57.42 | 0.6 | 1.1 | 1.1 | 3.8 | 2.0 | 38 | 55 |
| 1 | 1073 | Rastrites | F1 | 59.57 | 1.4 | 1.6 | 1.5 | 1.9 | 2.8 | 39 | 55 |
| | 14 | Lindegård | E3 | 61.37 | 0.2 | 3.2 | 0.3 | 25.5 | 0.6 | 26 | 48 |
| 1 | 1079 | Lindegård | E3 | 63.52 | 0.1 | 3.9 | 0.1 | 31.6 | 0.3 | 23 | 45 |
| 1 | 1080 | Lindegård | E2 | 65.70 | 0.1 | 1.1 | 0.3 | 8.8 | 0.6 | 28 | 62 |
| | 15 | Lindegård | E1 | 69.53 | 0.2 | 1.4 | 0.0 | 10.2 | 0.1 | 26 | 64 |
| 1 | 1085 | Lindegård | E1 | 71.38 | 0.1 | 1.3 | 0.0 | 9.7 | 0.1 | 31 | 59 |
| 1 | 1087 | Lindegård | E1 | 73.87 | 0.1 | 0.5 | 0.2 | 3.7 | 0.4 | 49 | 47 |
| | 16 | Dicellogp. | D3 | 74.99 | 2.0 | 2.2 | 0.8 | 2.1 | 1.4 | 29 | 65 |
| 1 | 1096 | Dicellogp. | D3 | 76.09 | 3.7 | 4.0 | 1.4 | 3.2 | 2.5 | 60 | 30 |
| | 17 | Dicellogp. | D3 | 76.89 | 3.1 | 3.4 | 1.0 | 2.4 | 1.9 | 32 | 61 |

**Table 1 (Continued).**

| | | | | | Quantitative | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| this report | Sample | Formation | Unit | Base (m) | TOC % | TC % | TS % | Carb. % | Pyrite % | Q % | Unre-solved % |
| | 18 | Dicellogp. | D3 | 80.47 | 3.9 | 4.4 | 1.8 | 3.5 | 3.4 | 38 | 51 |
| | 19 | Dicellogp. | D2 | 86.68 | 0.7 | 1.3 | 1.0 | 5.2 | 1.9 | 39 | 53 |
| 1 | 1131 | Dicellogp. | D1 | 92.42 | 0.7 | 1.5 | 1.3 | 6.4 | 2.5 | 54 | 37 |
| | 20 | Dicellogp. | D1 | 93.47 | 0.7 | 0.9 | 0.9 | 2.2 | 1.7 | 49 | 46 |
| 1 | 1140 | Alum | B4 | 96.36 | 6.3 | 6.6 | 1.6 | 2.1 | 3.0 | 54 | 34 |
| | 21 | Alum | B4 | 96.76 | 6.7 | 7.2 | 2.8 | 3.5 | 5.2 | 37 | 47 |
| 1 | 1143 | Alum | B4 | 98.18 | 8.5 | 8.7 | 3.0 | 1.8 | 5.7 | 40 | 44 |
| | 22 | Alum | B3 | 98.90 | 7.1 | 7.4 | 3.6 | 3.1 | 6.7 | 27 | 56 |
| 1 | 1148 | Alum | B3 | 100.55 | 11.8 | 12.1 | 5.2 | 2.5 | 9.7 | 33 | 43 |
| | 23 | Alum | B3 | 101.57 | 9.5 | 9.9 | 4.8 | 3.2 | 9.0 | 19 | 59 |
| | 24 | Alum | B3 | 102.93 | 11.3 | 11.9 | 4.9 | 4.8 | 9.1 | 19 | 55 |
| 1 | 1155 | Alum | B3 | 104.14 | 11.2 | 11.7 | 5.1 | 4.2 | 9.6 | 24 | 51 |
| | 25 | Alum | B3 | 105.90 | 10.1 | 10.9 | 4.3 | 6.8 | 8.0 | 22 | 53 |
| 1 | 1160 | Alum | B3 | 107.97 | 7.9 | 8.1 | 12.2 | 1.8 | 22.8 | 21 | 46 |
| 1 | 1162 | Alum | B3 | 109.26 | 8.3 | 8.3 | 9.6 | 0.0 | 17.9 | 26 | 48 |
| | 26 | Alum | B3 | 110.98 | 8.4 | 9.0 | 6.4 | 4.8 | 12.0 | 17 | 57 |
| 1 | 1167 | Alum | B3 | 112.52 | 9.3 | 9.1 | 8.8 | 0.0 | 16.4 | 20 | 54 |
| | 27 | Alum | B2 | 113.35 | 7.9 | 8.0 | 5.0 | 0.6 | 9.3 | 24 | 58 |
| | 28 | Alum | B2 | 115.75 | 8.8 | 9.4 | 4.7 | 5.3 | 8.8 | 21 | 56 |
| 1 | 1171 | Alum | B2 | 116.02 | 6.6 | 6.6 | 7.6 | 0.0 | 14.3 | 9 | 70 |
| | 29 | Alum | B2 | 116.86 | 7.3 | 7.6 | 6.4 | 1.9 | 11.9 | 18 | 61 |
| 1 | 1175 | Alum | B2 | 117.70 | 6.7 | 6.7 | 6.7 | 0.0 | 12.5 | 21 | 60 |
| | 30 | Alum | B2 | 119.90 | 5.2 | 5.3 | 4.8 | 1.1 | 9.0 | 18 | 67 |
| 1 | 1178 | Alum | B1 | 121.89 | 2.3 | 2.2 | 3.5 | 0.0 | 6.6 | 33 | 58 |

**Table 2.** Identified minerals on the XRD spectra. Number indicates the measured peak height.

| **Formation** | **Unit** | **Base (m)** | **Kaolinite Peak Height** | **Mica Peak Height** | **Clay peak Height** | **Quartz Peak Height** | **Plagio. Peak Height** | **Calcite Peak Height** | **Pyrite/ Marcasite peak height** | **Dolomite/ Ankerite peak height** |
|---|---|---|---|---|---|---|---|---|---|---|
| Rastrites | F5 | 5.28 | 30 | 13 | 23 | 94 | | | 24 | |
| Rastrites | F5 | 8.27 | 55 | 24 | 38 | 136 | | | | |
| Rastrites | F4 | 10.70 | 39 | 16 | 26 | 95 | | | 20 | |
| Rastrites | F4 | 13.13 | 75 | 20 | 38 | 112 | | | | |
| Rastrites | F4 | 14.97 | 37 | 10 | 32 | 85 | | | 16 | |
| Rastrites | F4 | 17.36 | 48 | 17 | 40 | 105 | | | | |
| Rastrites | F4 | 18.37 | 47 | 23 | 42 | 135 | | | 12 | |
| Rastrites | F4 | 19.95 | 14 | 8 | 26 | 118 | | | 16 | |
| Rastrites | F4 | 21.31 | 21 | 7 | 25 | 175 | | 25 | 15 | |
| Rastrites | F4 | 23.18 | 19 | 9 | 29 | 103 | | | 23 | |
| Rastrites | F4 | 24.90 | 20 | 12 | 30 | 62 | | | 24 | |
| Rastrites | F4 | 27.35 | 30 | 14 | 30 | 96 | | 150 | 15 | |
| Rastrites | F4 | 29.99 | 32 | 12 | 35 | 126 | | | 18 | |
| Rastrites | F3 | 32.52 | 31 | 10 | 25 | 79 | | 324 | 14 | |
| Rastrites | F3 | 35.10 | 23 | 12 | 21 | 101 | | 206 | 12 | |
| Rastrites | F3 | 38.99 | 23 | 12 | 25 | 99 | | 163 | 12 | |
| Rastrites | F3 | 41.15 | 22 | 16 | 20 | 110 | | 174 | | |
| Rastrites | F3 | 42.74 | 27 | 11 | 22 | 87 | | 120 | | |
| Rastrites | F3 | 45.00 | 36 | 13 | 36 | 91 | | | 21 | |
| Rastrites | F2 | 47.07 | 38 | 18 | 33 | 118 | | | 23 | |
| Rastrites | F2 | 49.48 | 32 | 17 | 38 | 138 | | | 27 | |
| Rastrites | F2 | 50.90 | 38 | 15 | 29 | 161 | | | | |
| Rastrites | F2 | 52.30 | 48 | 17 | 35 | 130 | | 35 | 17 | |
| Rastrites | F2 | 55.10 | 52 | 17 | 33 | 123 | | 733 | 17 | |
| Rastrites | F1 | 56.60 | 43 | 14 | 25 | 110 | | 104 | | |
| Rastrites | F1 | 57.42 | 52 | 20 | 35 | 127 | | 57 | 13 | |
| Rastrites | F1 | 59.57 | 47 | 17 | 37 | 108 | | 27 | 18 | |
| Lindegård | E3 | 61.37 | 28 | 11 | 23 | 94 | | 196 | | |
| Lindegård | E3 | 63.52 | 27 | 10 | 26 | 112 | | 258 | | |
| Lindegård | E2 | 65.70 | 49 | 18 | 38 | 95 | | 90 | | |
| Lindegård | E1 | 69.53 | 67 | 9 | 31 | 75 | | | | 45 |
| Lindegård | E1 | 71.38 | 104 | 14 | 30 | 112 | | 184 | | |
| Lindegård | E1 | 73.87 | 62 | 15 | 35 | 162 | | 35 | | |
| Dicellogp. | D3 | 74.99 | 23 | 13 | 27 | 114 | | | | |
| Dicellogp. | D3 | 76.09 | 27 | 10 | 27 | 180 | | 32 | | |
| Dicellogp. | D3 | 76.89 | 16 | 8 | 19 | 101 | | | 8 | |
| Dicellogp. | D3 | 80.47 | 13 | 7 | 15 | 124 | | | 12 | |
| Dicellogp. | D2 | 86.68 | 23 | 11 | 21 | 129 | | 40 | 9 | |

**Table 2 (Continued).**

| Formation | Unit | Base (m) | Kaolinite Peak Height | Mica Peak Height | Clay peak Height | Quartz Peak Height | Plagio. Peak Height | Calcite Peak Height | Pyrite/ Marcasite peak height | Dolomite/ Ankerite peak height |
|---|---|---|---|---|---|---|---|---|---|---|
| Dicellogp. | D1 | 92.42 | 22 |  | 23 | 157 |  | 77 | 17 |  |
| Dicellogp. | D1 | 93.47 |  |  | 18 | 156 |  |  | 9 |  |
| Alum | B4 | 96.36 | 21 | 12 | 30 | 233 |  |  | 14 |  |
| Alum | B4 | 96.76 | 11 | 12 | 24 | 143 |  |  | 15 |  |
| Alum | B4 | 98.18 | 20 | 17 | 35 | 152 |  |  | 22 |  |
| Alum | B3 | 98.90 | 8 | 14 | 25 | 117 |  |  | 21 |  |
| Alum | B3 | 100.55 | 10 | 20 | 33 | 108 |  |  | 43 |  |
| Alum | B3 | 101.57 |  | 15 | 23 | 88 |  |  | 40 |  |
| Alum | B3 | 102.93 |  | 14 | 25 | 73 |  |  | 37 |  |
| Alum | B3 | 104.14 |  | 23 | 35 | 108 |  | 93 | 48 |  |
| Alum | B3 | 105.90 |  | 17 | 26 | 84 |  | 43 | 41 |  |
| Alum | B3 | 107.97 |  | 19 | 31 | 75 |  | 44 | 101 |  |
| Alum | B3 | 109.26 |  | 18 | 30 | 112 |  |  | 83 |  |
| Alum | B3 | 110.98 |  | 14 | 20 | 79 |  |  | 43 |  |
| Alum | B3 | 112.52 |  | 18 | 30 | 65 |  |  | 81 |  |
| Alum | B2 | 113.35 |  | 15 | 25 | 90 |  |  | 58 |  |
| Alum | B2 | 115.75 |  | 14 | 28 | 73 |  |  | 41 |  |
| Alum | B2 | 116.02 | 17 | 20 | 30 | 70 |  |  | 80 |  |
| Alum | B2 | 116.86 | 12 | 14 | 20 | 71 |  |  | 62 |  |
| Alum | B2 | 117.70 | 19 | 23 | 34 | 95 |  |  | 66 |  |
| Alum | B2 | 119.90 | 16 | 19 | 24 | 82 |  |  | 43 |  |
| Alum | B1 | 121.89 | 20 | 18 | 43 | 137 |  |  | 37 |  |

**Table 3.** Semi quantitative determination of clay types.

| | | | | Semi quantitative | | | | |
|---|---|---|---|---|---|---|---|---|
| Sample | Formation | Unit | Base (m) | % Kaolinite | % Mica | % Clay | % Plagioclase | Q/(total Clay) |
| 1 | Rastrites | F5 | 5.28 | 30 | 13 | 23 | 0 | 0.43 |
| 1007 | Rastrites | F5 | 8.27 | 31 | 14 | 21 | 0 | 0.50 |
| 2 | Rastrites | F4 | 10.70 | 34 | 14 | 23 | 0 | 0.34 |
| 1012 | Rastrites | F4 | 13.13 | 35 | 9 | 18 | 0 | 0.56 |
| 3 | Rastrites | F4 | 14.97 | 33 | 9 | 29 | 0 | 0.35 |
| 1017 | Rastrites | F4 | 17.36 | 32 | 11 | 27 | 0 | 0.41 |
| 1020 | Rastrites | F4 | 18.37 | 28 | 14 | 25 | 0 | 0.44 |
| 4 | Rastrites | F4 | 19.95 | 13 | 8 | 25 | 0 | 0.97 |
| 1027 | Rastrites | F4 | 21.31 | 12 | 4 | 14 | 0 | 2.15 |
| 5 | Rastrites | F4 | 23.18 | 13 | 6 | 20 | 0 | 1.28 |
| 6 | Rastrites | F4 | 24.90 | 21 | 13 | 32 | 0 | 0.35 |
| 1035 | Rastrites | F4 | 27.35 | 21 | 10 | 21 | 0 | 0.57 |
| 7 | Rastrites | F4 | 29.99 | 26 | 10 | 28 | 0 | 0.52 |
| 1041 | Rastrites | F3 | 32.52 | 23 | 7 | 18 | 0 | 0.59 |
| 8 | Rastrites | F3 | 35.10 | 20 | 11 | 19 | 0 | 0.54 |
| 1046 | Rastrites | F3 | 38.99 | 18 | 9 | 20 | 0 | 0.57 |
| 9 | Rastrites | F3 | 41.15 | 18 | 13 | 17 | 0 | 0.57 |
| 10 | Rastrites | F3 | 42.74 | 24 | 10 | 20 | 0 | 0.47 |
| 11 | Rastrites | F3 | 45.00 | 28 | 10 | 28 | 0 | 0.46 |
| 1053 | Rastrites | F2 | 47.07 | 24 | 11 | 20 | 0 | 0.72 |
| 1057 | Rastrites | F2 | 49.48 | 21 | 11 | 24 | 0 | 0.67 |
| 12 | Rastrites | F2 | 50.90 | 26 | 10 | 20 | 0 | 0.72 |
| 1062 | Rastrites | F2 | 52.30 | 26 | 9 | 19 | 0 | 0.76 |
| 1066 | Rastrites | F2 | 55.10 | 25 | 8 | 16 | 0 | 0.86 |
| 13 | Rastrites | F1 | 56.60 | 31 | 10 | 18 | 0 | 0.51 |
| 1069 | Rastrites | F1 | 57.42 | 27 | 10 | 18 | 0 | 0.69 |
| 1073 | Rastrites | F1 | 59.57 | 26 | 9 | 20 | 0 | 0.71 |
| 14 | Lindegård | E3 | 61.37 | 22 | 8 | 18 | 0 | 0.54 |
| 1079 | Lindegård | E3 | 63.52 | 19 | 7 | 19 | 0 | 0.51 |
| 1080 | Lindegård | E2 | 65.70 | 29 | 11 | 23 | 0 | 0.46 |
| 15 | Lindegård | E1 | 69.53 | 40 | 5 | 18 | 0 | 0.41 |
| 1085 | Lindegård | E1 | 71.38 | 41 | 6 | 12 | 0 | 0.53 |
| 1087 | Lindegård | E1 | 73.87 | 26 | 6 | 15 | 0 | 1.05 |
| 16 | Dicellogp. | D3 | 74.99 | 24 | 13 | 28 | 0 | 0.45 |
| 1096 | Dicellogp. | D3 | 76.09 | 13 | 5 | 13 | 0 | 1.98 |
| 17 | Dicellogp. | D3 | 76.89 | 23 | 11 | 27 | 0 | 0.52 |
| 18 | Dicellogp. | D3 | 80.47 | 19 | 10 | 22 | 0 | 0.76 |
| 19 | Dicellogp. | D2 | 86.68 | 22 | 11 | 20 | 0 | 0.73 |

**Table 3 (Continued).**

| | | | | Semi quantitative | | | | |
|---|---|---|---|---|---|---|---|---|
| **Sample** | **Formation** | **Unit** | **Base (m)** | **% Kaolinite** | **% Mica** | **% Clay** | **% Plagioclase** | **Q/(total Clay)** |
| 1131 | Dicellogp. | D1 | 92.42 | 18 | 0 | 19 | 0 | 1.45 |
| 20 | Dicellogp. | D1 | 93.47 | 0 | 0 | 46 | 0 | 1.07 |
| 1140 | Alum | B4 | 96.36 | 11 | 7 | 16 | 0 | 1.57 |
| 21 | Alum | B4 | 96.76 | 11 | 12 | 24 | 0 | 0.79 |
| 1143 | Alum | B4 | 98.18 | 12 | 10 | 21 | 0 | 0.93 |
| 22 | Alum | B3 | 98.90 | 9 | 17 | 30 | 0 | 0.49 |
| 1148 | Alum | B3 | 100.55 | 7 | 14 | 22 | 0 | 0.78 |
| 23 | Alum | B3 | 101.57 | 0 | 23 | 36 | 0 | 0.32 |
| 24 | Alum | B3 | 102.93 | 0 | 20 | 36 | 0 | 0.35 |
| 1155 | Alum | B3 | 104.14 | 0 | 20 | 31 | 0 | 0.47 |
| 25 | Alum | B3 | 105.90 | 0 | 21 | 32 | 0 | 0.42 |
| 1160 | Alum | B3 | 107.97 | 0 | 18 | 29 | 0 | 0.46 |
| 1162 | Alum | B3 | 109.26 | 0 | 18 | 30 | 0 | 0.53 |
| 26 | Alum | B3 | 110.98 | 0 | 24 | 34 | 0 | 0.30 |
| 1167 | Alum | B3 | 112.52 | 0 | 20 | 34 | 0 | 0.38 |
| 27 | Alum | B2 | 113.35 | 0 | 22 | 37 | 0 | 0.41 |
| 28 | Alum | B2 | 115.75 | 0 | 19 | 37 | 0 | 0.38 |
| 1171 | Alum | B2 | 116.02 | 18 | 21 | 31 | 0 | 0.13 |
| 29 | Alum | B2 | 116.86 | 16 | 19 | 26 | 0 | 0.29 |
| 1175 | Alum | B2 | 117.70 | 15 | 18 | 27 | 0 | 0.35 |
| 30 | Alum | B2 | 119.90 | 18 | 21 | 27 | 0 | 0.27 |
| 1178 | Alum | B1 | 121.89 | 14 | 13 | 31 | 0 | 0.56 |

# 4. Relationship between fractures and mineralogy

There is a clear relationship between mineralogical composition and fracture intensity (Figure 19). The fault zones are characterised by a fracture intensity >15 fractures pr m (Figure 19). The fault zones are typically associated spatially with either the top or the basal part of the carbonate rich intervals (Figure 19). The carbonate rich parts of the shales itself are typically characterised by low fracture intensity and if fractures occur there tend to be carbonate cemented.

Elevated fracture intensities are also associated spatially with the top or basal parts of the quartz rich units (Figure 19).

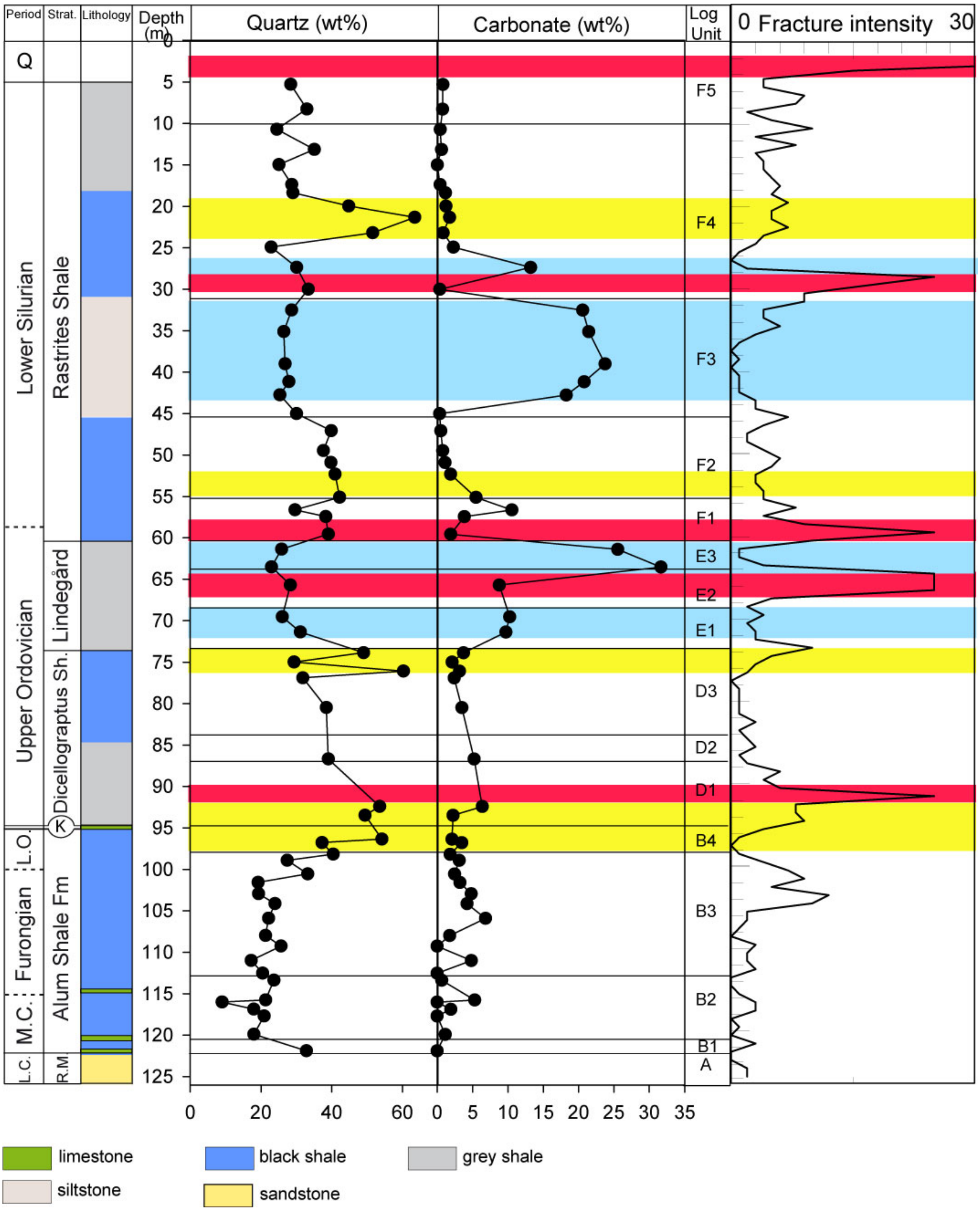


**Figure 19.** Variation in quartz and carbonate content and the fracture intensity in the Billegrav-2 well. Yellow colour bars indicate intervals with quartz >40%, blue colour bars indicate intervals with carbonate >10% and red colour bars indicates intervals with a fracture intensity >15 fracture pr m.

# 5. References

Schovsbo, N.H., Nielsen, A.T., Klitten, K., Mathiesen, A., Rasmussen, P., 2011. Shale gas investigations in Denmark: Lower Palaeozoic shales on Bornholm. Geological Survey of Denmark and Greenland Bulletin 23, 9–14.

Schovsbo, N.H., 2011a. Completion report Billegrav-2 well (DGU 248.61) Part 1: Down hole logs, core scanning data and core photos. Geological Survey of Denmark and Greenland Report 2011/53, 1–18.

Schovsbo, N.H., 2011b. Completion report Billegrav-2 well (DGU 248.61) Part 2: Review of Skelbro-1 and Billegrav-1. Geological Survey of Denmark and Greenland Report 2011/79, 1–32.

Schovsbo, N.H., 2012. Completion report Billegrav-2 well (DGU 248.61) Part 3: Results of core plug analysis. Geological Survey of Denmark and Greenland Report 2012/16. 1–47.

Nielsen, A.T., Schovsbo, N.H., 2012. Completion report Billegrav-2 well (DGU 248.61) Part 4: Stratigraphy and sedimentological description of the cored Lower Silurian – Lower Cambrian strata. Geological Survey of Denmark and Greenland Report 2012/18. Not yet paginated.

# 6. Data included on CD

Attached to this report is a CD that contains the following documentation:

1. In folder *Appendix:*
    a. Pdf files of fracture description for each core box presented in Appendix A
    b. Excel version of the fracture intensity log presented in Appendix B
2. In folder *Table* are Excel versions of tables presented in the report
3. A pdf of the report Completion report Billegrav-2 part 5.pdf

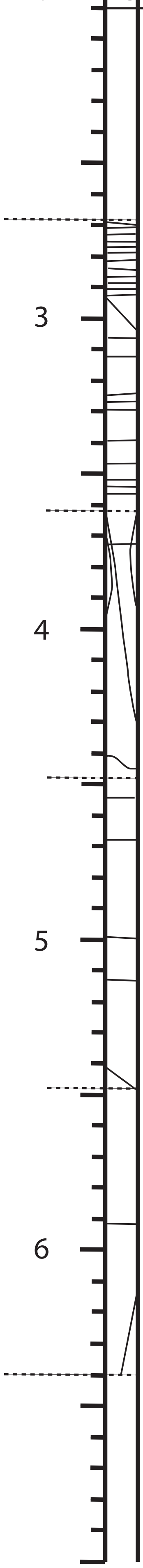
# Appendix A: Fracture descriptions

Legend

| | |
|---|---|
| │ | Fracture trace |
| ▨ | Fault breccia |

| | | | | | |
|---|---|---|---|---|---|
| Shape | st: straight | un: undulating | ir: irregular | | |
| Roughness | sm: smooth | sl: slickenside | ro: rough | | |
| Surfacecover | ca: calcite | py: pyrite | fe: iron | clay | silt |
| Open/Closed | cl: closed | | | | |

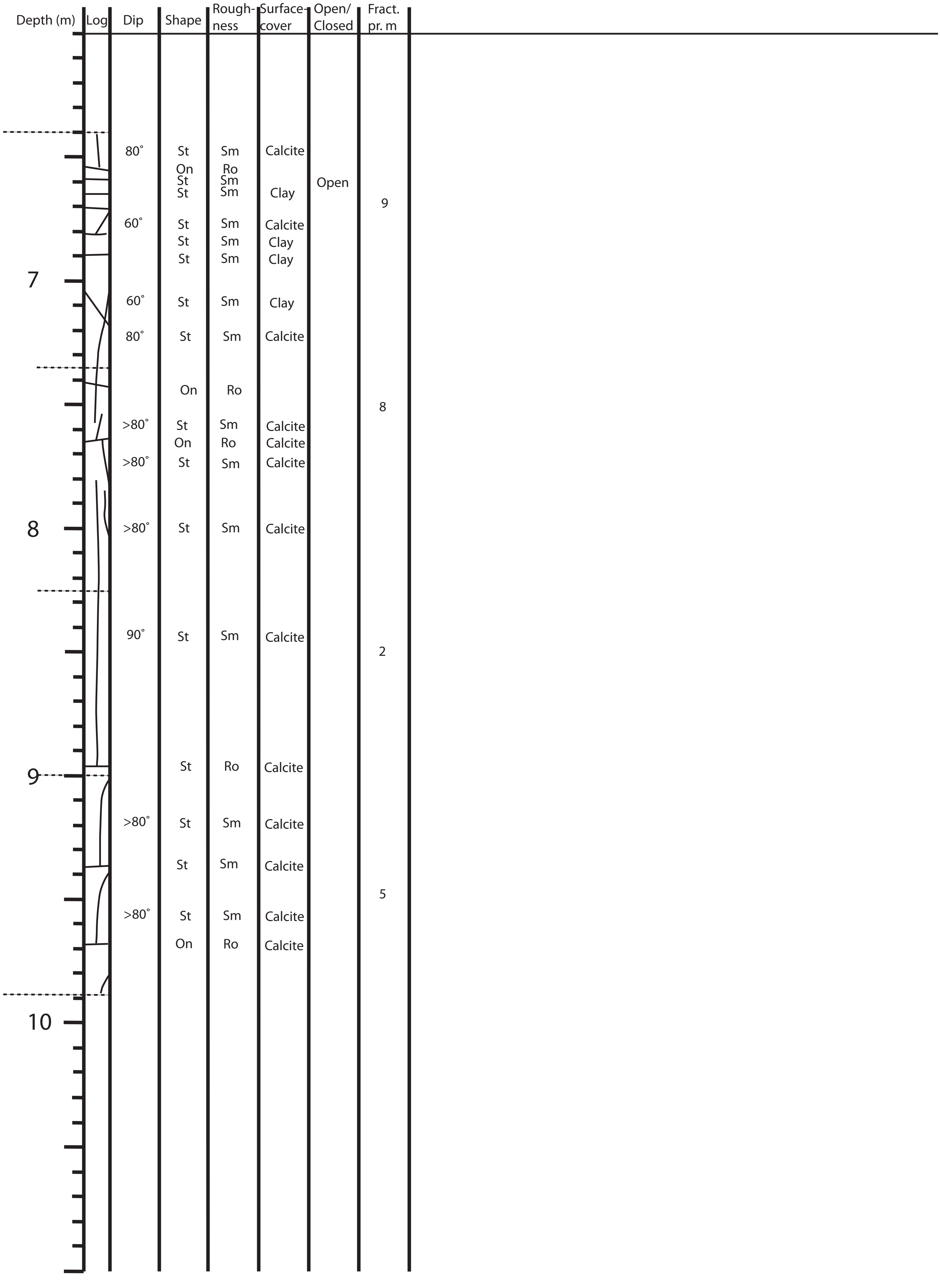
# Billegrav 2; DGUnr.: 248.61 Box 1; 2.86 - 6.40 m



| Depth (m) | Dip | Shape | Rough-ness | Surface-cover | Open/ Closed | Fract. pr. m |
|---|---|---|---|---|---|---|
| | | | | Clay+ Fe | Open | 43 |
| 3 | 50° | St | Sm | Clay | | |
| | | St | Sm | Clay | | |
| | | St | Sm | Clay | | |
| | | St | Sm | Clay | | |
| | | St | Sm | Clay | | |
| | | St | Sm | Clay | | |
| | | St | Sm | Clay | | 15 |
| | | St | Sm | Clay | | |
| | 80° | St | Sm | Clay,Fe | | |
| | 80° | St | Sm | Clay,Fe | | |
| 4 | 80° | St | Ro | Clay,Fe | | |
| | 30° | | Ro | | | |
| | | | | | | 4 |
| | | St | Sm | | | |
| | | St | Sm | Clay | | |
| 5 | | St | Sm | Clay | | |
| | | St | Sm | Clay | | |
| | 30° | On | Ro | | | |
| | | | | | | 4 |
| | | St | Sm | | | |
| 6 | | | | | | |
| | 80° | St | Sm | Calcite | | |

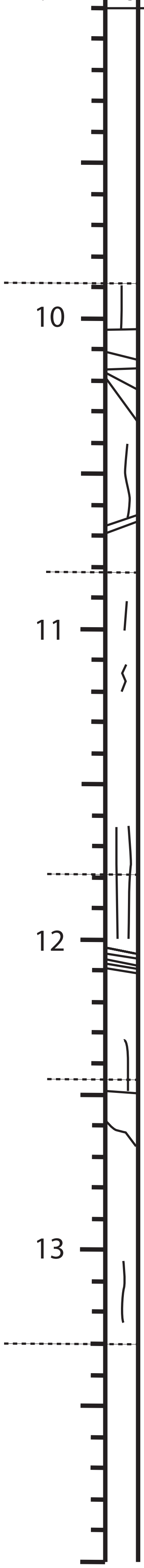
Foto: 2.85 m, Clay and Fe cover

# Billegrav 2; DGUnr.: 248.61 Box 2; 6.40 - 9.89 m



| Dip | Shape | Rough-ness | Surface-cover | Open/ Closed | Fract. pr. m |
|---|---|---|---|---|---|
| 80° | St | Sm | Calcite | | |
| | On | Ro | | | |
| | St | Sm | | Open | |
| | St | Sm | Clay | | 9 |
| 60° | St | Sm | Calcite | | |
| | St | Sm | Clay | | |
| | St | Sm | Clay | | |
| 60° | St | Sm | Clay | | |
| 80° | St | Sm | Calcite | | |
| | On | Ro | | | 8 |
| >80° | St | Sm | Calcite | | |
| | On | Ro | Calcite | | |
| >80° | St | Sm | Calcite | | |
| >80° | St | Sm | Calcite | | |
| 90° | St | Sm | Calcite | | 2 |
| | St | Ro | Calcite | | |
| >80° | St | Sm | Calcite | | |
| | St | Sm | Calcite | | 5 |
| >80° | St | Sm | Calcite | | |
| | On | Ro | Calcite | | |

## Billegrav 2; DGUnr.: 248.61 Box 3; 9.89 - 13.30 m

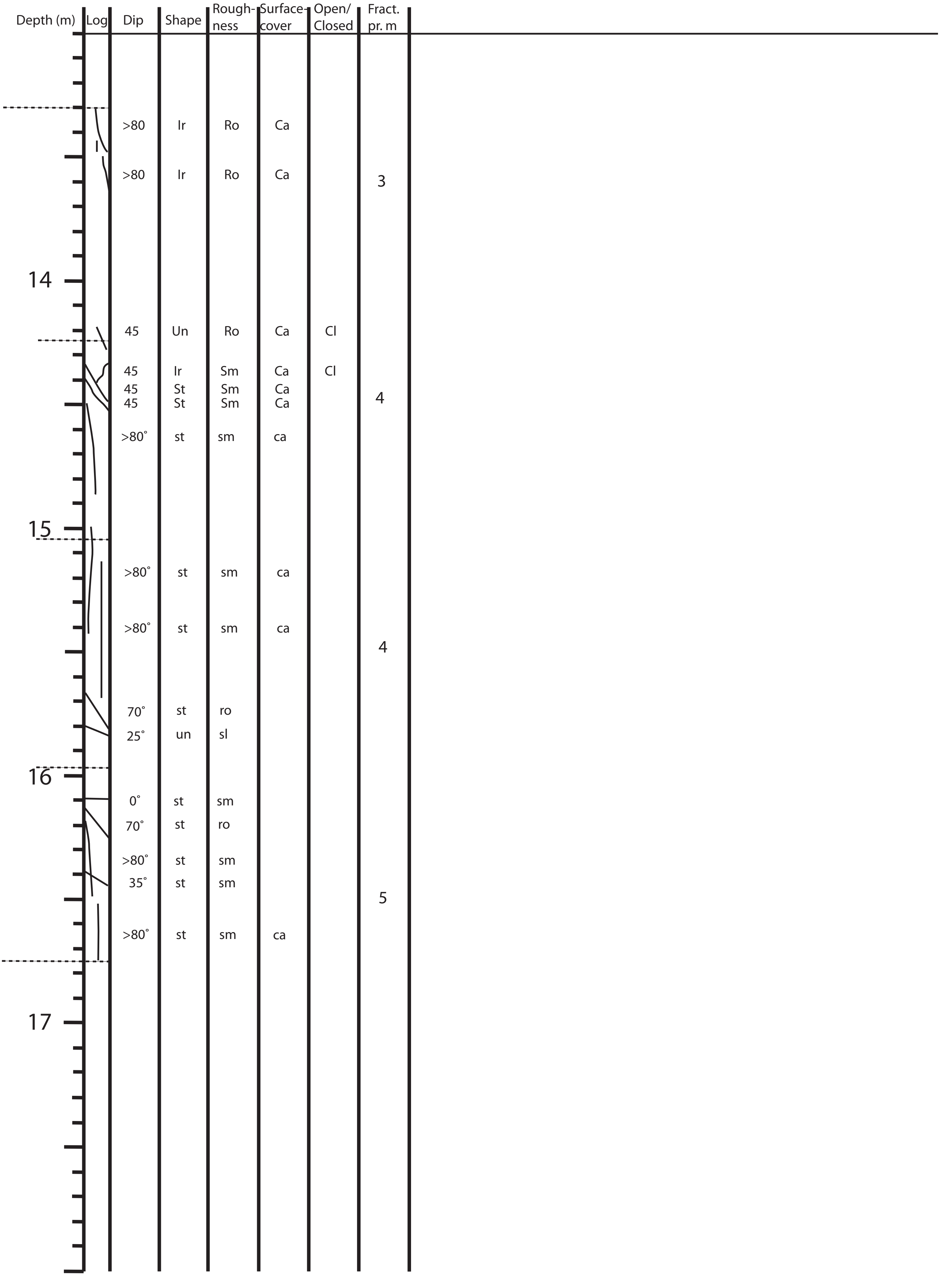


| Depth (m) | Log | Dip | Shape | Roughness | Surface-cover | Open/ Closed | Fract. pr. m |
|---|---|---|---|---|---|---|---|
| 10 | | >80° | st | sm | ca | | |
| | | 0° | st | sm | | | |
| | | 10° | st | ro | | | |
| | | 0° | st | sm | | | |
| | | 40° | st | sl | | | |
| | | 70° | ir | ro | ca | | |
| | | >80° | st | sm | ca | | 10 |
| | | 30° | st | sl | | | |
| | | 30° | un | sl | | | |
| 11 | | >80° | st | sm | ca | | |
| | | >80° | ir | ro | ca | | |
| | | | | | | | 3 |
| | | >80° | st | sm | ca | | |
| | | >80° | st | ro | ca | | |
| 12 | | 25° | un | sl | | | |
| | | >80° | st | sm | ca | | |
| | | 0° | st | sm | ca | | 8 |
| | | 70° | ir | sm | ca | | |
| 13 | | | | | | | |
| | | >80° | ir | ro | ca | | |

⊘ two fracture set, 45° angel

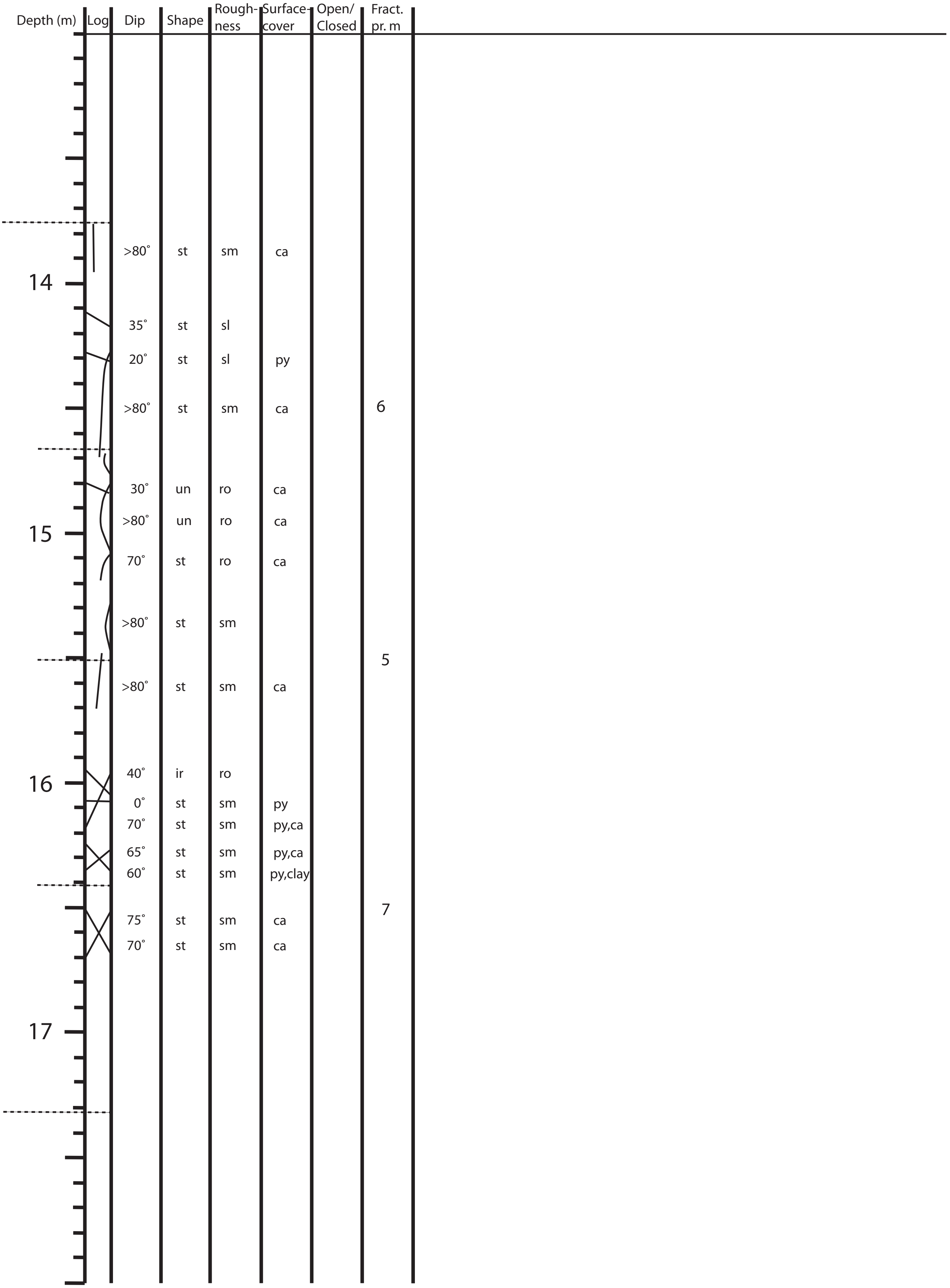
Closely spaced fractures with slickenside

# Billegrav 2; DGUnr.: 248.61 Box 4; 13.30 - 16.77 m



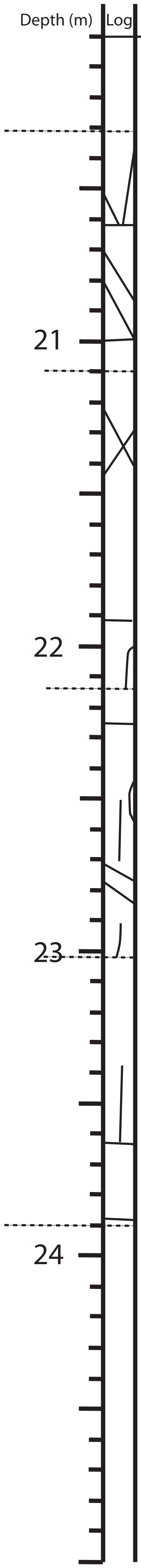
| Dip | Shape | Roughness | Surface cover | Open/ Closed | Fract. pr. m |
|---|---|---|---|---|---|
| >80 | Ir | Ro | Ca | | 3 |
| >80 | Ir | Ro | Ca | | |
| 45 | Un | Ro | Ca | Cl | |
| 45 | Ir | Sm | Ca | Cl | 4 |
| 45 | St | Sm | Ca | | |
| 45 | St | Sm | Ca | | |
| >80° | st | sm | ca | | |
| >80° | st | sm | ca | | 4 |
| >80° | st | sm | ca | | |
| 70° | st | ro | | | |
| 25° | un | sl | | | |
| 0° | st | sm | | | 5 |
| 70° | st | ro | | | |
| >80° | st | sm | | | |
| 35° | st | sm | | | |
| >80° | st | sm | ca | | |

# Billegrav 2; DGUnr.: 248.61    Box 5;  16.77 - 20.32 m



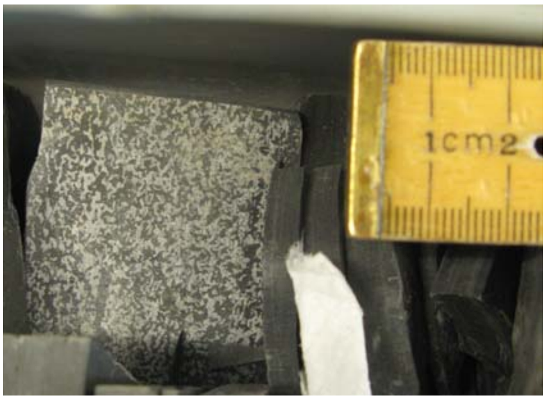
| Dip | Shape | Rough-ness | Surface-cover | Open/ Closed | Fract. pr. m |
|---|---|---|---|---|---|
| >80˚ | st | sm | ca | | |
| 35˚ | st | sl | | | |
| 20˚ | st | sl | py | | |
| >80˚ | st | sm | ca | | 6 |
| 30˚ | un | ro | ca | | |
| >80˚ | un | ro | ca | | |
| 70˚ | st | ro | ca | | |
| >80˚ | st | sm | | | |
| >80˚ | st | sm | ca | | 5 |
| 40˚ | ir | ro | | | |
| 0˚ | st | sm | py | | |
| 70˚ | st | sm | py,ca | | |
| 65˚ | st | sm | py,ca | | |
| 60˚ | st | sm | py,clay | | |
| 75˚ | st | sm | ca | | 7 |
| 70˚ | st | sm | ca | | |

# Billegrav 2; DGUnr.: 248.61 Box 6; 20.32 - 23.90 m

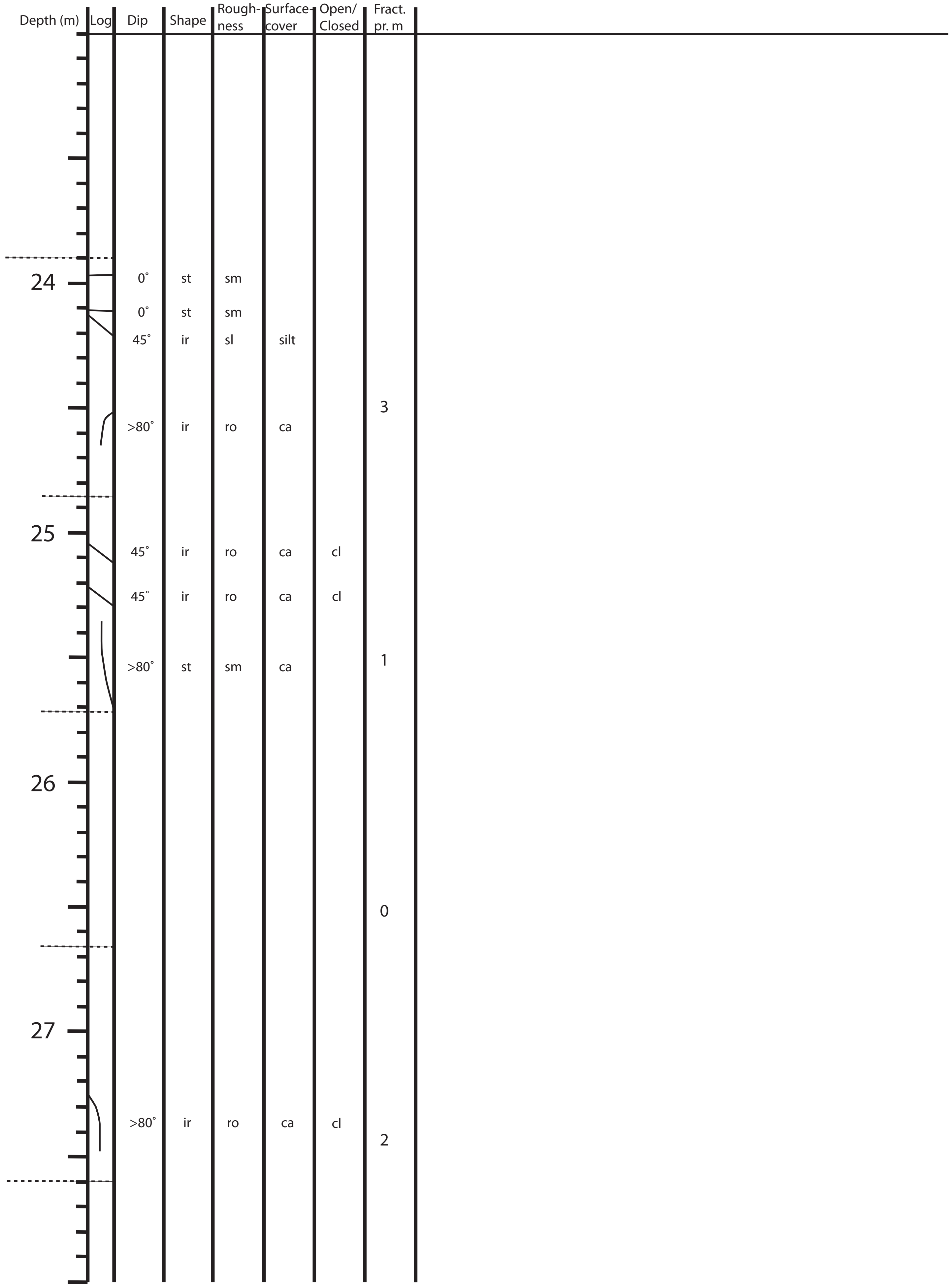


| Dip | Shape | Rough-ness | Surface-cover | Open/ Closed | Fract. pr. m |
|---|---|---|---|---|---|
| >80° | st | sm | ca, py | | |
| 70° | st | sm | ca,py | | 5 |
| 0° | st | sm | | | |
| 70° | st | sm | ca,py | | |
| 70° | st | sm | ca,py | | |
| 0° | st | sm | | | |
| 70° | st | sm | | | |
| 70° | st | sm | | | |
| | | | | | 5 |
| 0° | st | sm | | | |
| >80° | ir | ro | ca | | |
| 0° | st | sm | | | |
| >80° | un | sm | ca | | 7 |
| >80° | st | sm | ca | | |
| 45° | st | sl | | | |
| 45° | st | sl | | | |
| >80° | st | sm | ca | | |
| >80° | st | sm | ca | | 4 |
| 0° | st | sm | ca | | |
| 0° | st | ro | ca | | |

Foto 23.4m
Ca surface cover on vertical fracture

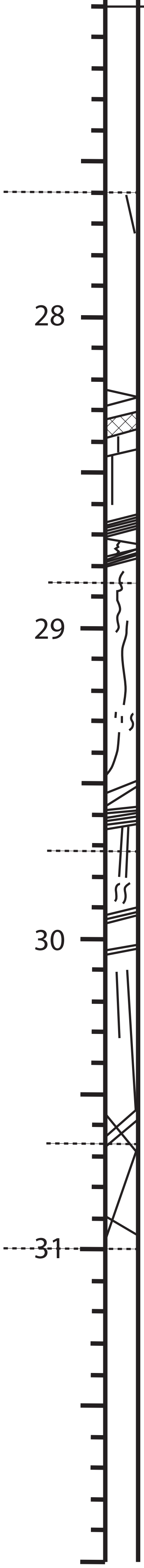


# Billegrav 2; DGUnr.: 248.61 Box 7; 23.90 - 27.60 m



| Depth (m) | Log | Dip | Shape | Rough-ness | Surface-cover | Open/ Closed | Fract. pr. m |
|---|---|---|---|---|---|---|---|
| | | 0° | st | sm | | | |
| | | 0° | st | sm | | | |
| | | 45° | ir | sl | silt | | |
| | | >80° | ir | ro | ca | | 3 |
| | | 45° | ir | ro | ca | cl | |
| | | 45° | ir | ro | ca | cl | |
| | | >80° | st | sm | ca | | 1 |
| | | | | | | | 0 |
| | | >80° | ir | ro | ca | cl | 2 |

# Billegrav 2; DGUnr.: 248.61    Box 8;  27.60 - 31.00 m



| Dip | Shape | Rough-ness | Surface-cover | Open/ Closed | Fract. pr. m |
|---|---|---|---|---|---|
| >80˚ | st | sm | silt | | |
| 20˚ | st | sl | | | |
| 20˚ | st | sl | | | |
| 30˚ | breccia | | | | |
| >80˚ | st | sm | | | |
| 30˚ | st | sl | | | 25 |
| >80˚ | st | sm | | | |
| 20˚ | st | sl | | | |
| 20˚ | st | sl | | | |
| 20˚ | st | sl | | | |
| >80˚ | ir | ro | ca | | |
| >80˚ | st | ro | | | |
| >80˚ | ir | ro | ca | cl | |
| >80˚ | st | sm | | | |
| 30˚ | st | sl | | | 17 |
| 60˚ | st | sl | | | |
| 10˚ | st | sl | | | |
| >80˚ | st | sm | | | |
| >80˚ | ir | ro | ca | cl | |
| 20˚ | st | sl | | | |
| 20˚ | st | sl | | | |
| >80˚ | st | sm | | | |
| >80˚ | st | sm | | | |
| 55˚ | st | sm | | | 9 |
| 55˚ | st | sm | | | |
| 75˚ | st | sm | | | |
| 80˚ | st | sm | | | |
| 60˚ | st | sm | | | |

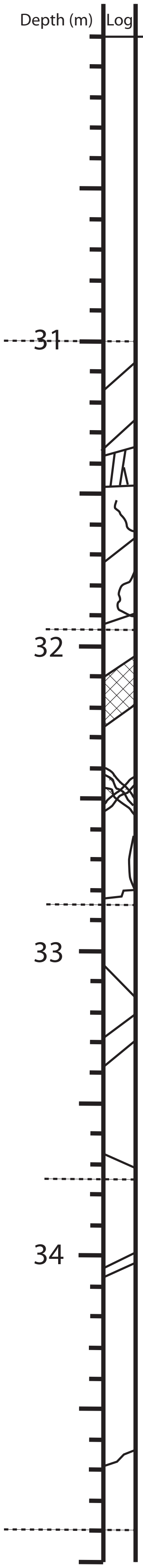
Fault breccia

2 zones with many parallel fractures with slickenside

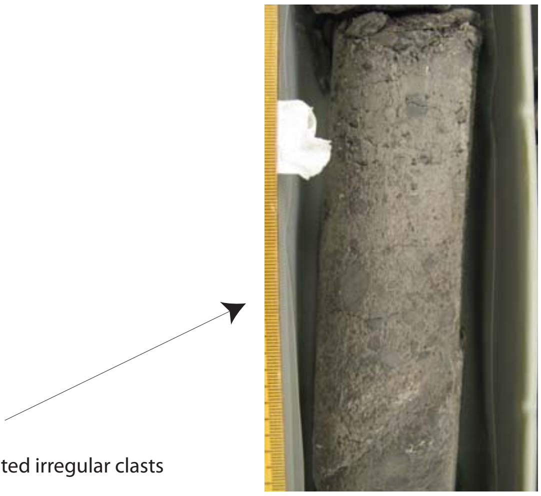
zone with closely spaced fraktures with slickenside

irregular sigmoidale shaped fractures, healed with calcite cement

# Billegrav 2; DGUnr.: 248.61 Box 9; 31.00 - 34.90 m



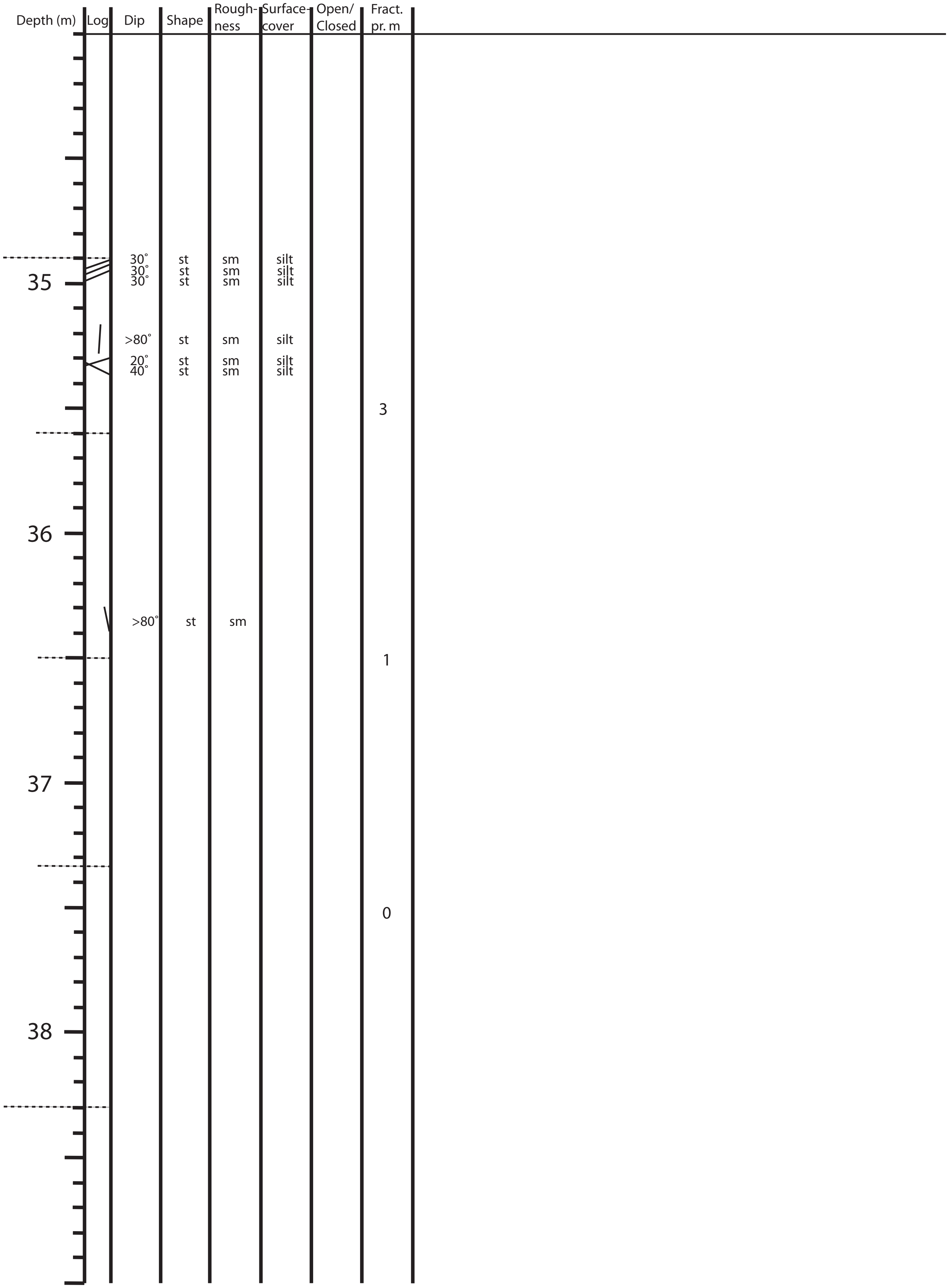
| Depth (m) | Log | Dip | Shape | Rough-ness | Surface-cover | Open/ Closed | Fract. pr. m |
|---|---|---|---|---|---|---|---|
| 31 | | | | | | | |
| | | 45° | st | ro | silt | | |
| | | 45° | st | ro | silt | | |
| | | 20° | st | sm | silt | | |
| | | >80° | st | sm | silt | | |
| | | 0° | st | sm | silt | | 9 |
| | | | ir | ro | clay,ca | | |
| | | >80° | st | sm | silt | | |
| | | | ir | ro | clay,ca | | |
| | | 20° | st | ro | clay | | |
| 32 | | | | | | | |
| | | 45° | Breccia | | | | |
| | | | | | | | 4 |
| | | >80° | st | sm | | | |
| | | 20° | ir | ro | py,ca | | |
| 33 | | | | | | | |
| | | 45° | st | sm | silt | | |
| | | 30° | st | sm | silt | | |
| | | 30° | st | sm | silt | | |
| | | | | | | | 4 |
| | | 30° | st | sm | silt | | |
| 34 | | 30° | st | sm | silt | | |
| | | 30° | st | sm | silt | | |
| | | | | | | | 6 |
| | | 30° | ir | sm | clay | | |



Fault breccia
with matrix supported irregular clasts

Zone with conjugating, irregular,
cacite filled fractures

## Billegrav 2; DGUnr.: 248.61 Box 10; 34.90 - 38.30 m



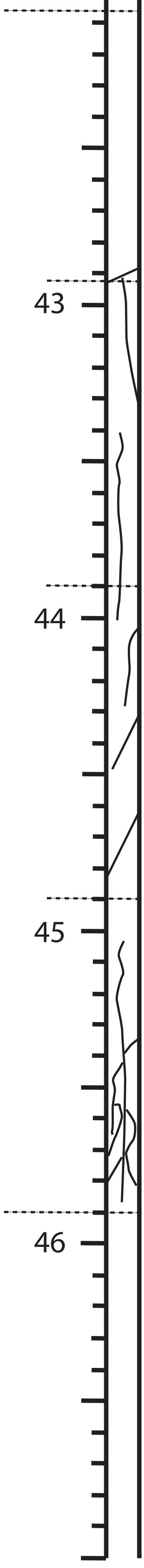
| Dip | Shape | Rough-ness | Surface-cover | Open/ Closed | Fract. pr. m |
|---|---|---|---|---|---|
| 30˚ | st | sm | silt | | |
| 30˚ | st | sm | silt | | |
| 30˚ | st | sm | silt | | |
| >80˚ | st | sm | silt | | |
| 20˚ | st | sm | silt | | |
| 40˚ | st | sm | silt | | |
| | | | | | 3 |
| >80˚ | st | sm | | | |
| | | | | | 1 |
| | | | | | 0 |

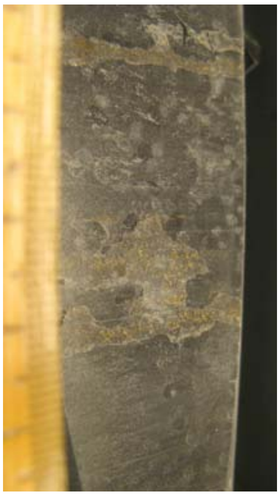
# Billegrav 2; DGUnr.: 248.61    Box 11;  38.30 - 42.07 m

| Depth (m) | Log | Dip | Shape | Rough-ness | Surface-cover | Open/ Closed | Fract. pr. m | |
|---|---|---|---|---|---|---|---|---|
| | | | | | | | 1 | |
| | | 30 | st | sm | | | | |
| 39 | | | | | | | | |
| | | | | | | | 1 | |
| | | 90 | | | Ca | cl | | Calcite cemented fiderspalte |
| 40 | | | | | | | | |
| | | | | | | | 1 | |
| | | >80 | ir | ro | Ca, clay | | | |
| 41 | | | | | | | | |
| | | | | | | | 2 | |
| | | 90 | | | Ca | cl | | |
| | | 30 | st | sm | | | | |
| 42 | | | | | | | | |

# Billegrav 2; DGUnr.: 248.61 Box 12; 42.07 - 45.90 m

| Depth (m) | Log | Dip | Shape | Roughness | Surface-cover | Open/ Closed | Fract. pr. m |
|---|---|---|---|---|---|---|---|
| | | 40° | st | sm | clay | | |
| | | >80° | st | sm | py,clay | | |
| | | >80° | st | sm | ca | cl | |
| | | >80° | st | sm | ca | cl | |
| | | 70° | st | sm | ca | cl | |
| | | 70° | st | sm | ca | cl | |
| | | >80° | ir | ro | ca | cl | |
| | | >80° | ir | sm | ca, clay | cl | |

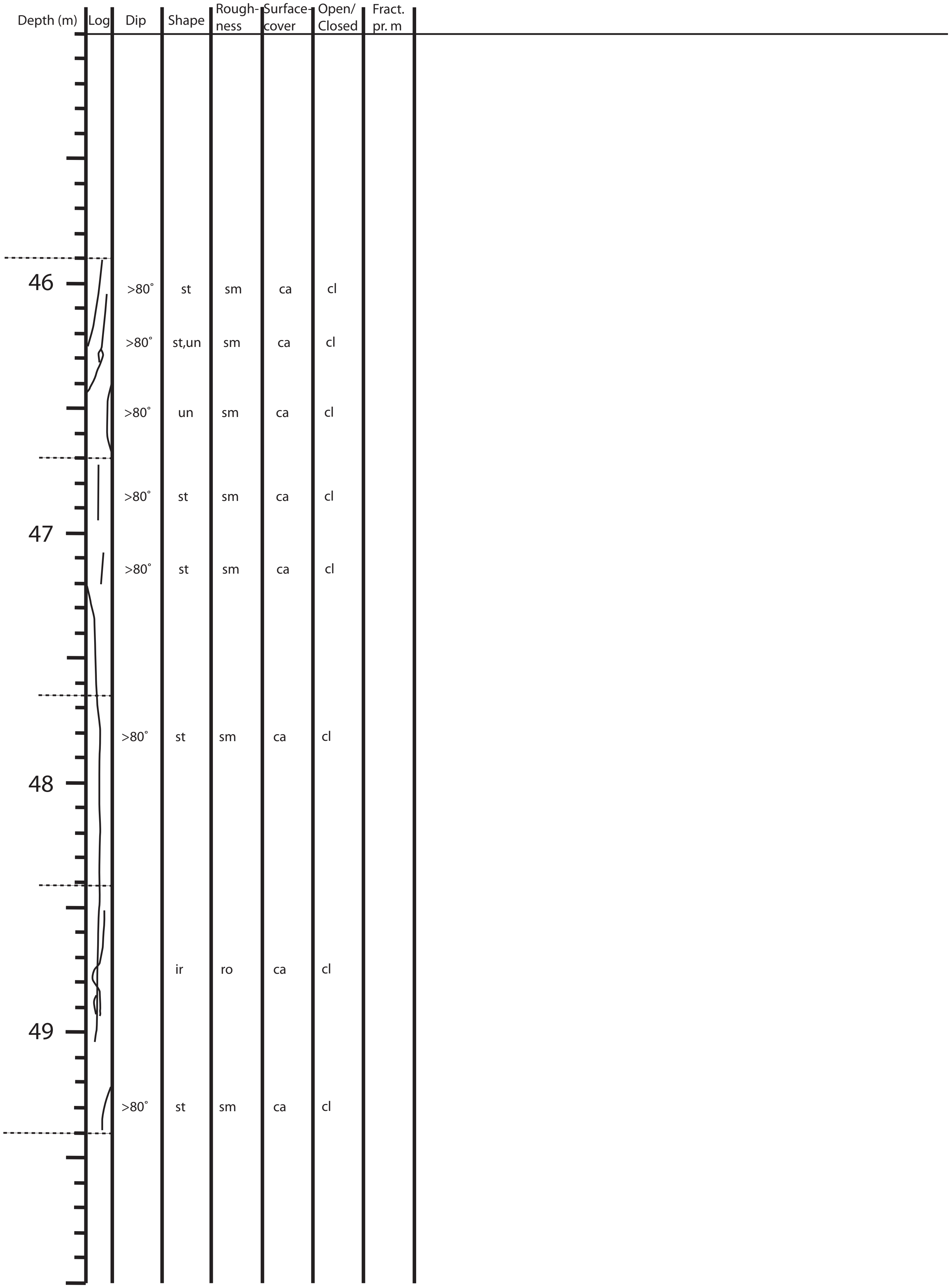



pyrite on a fracture surface


Fracture network. Fractures are healed with calcite cement, with up to mm large krystals.

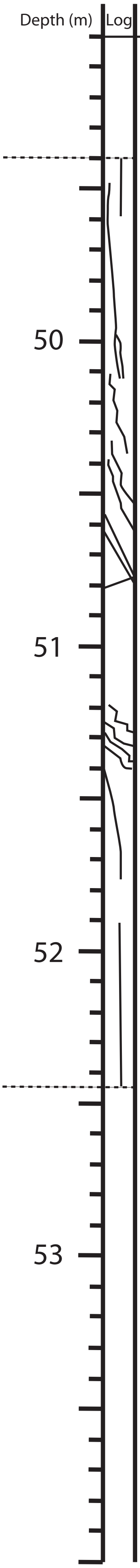

Two generations of fracture formation. First generation was cemented with calcite. Subsequently fractures were formed and clay was injected from clay layer into the fracture.

# Billegrav 2; DGUnr.: 248.61 Box 13; 45.90 - 49.40 m



| Dip | Shape | Rough-ness | Surface-cover | Open/ Closed | Fract. pr. m |
|---|---|---|---|---|---|
| >80˚ | st | sm | ca | cl | |
| >80˚ | st,un | sm | ca | cl | |
| >80˚ | un | sm | ca | cl | |
| >80˚ | st | sm | ca | cl | |
| >80˚ | st | sm | ca | cl | |
| >80˚ | st | sm | ca | cl | |
| | ir | ro | ca | cl | |
| >80˚ | st | sm | ca | cl | |

# Billegrav 2; DGUnr.: 248.61    Box 14;  49.40 - 52.45 m



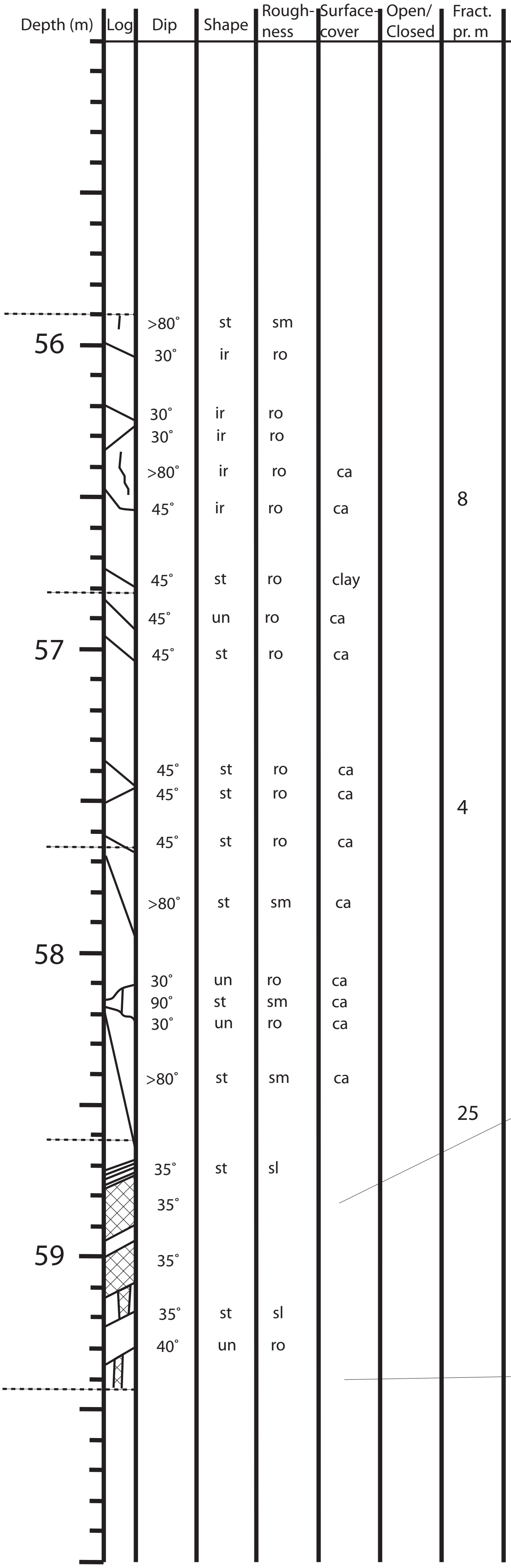
| Dip | Shape | Roughness | Surface-cover | Open/ Closed | Fract. pr. m |
|---|---|---|---|---|---|
| >80° | ir | ro | clay,ca | cl | 4 |
| >80° | ir | ro | ca | cl | |
| >80° | ir | ro | ca | cl | |
| 60° | ir | ro | ca | cl | |
| 60° | ir | ro | ca | cl | 6 |
| 60° | st | sm | ca | cl | |
| 60° | st | sm | ca | cl | |
| 30° | st | sm | ca | | |
| 45° | ir | ro | clay | | |
| 45° | ir | ro | clay | | |
| 45° | ir | ro | clay | | |
| 45° | ir | ro | clay | | |
| >80° | st | sm | ca | cl | 5 |
| >80° | st | sm | ca | cl | |

Very irregular, open, partly clayfilled fractures (33% of water inflow to borehole)

# Billegrav 2; DGUnr.: 248.61 Box 15; 52.45- 55.90 m

| Depth (m) | Log | Dip | Shape | Rough-ness | Surface-cover | Open/ Closed | Fract. pr. m | |
|---|---|---|---|---|---|---|---|---|
| | | >80° | st | sm | | | 3 | |
| | | >80° | st | sm | ca | | | |
| | | 0° | st | sm | | | | |
| 53 | | | | | | | | |
| | | >80° | st | sm | ca | cl | | |
| | | >80° | st | sm | ca | cl | | |
| | | 45° | st | sm | ca | cl | 3 | |
| 54 | | | | | | | | |
| | | >80° | un | ro | ca | | | |
| | | 80° | st | ro | ca | cl | | |
| | | 80° | st | ro | ca | cl | 4 | |
| 55 | | | | | | | | |
| | | 80° | st | ro | | | | small fault breccia.<br>1 cm thick. |
| | | | | | | | 4 | |
| | | 30° | st | sm | ca | | | |
| | | 30° | st | sm | ca | | | |
| | | >80° | st | sm | | | | |
| 56 | | | | | | | | |

# Billegrav 2; DGUnr.: 248.61 Box 16; 55.90- 59.47 m

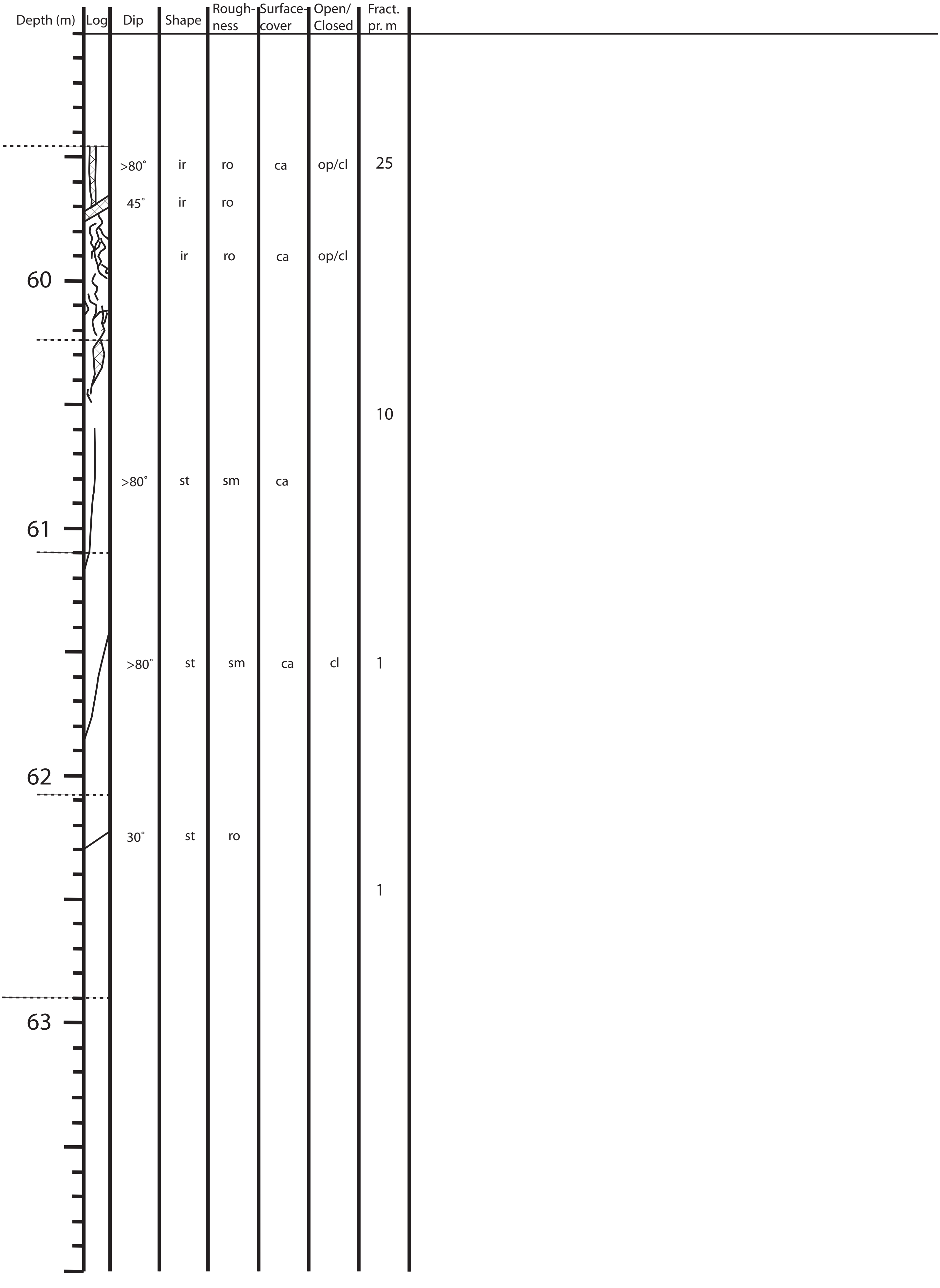


| Dip | Shape | Rough-ness | Surface-cover | Open/ Closed | Fract. pr. m |
|---|---|---|---|---|---|
| >80° | st | sm | | | |
| 30° | ir | ro | | | |
| 30° | ir | ro | | | |
| 30° | ir | ro | | | |
| >80° | ir | ro | ca | | |
| 45° | ir | ro | ca | | 8 |
| 45° | st | ro | clay | | |
| 45° | un | ro | ca | | |
| 45° | st | ro | ca | | |
| 45° | st | ro | ca | | |
| 45° | st | ro | ca | | 4 |
| 45° | st | ro | ca | | |
| >80° | st | sm | ca | | |
| 30° | un | ro | ca | | |
| 90° | st | sm | ca | | |
| 30° | un | ro | ca | | |
| >80° | st | sm | ca | | 25 |
| 35° | st | sl | | | |
| 35° | | | | | |
| 35° | | | | | |
| 35° | st | sl | | | |
| 40° | un | ro | | | |

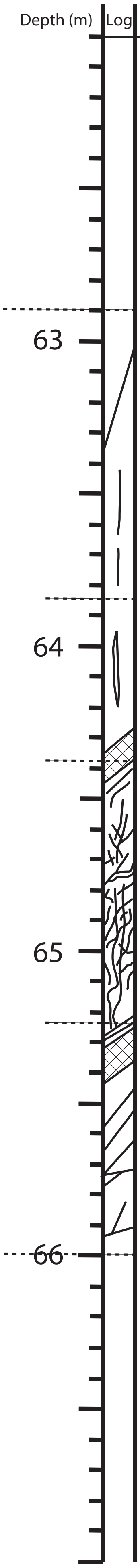
Fault breccia

Two generation of fault breccias.
The oldest is cemented with calcite,
and subsequently brecciated.

Billegrav 2; DGUnr.: 248.61 Box 17; 59.47- 62.90 m



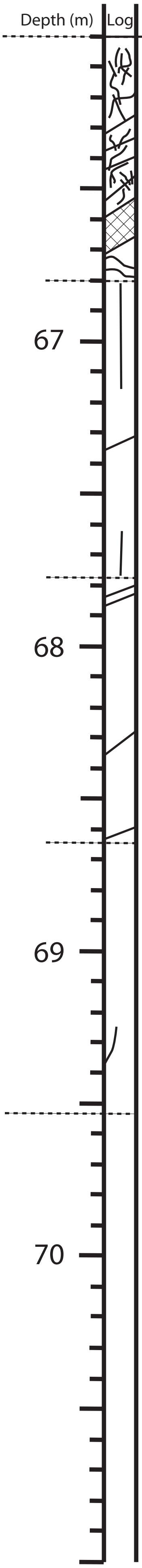
# Billegrav 2; DGUnr.: 248.61 Box 18; 62.90- 66.00 m



| Dip | Shape | Rough-ness | Surface-cover | Open/ Closed | Fract. pr. m |
|---|---|---|---|---|---|
| 80° | st | ro | ca | cl | |
| >80° | st | ro | ca | cl | 4 |
| >80° | st | ro | ca | cl | |
| >80° | st | sm | ca | cl | |
| 45° | breccia | ro | clay | | |
| | | | | | 25 |
| | | | ca, clay | cl | |
| 45° | breccia | ro | ca,clay | | |
| 60° | st | sm | ca | cl | |
| 60° | st | sm | ca | cl | 25 |
| 60° | st | sm | ca | cl | |
| >80° | st | sm | ca | cl | |
| 20° | ir | ro | ca | cl | |

Two generation of brecciation, calcite cemented and clay filled

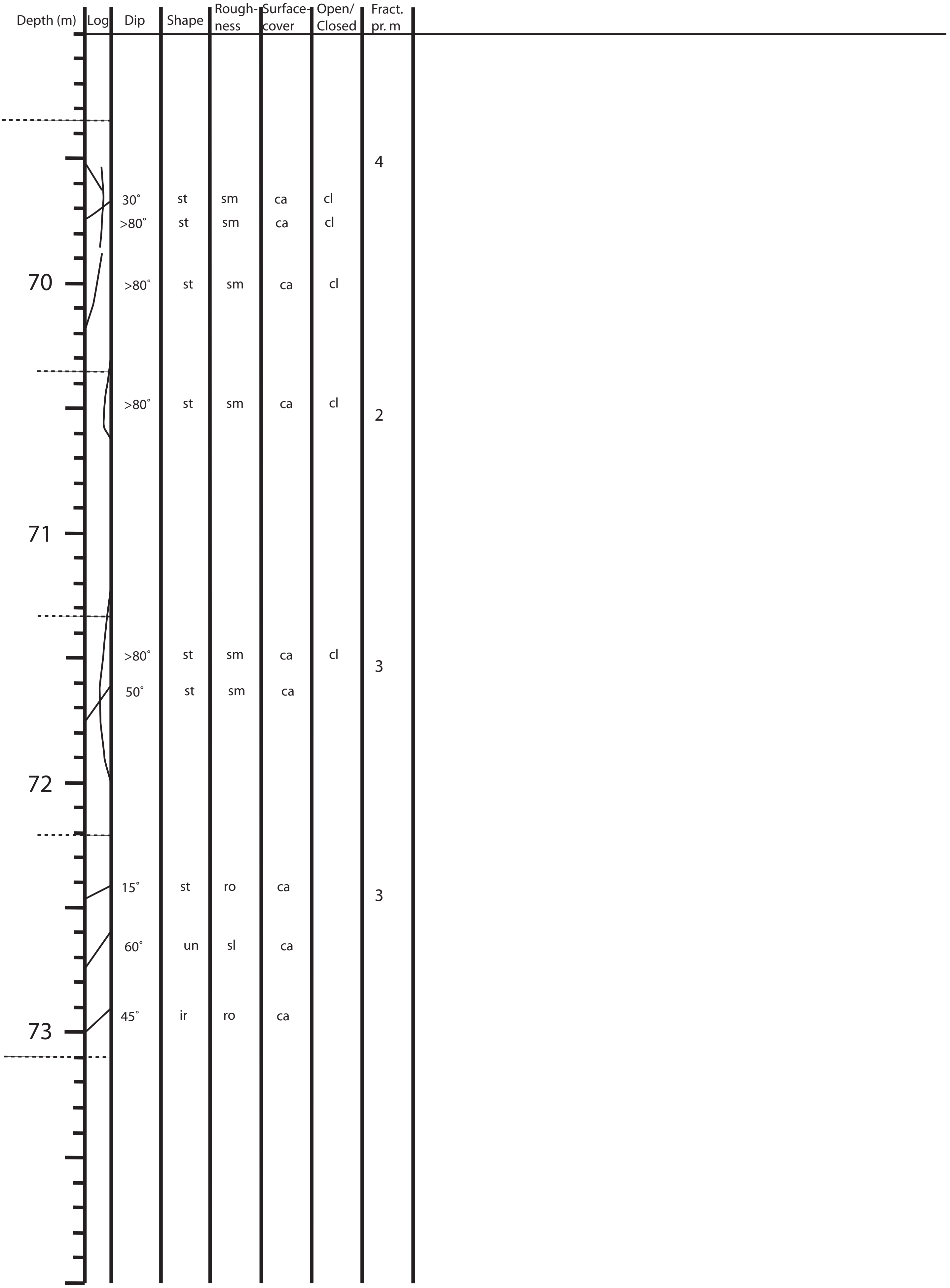
# Billegrav 2; DGUnr.: 248.61    Box 19;  66.00- 69.35 m



| Dip | Shape | Roughness | Surface cover | Open/ Closed | Fract. pr. m |
|---|---|---|---|---|---|
| 25° | st | sl |  |  | 25 |
| 25° | st | sl |  |  |  |
| 35° | ir | ro | clay | cl |  |
| 0° | un | ro | ca |  |  |
| 0° | un | ro | ca |  |  |
| >80° | st | sm | ca |  | 5 |
| 30° | st | sl |  |  |  |
| >80° | st | sm | ca | cl |  |
| 30° | un | sm | ca | cl |  |
| 30° | un | sm | ca | cl |  |
| 50° | st | ro | ca |  | 2 |
| 20° | st | sm | ca | cl |  |
| >80° | st | sm | ca | cl | 4 |

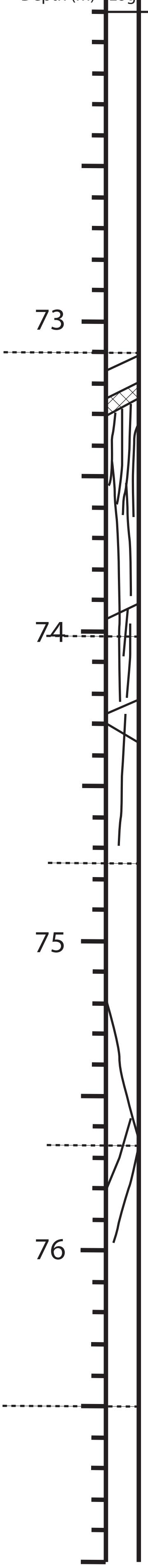
Irregular brecciated with few straight fractures with slickenside

# Billegrav 2; DGUnr.: 248.61 Box 20; 69.35- 73.10 m



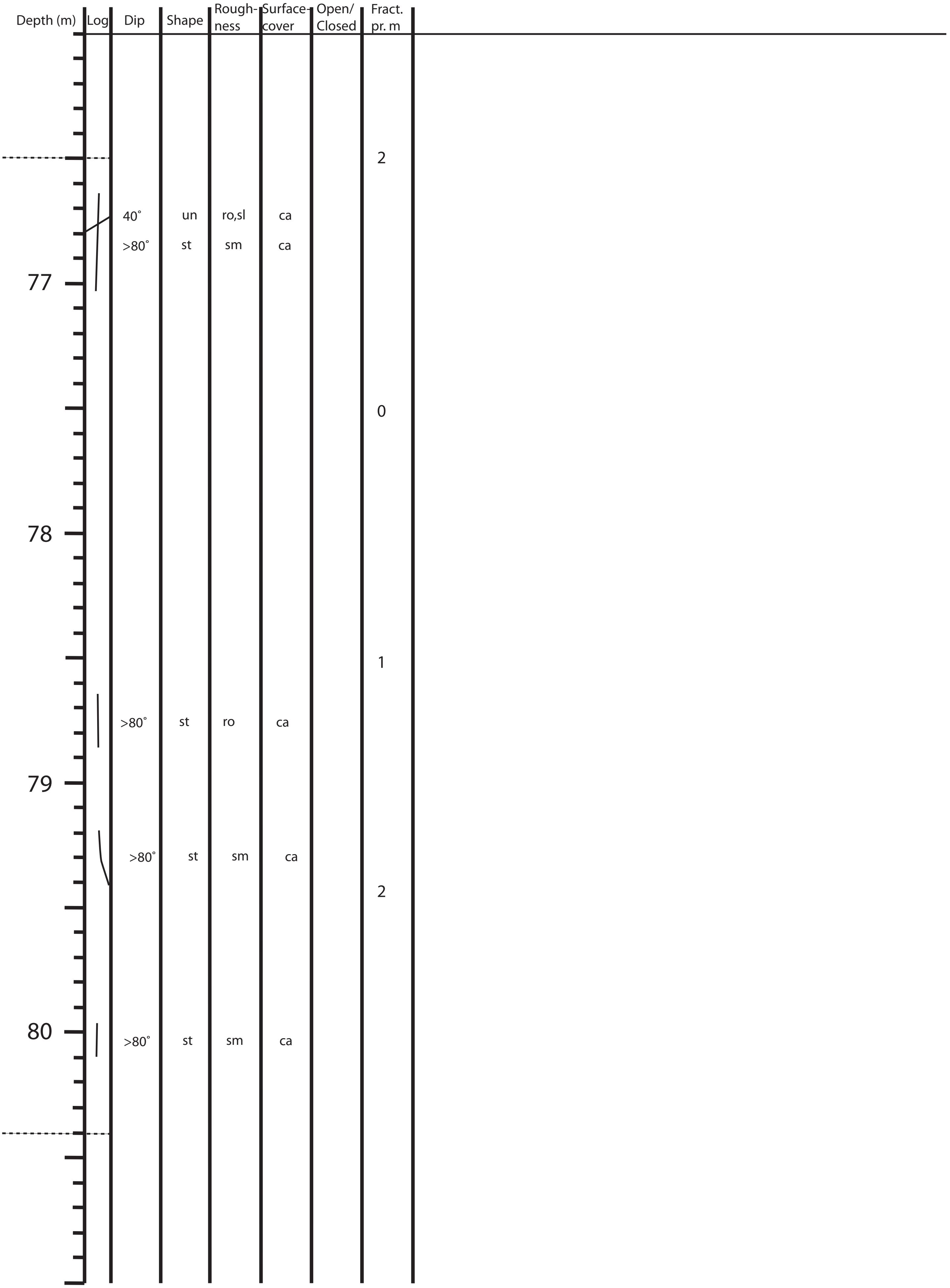
| Dip | Shape | Roughness | Surface-cover | Open/ Closed | Fract. pr. m |
|---|---|---|---|---|---|
| 30° | st | sm | ca | cl | 4 |
| >80° | st | sm | ca | cl | |
| >80° | st | sm | ca | cl | |
| >80° | st | sm | ca | cl | 2 |
| >80° | st | sm | ca | cl | 3 |
| 50° | st | sm | ca | | |
| 15° | st | ro | ca | | 3 |
| 60° | un | sl | ca | | |
| 45° | ir | ro | ca | | |

# Billegrav 2; DGUnr.: 248.61    Box 21;  73.10- 76.50 m

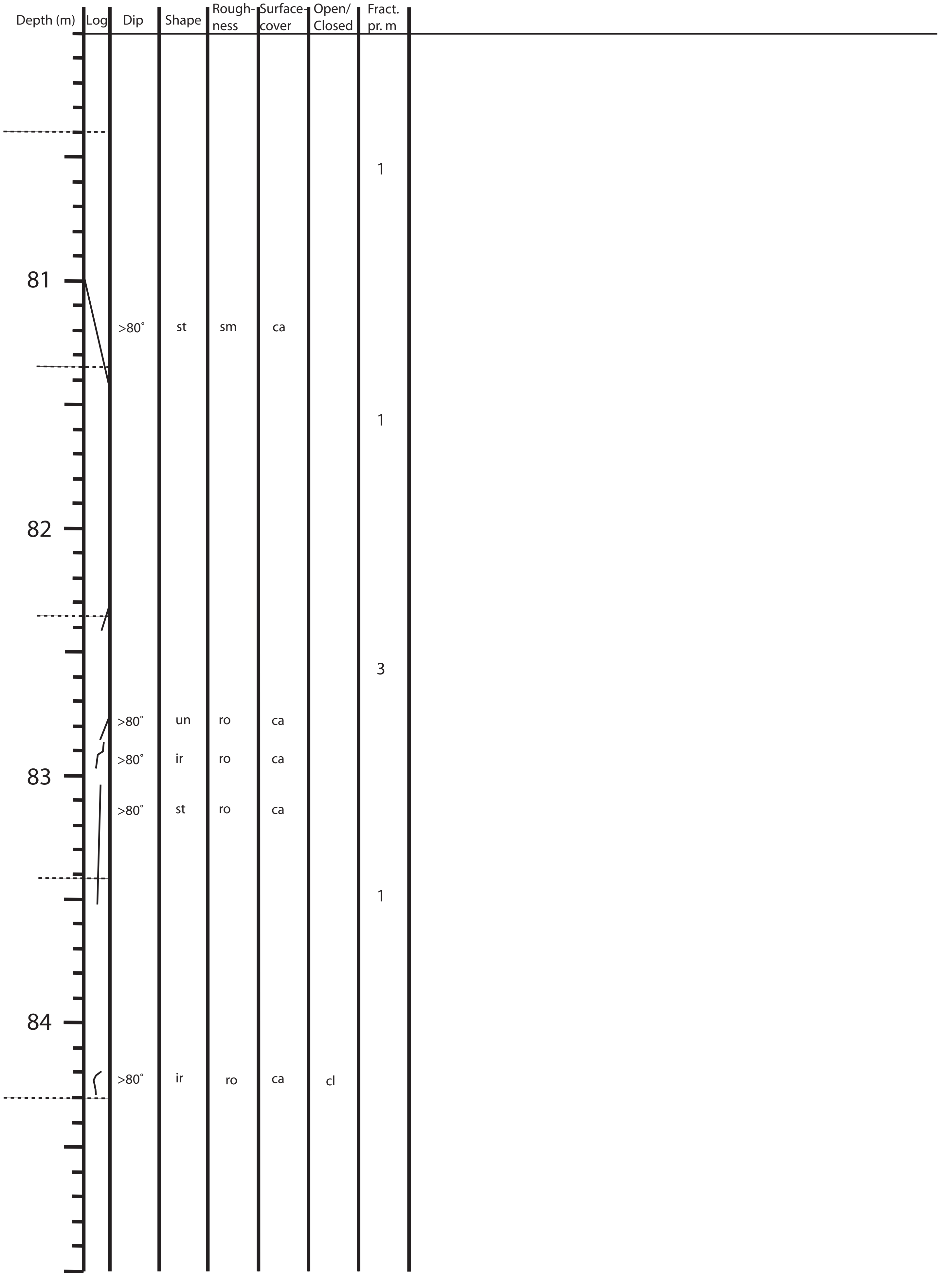


| Dip | Shape | Roughness | Surface-cover | Open/ Closed | Fract. pr. m | |
|---|---|---|---|---|---|---|
| 20° | st | sm | ca | | | |
| 20° | breccia | ro | | | | |
| >80° | ir | ro | ca | cl | 10 | zone with many closed fractures |
| 40° | un | sl | ca | | | |
| 20° | un | sl | | | | |
| 40° | un | sl | | | | |
| >80° | st | sm | ca | cl | 5 | |
| >80° | st | ro | ca | | | |
| | | | | | 3 | |
| >80° | st | ro | ca | | | |
| >80° | st | ro | ca | | | |

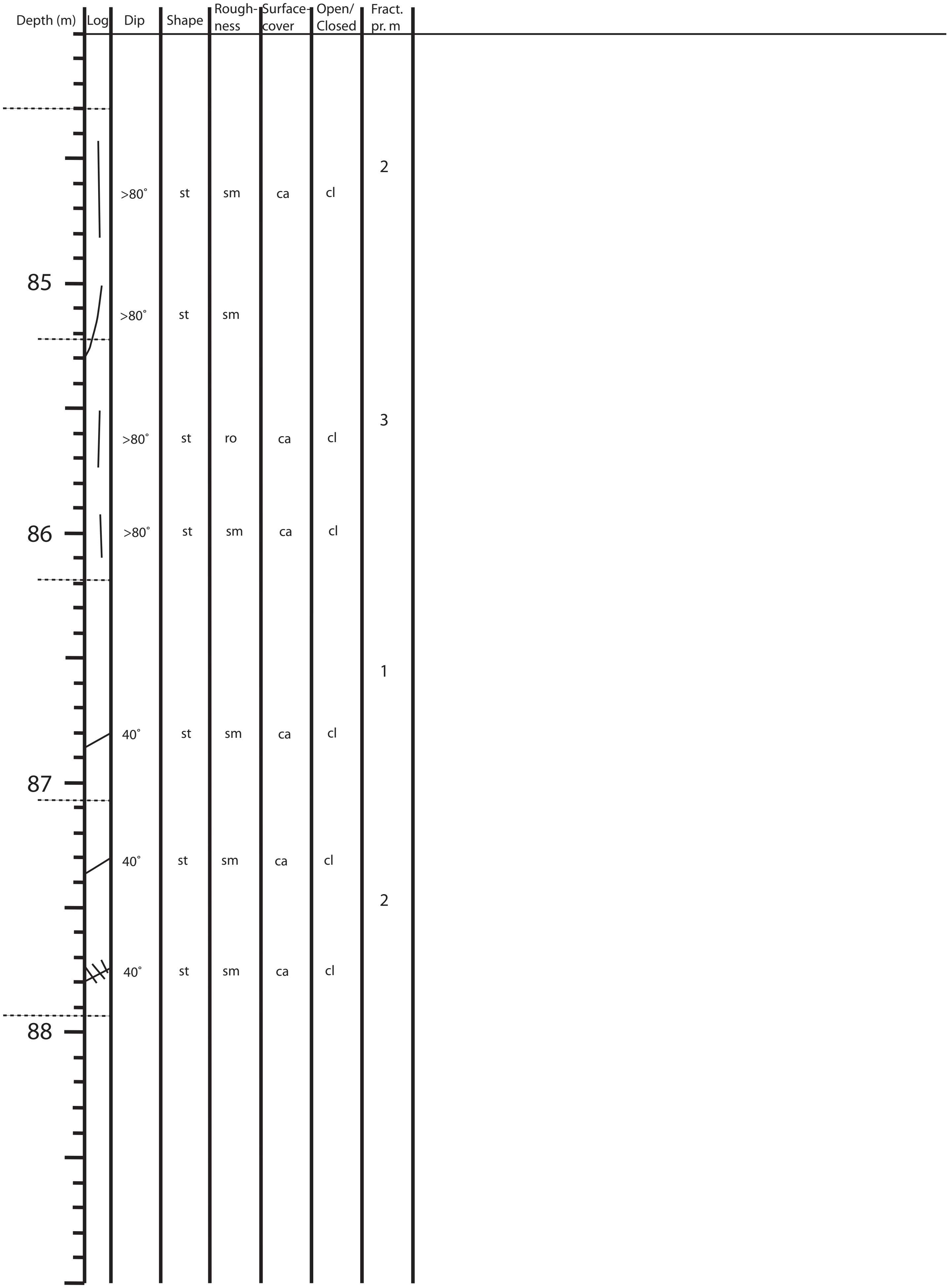
# Billegrav 2; DGUnr.: 248.61    Box 22;  76.50- 80.40 m



# Billegrav 2; DGUnr.: 248.61 Box 23; 80.40- 84.30 m

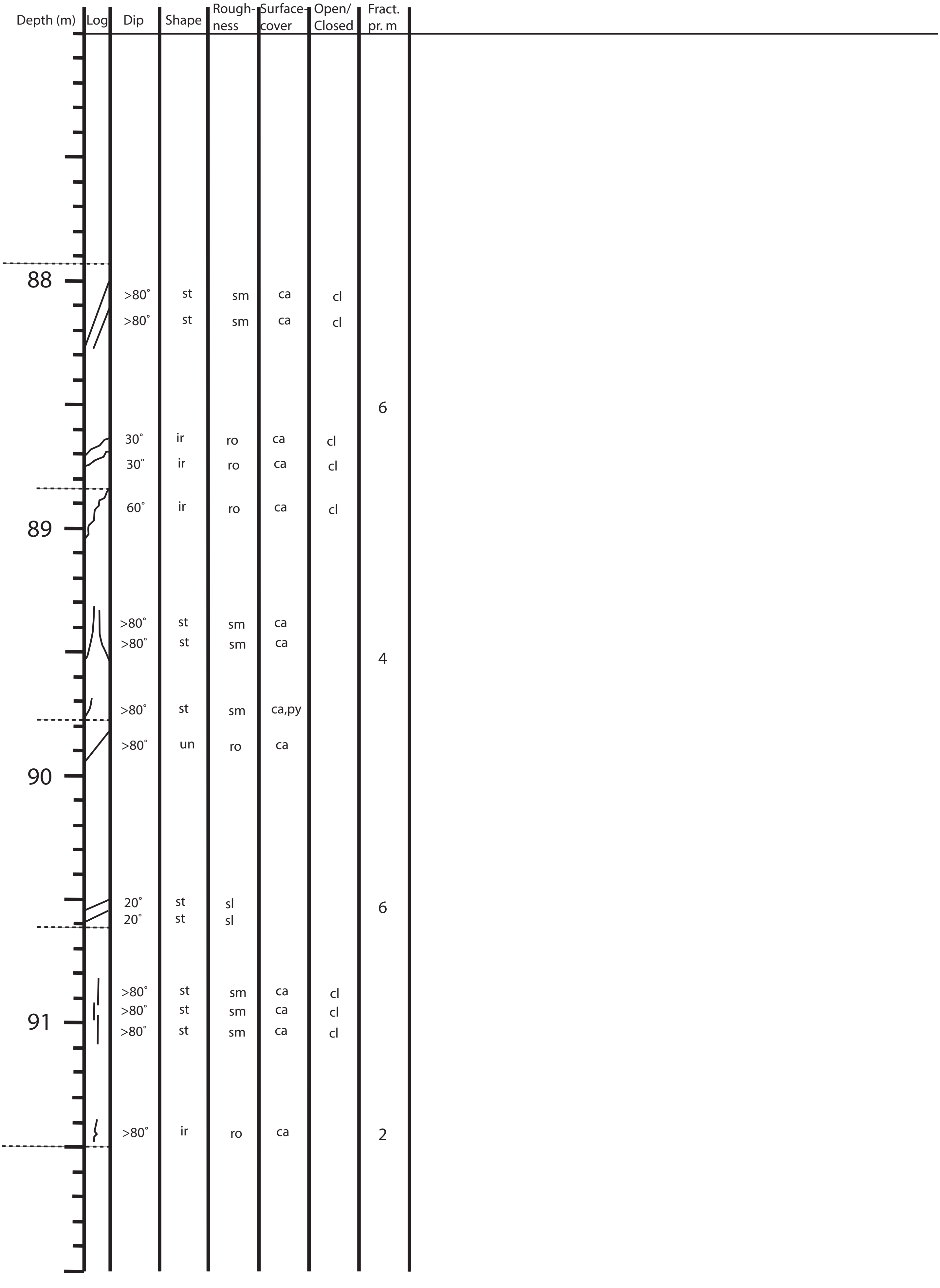


# Billegrav 2; DGUnr.: 248.61    Box 24;  84.30- 87.93 m



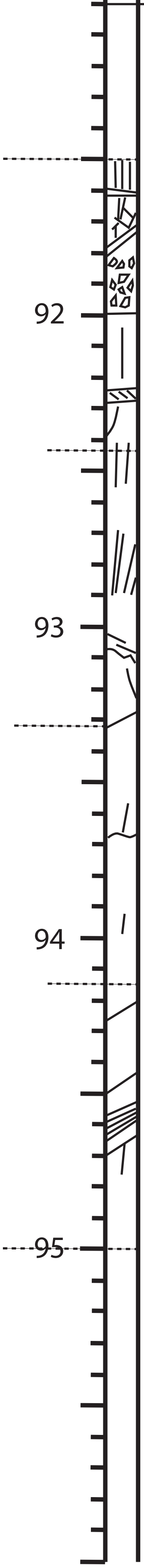
| Dip | Shape | Rough-ness | Surface-cover | Open/ Closed | Fract. pr. m |
|---|---|---|---|---|---|
| >80˚ | st | sm | ca | cl | 2 |
| >80˚ | st | sm | | | |
| >80˚ | st | ro | ca | cl | 3 |
| >80˚ | st | sm | ca | cl | |
| 40˚ | st | sm | ca | cl | 1 |
| 40˚ | st | sm | ca | cl | 2 |
| 40˚ | st | sm | ca | cl | |

# Billegrav 2; DGUnr.: 248.61 Box 25; 87.93- 91.50 m



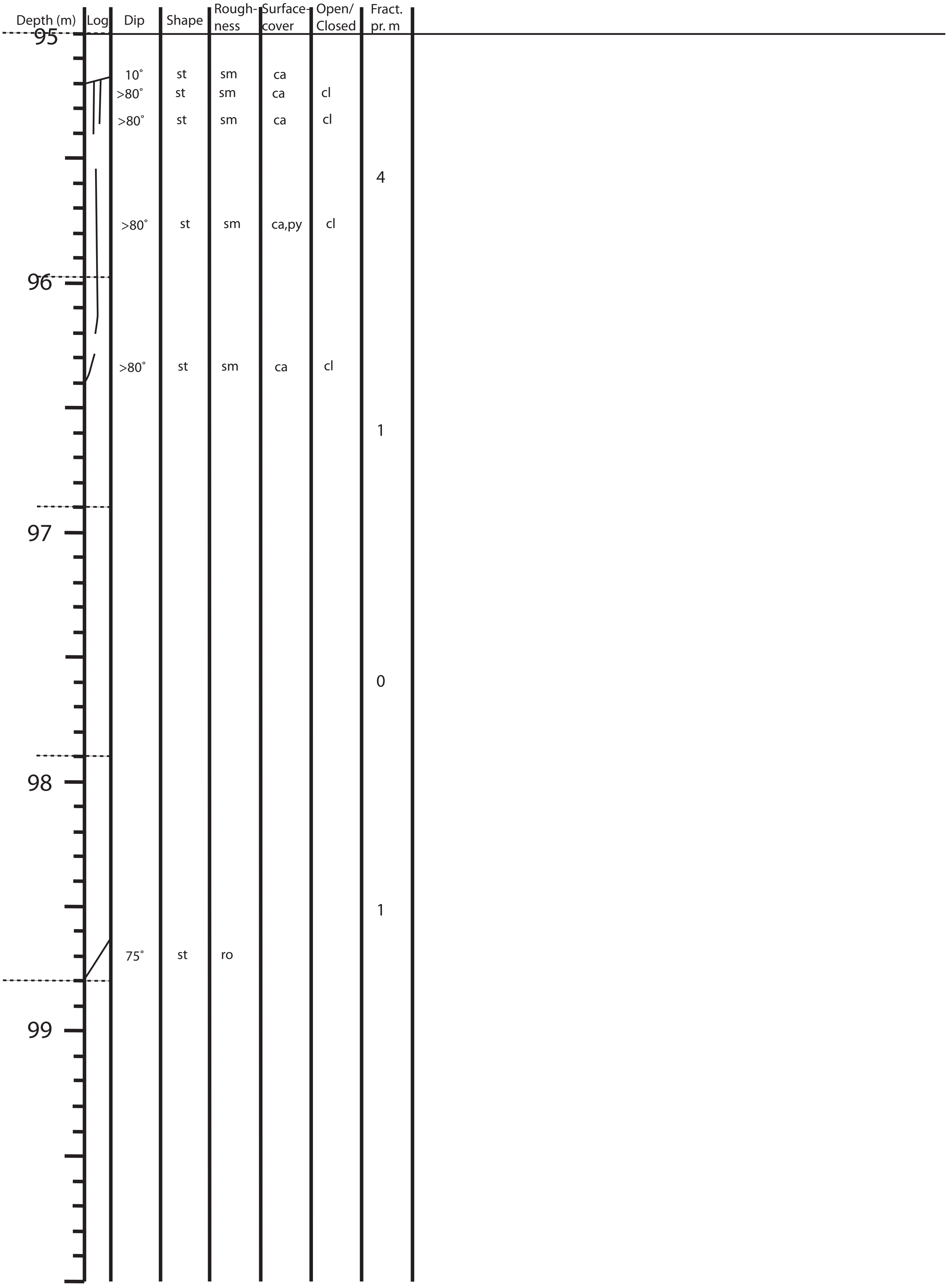
| Depth (m) | Log | Dip | Shape | Roughness | Surface cover | Open/ Closed | Fract. pr. m |
|---|---|---|---|---|---|---|---|
| 88 | | >80˚ | st | sm | ca | cl | 6 |
| | | >80˚ | st | sm | ca | cl | |
| | | 30˚ | ir | ro | ca | cl | |
| | | 30˚ | ir | ro | ca | cl | |
| 89 | | 60˚ | ir | ro | ca | cl | 4 |
| | | >80˚ | st | sm | ca | | |
| | | >80˚ | st | sm | ca | | |
| | | >80˚ | st | sm | ca,py | | |
| 90 | | >80˚ | un | ro | ca | | 6 |
| | | 20˚ | st | sl | | | |
| | | 20˚ | st | sl | | | |
| | | >80˚ | st | sm | ca | cl | 2 |
| 91 | | >80˚ | st | sm | ca | cl | |
| | | >80˚ | st | sm | ca | cl | |
| | | >80˚ | ir | ro | ca | | |

# Billegrav 2; DGUnr.: 248.61    Box 26;  91.50- 95.00 m



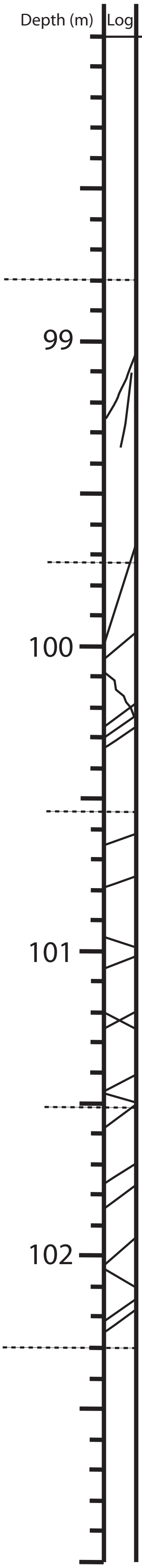
| Depth (m) | Dip | Shape | Roughness | Surface-cover | Open/ Closed | Fract. pr. m | |
|---|---|---|---|---|---|---|---|
| | >80° | st | sm | ca | cl | | |
| | >80° | st | sm | ca | cl | | |
| | >80° | st | sm | ca | cl | | |
| | | cl | | | | | |
| | | Breccia | | clay | cl | | Breccia with angular clasts and a clay matrix |
| 92 | | | | | | | |
| | >80° | st | sm | ca | | | |
| | | | | | | | sheared clay layer |
| | >80° | st | sm | ca | cl | | |
| | >80° | st | sm | ca | | | |
| | >80° | st | sm | ca | | 8 | |
| | >80° | st | sm | ca | cl | | |
| | >80° | st | sm | ca | cl | | |
| | >80° | st | sm | ca | cl | | |
| | >80° | st | sm | ca | cl | | |
| 93 | 20° | ir | ro | ca | cl | | |
| | >80° | st | ro | | | | |
| | 25° | un | ro | | | | |
| | | | | | | 8 | |
| | >80° | un | sm | ca | cl | | |
| | 0° | un | sm | ca | cl | | |
| 94 | >80° | st | sm | ca | cl | | |
| | 30° | un | ro | ca | cl | | |
| | 45° | st | sm | | | | |
| | 30° | un | ro | | | 9 | |
| | 30° | un | ro | | | | |
| | 40° | un | ro | | | | |
| | 30° | un | ro | clay | | | |
| | >80° | st | ro | | | | |
| 95 | | | | | | | |

# Billegrav 2; DGUnr.: 248.61    Box 27;  95.00- 98.80 m



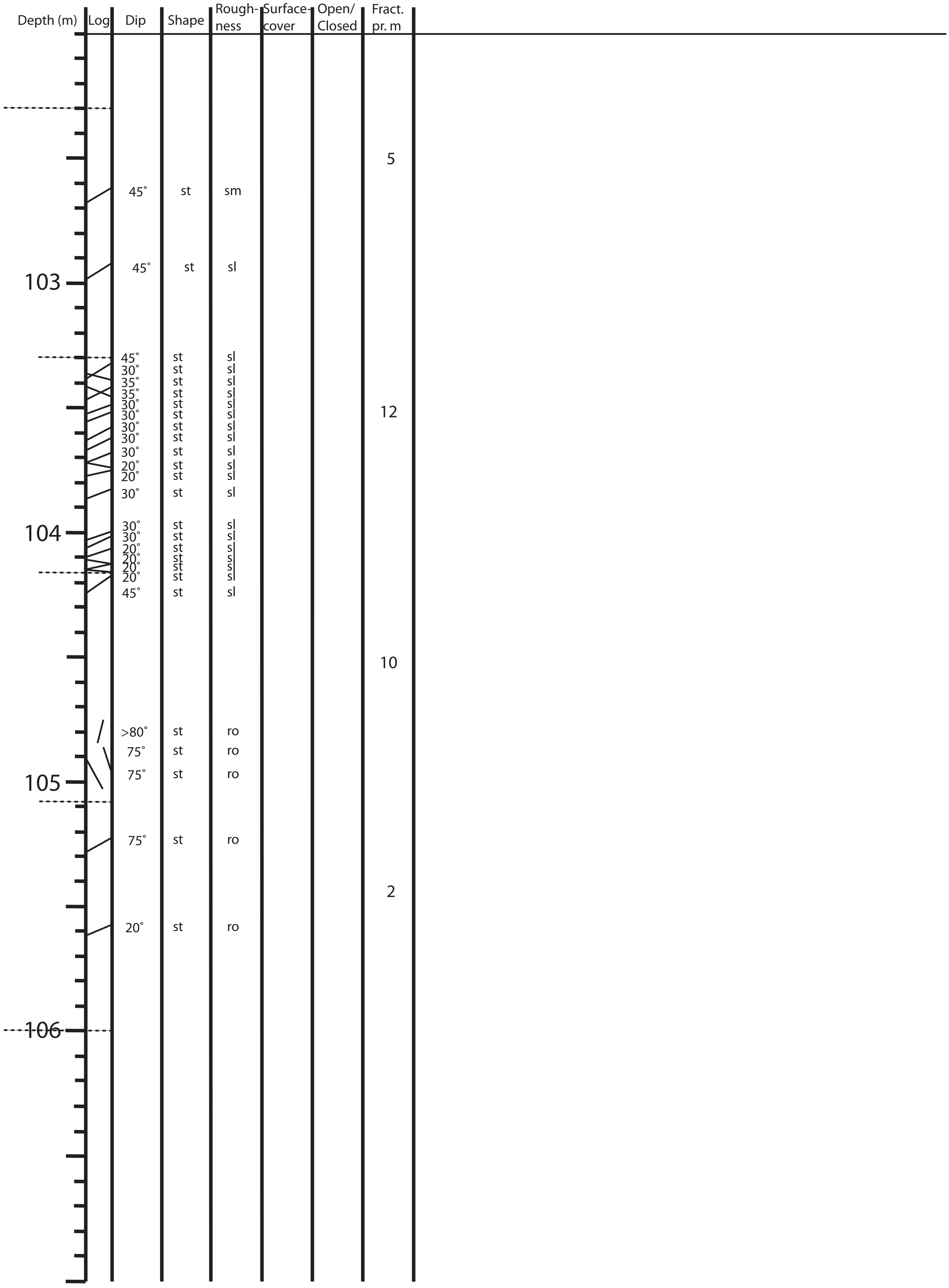
| Dip | Shape | Rough-ness | Surface-cover | Open/ Closed | Fract. pr. m |
|---|---|---|---|---|---|
| 10° | st | sm | ca | | |
| >80° | st | sm | ca | cl | |
| >80° | st | sm | ca | cl | |
| | | | | | 4 |
| >80° | st | sm | ca,py | cl | |
| >80° | st | sm | ca | cl | |
| | | | | | 1 |
| | | | | | 0 |
| | | | | | 1 |
| 75° | st | ro | | | |

# Billegrav 2; DGUnr.: 248.61    Box 28;  98.80- 102.30 m

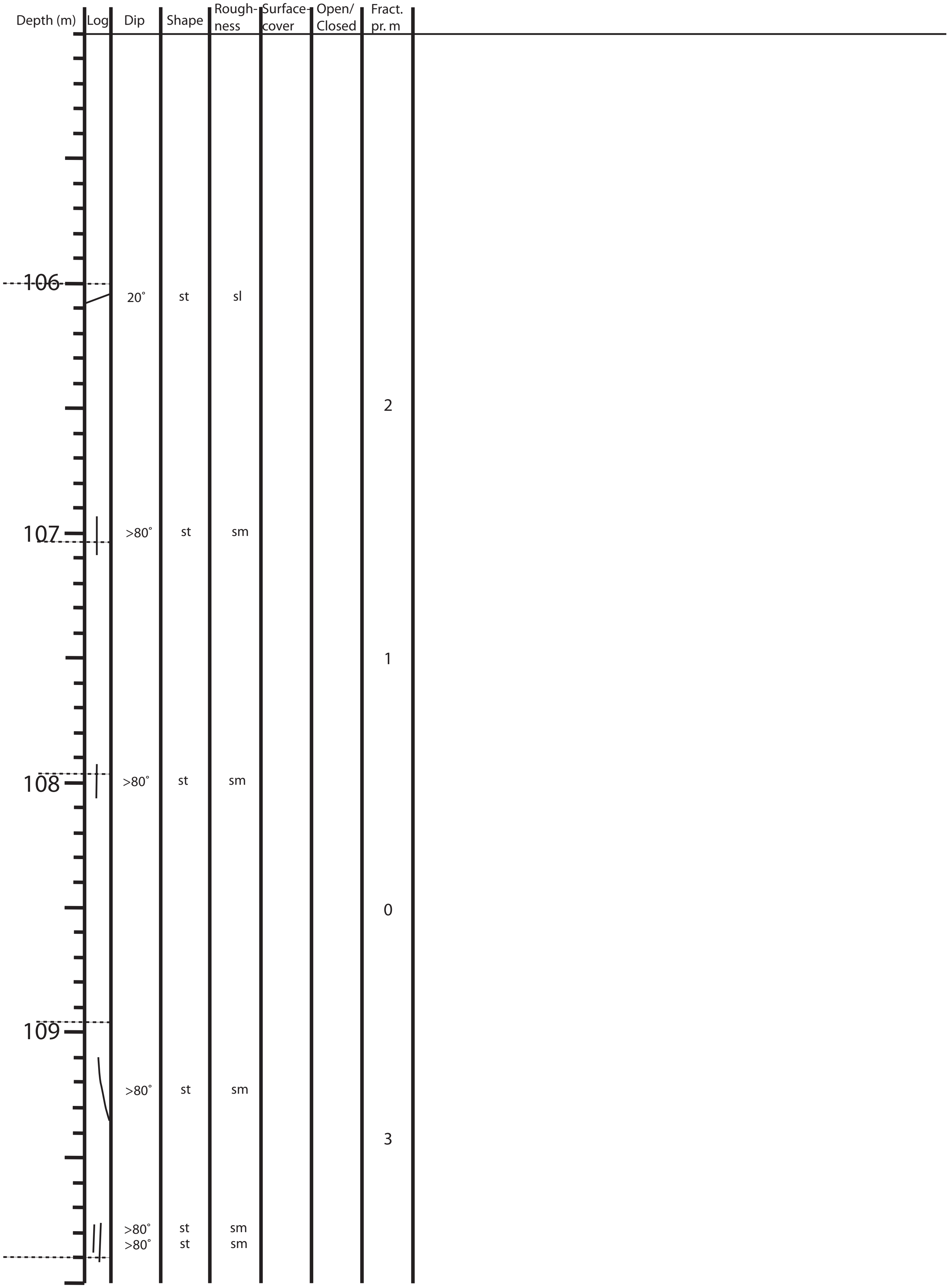


| Dip | Shape | Rough-ness | Surface-cover | Open/ Closed | Fract. pr. m |
|---|---|---|---|---|---|
| >80˚ | st | sm | ca | | |
| >80˚ | ir | sm | py | | |
| | | | | | 4 |
| 70˚ | ir | sm | | | |
| 35˚ | st | ro | ca | cl | |
| 75˚ | ir | ro | ca | cl | |
| 35˚ | st | ro | ca | cl | |
| 35˚ | st | ro | ca | cl | |
| 35˚ | st | ro | ca | cl | |
| | | | | | 7 |
| 20˚ | un | ro | | | |
| 25˚ | un | ro | | | |
| 10˚ | st | sl | | | |
| 20˚ | st | sl | | | |
| 20˚ | st | sl | | | |
| 20˚ | st | sl | | | |
| 20˚ | un | ro | | | |
| 10˚ | un | ro | | | |
| 45˚ | un | ro | | | 9 |
| 45˚ | ir | ro | | | |
| 35˚ | ir | ro | | | |
| 50˚ | ir | ro | | | |
| 45˚ | ir | ro | | | |
| 45˚ | ir | ro | | | |
| 45˚ | ir | ro | | | |

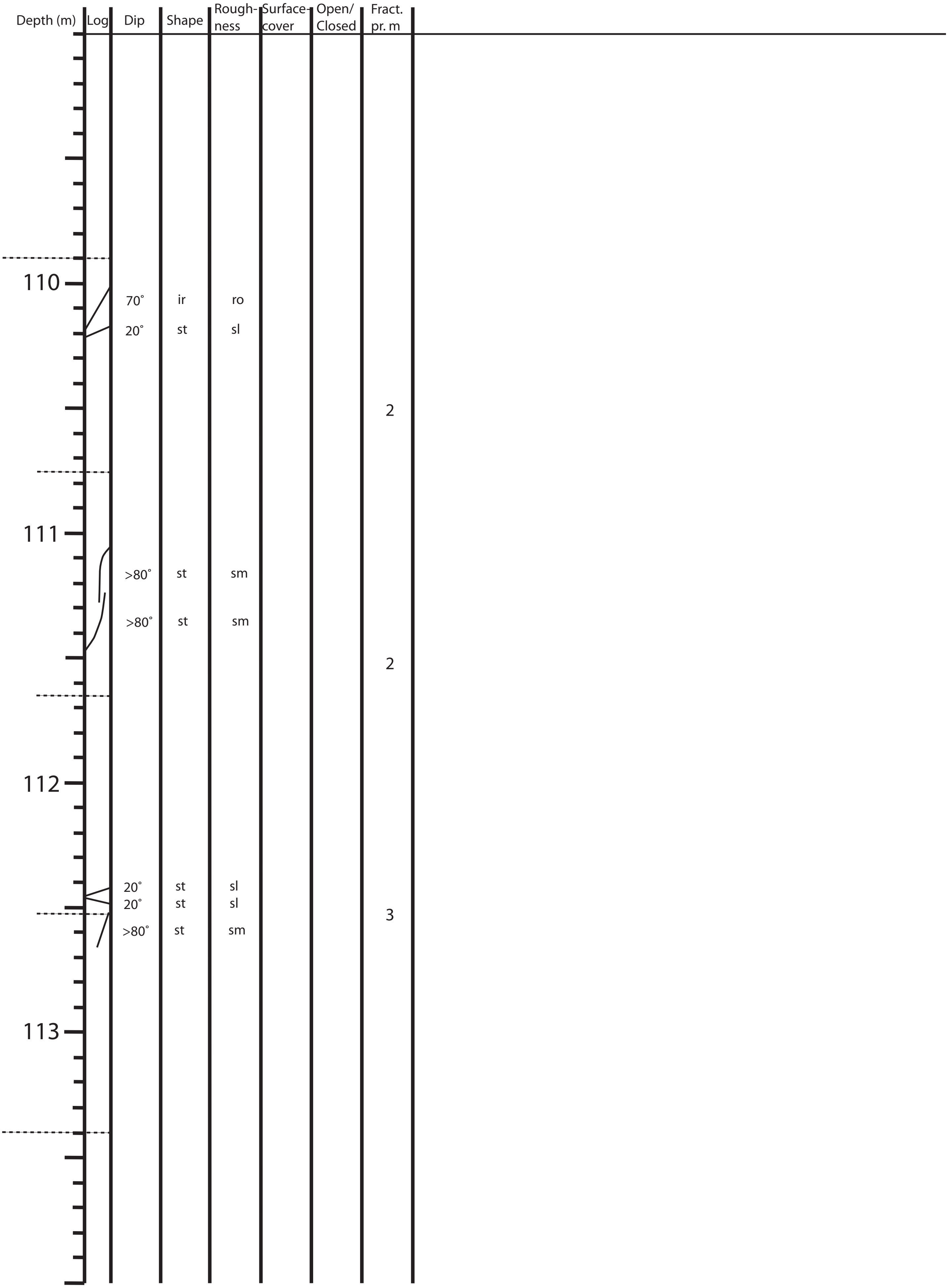
# Billegrav 2; DGUnr.: 248.61    Box 29;  102.30- 106.00 m



# Billegrav 2; DGUnr.: 248.61 Box 30; 106.00- 109.90 m

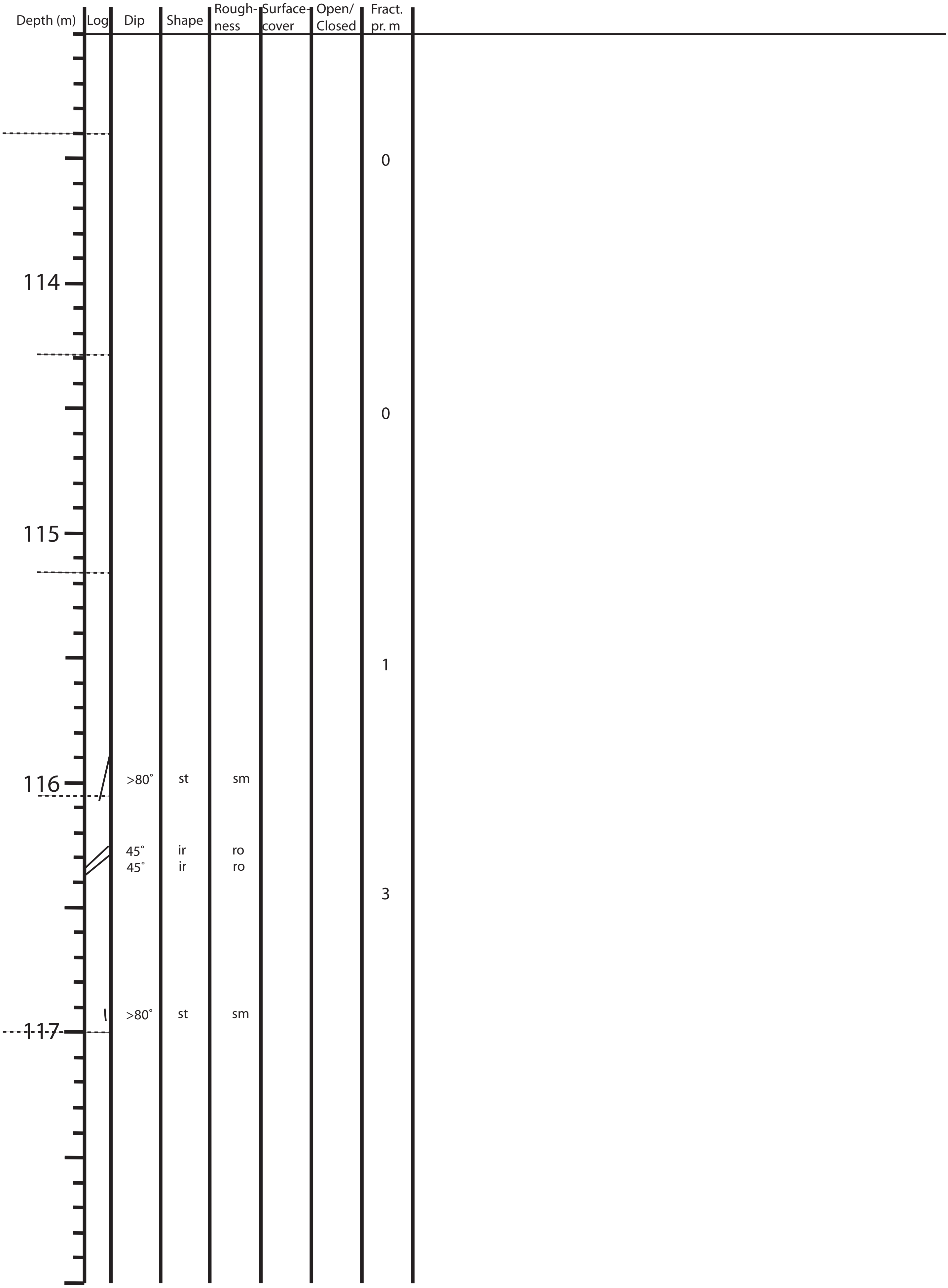


# Billegrav 2; DGUnr.: 248.61    Box 31;  109.90- 113.40 m

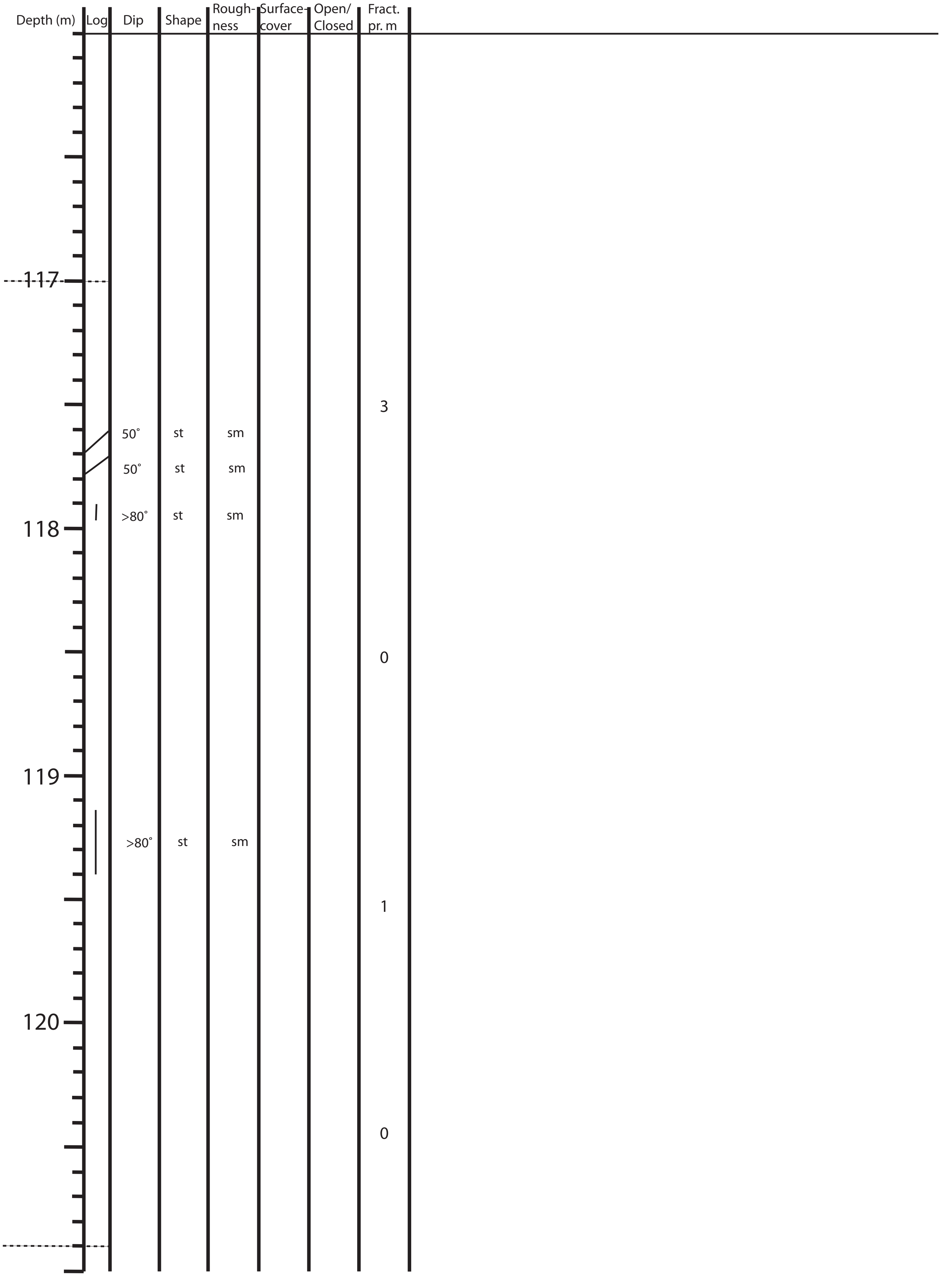


| Dip | Shape | Rough-ness | Surface-cover | Open/ Closed | Fract. pr. m |
|---|---|---|---|---|---|
| 70° | ir | ro | | | 2 |
| 20° | st | sl | | | |
| >80° | st | sm | | | 2 |
| >80° | st | sm | | | |
| 20° | st | sl | | | 3 |
| 20° | st | sl | | | |
| >80° | st | sm | | | |

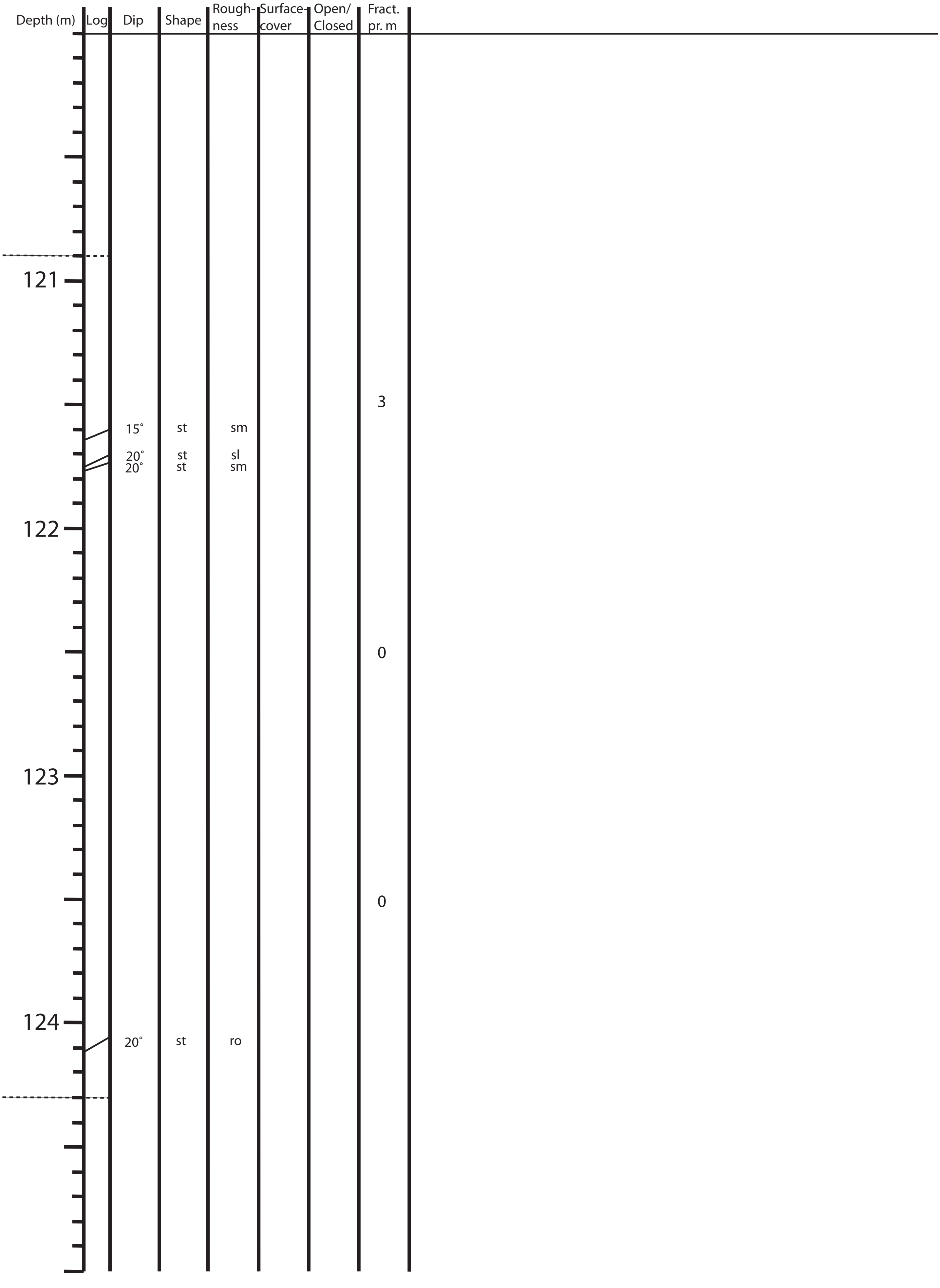
## Billegrav 2; DGUnr.: 248.61 Box 32; 113.40- 117.00 m



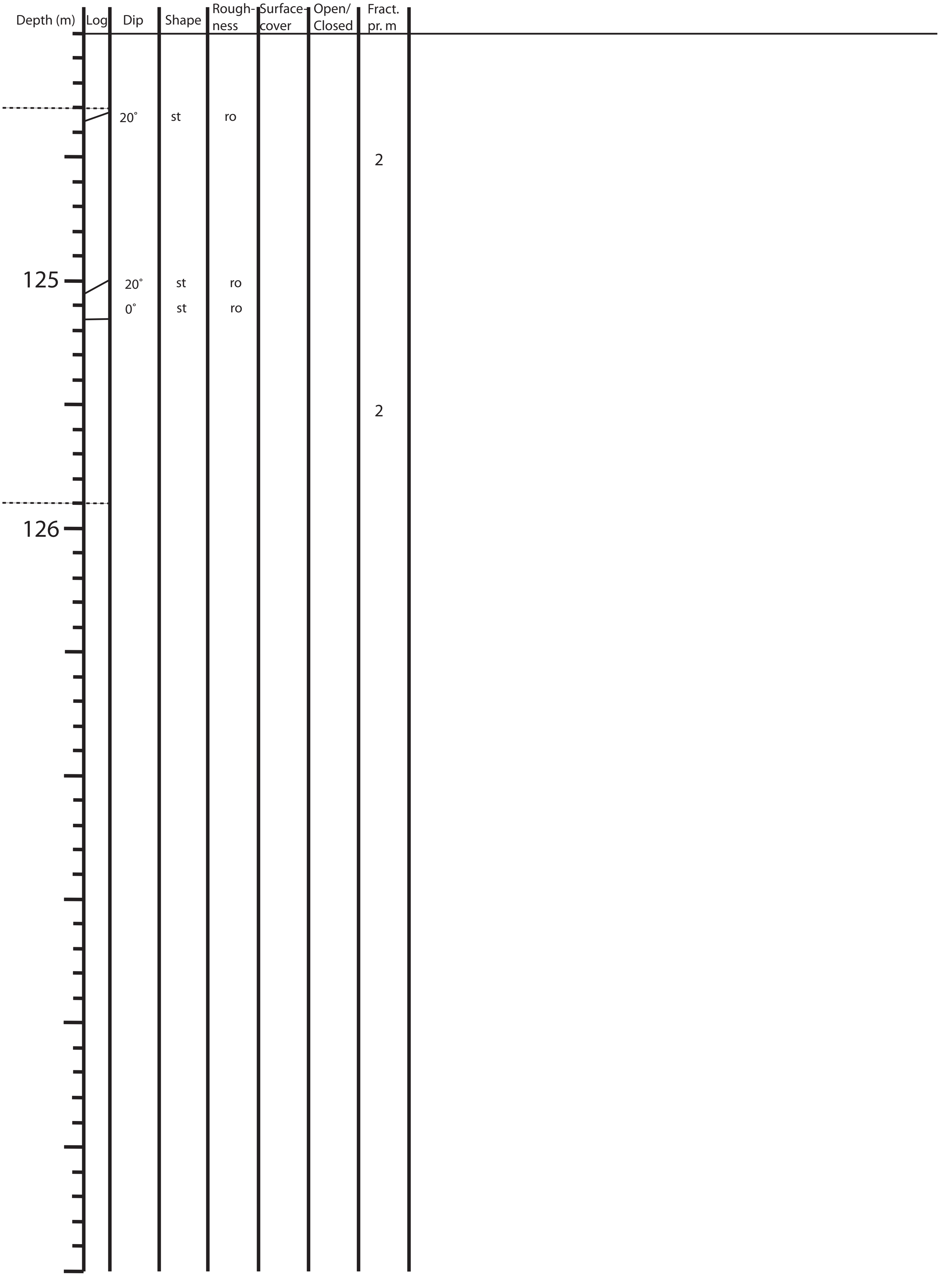
# Billegrav 2; DGUnr.: 248.61 Box 33; 117.00- 120.90 m



## Billegrav 2; DGUnr.: 248.61 Box 34; 120.90- 124.30 m



Billegrav 2; DGUnr.: 248.61 Box 35; 124.30- 125.90 m



# Appendix B: Fracture intensity log

File: ‘Appendix B fracture intensity log.xlsx’ in folder Appendix on the attached CD.

| Depth (m) | Fracture intensity |
|---:|---:|
| 2.5 | 43 |
| 3.5 | 15 |
| 4.5 | 4 |
| 5.5 | 4 |
| 6.5 | 9 |
| 7.5 | 8 |
| 8.5 | 2 |
| 9.5 | 5 |
| 10.5 | 10 |
| 11.5 | 3 |
| 12.5 | 8 |
| 13.5 | 3 |
| 14.5 | 4 |
| 15.5 | 4 |
| 16.5 | 5 |
| 17.5 | 6 |
| 18.5 | 5 |
| 19.5 | 7 |
| 20.5 | 5 |
| 21.5 | 5 |
| 22.5 | 7 |
| 23.5 | 4 |
| 24.5 | 3 |
| 25.5 | 1 |
| 26.5 | 0 |
| 27.5 | 2 |
| 28.5 | 25 |
| 29.5 | 17 |
| 30.5 | 9 |
| 31.5 | 9 |
| 32.5 | 4 |
| 33.5 | 4 |
| 34.5 | 6 |
| 35.5 | 3 |
| 36.5 | 1 |
| 37.5 | 0 |
| 38.5 | 1 |
| 39.5 | 0 |
| 40.5 | 1 |
| 41.5 | 1 |
| 42.5 | 1 |
| 43.5 | 3 |
| 44.5 | 3 |
| 45.5 | 7 |

| Depth (m) | Fracture intensity |
|---|---|
| 46.5 | 4 |
| 47.5 | 2 |
| 48.5 | 2 |
| 49.5 | 4 |
| 50.5 | 6 |
| 51.5 | 5 |
| 52.5 | 3 |
| 53.5 | 3 |
| 54.5 | 4 |
| 55.5 | 4 |
| 56.5 | 8 |
| 57.5 | 4 |
| 58.5 | 9 |
| 59.5 | 25 |
| 60.5 | 10 |
| 61.5 | 1 |
| 62.5 | 1 |
| 63.5 | 4 |
| 64.5 | 25 |
| 65.5 | 25 |
| 66.5 | 25 |
| 67.5 | 5 |
| 68.5 | 2 |
| 69.5 | 4 |
| 70.5 | 2 |
| 71.5 | 3 |
| 72.5 | 3 |
| 73.5 | 10 |
| 74.5 | 5 |
| 75.5 | 3 |
| 76.5 | 2 |
| 77.5 | 0 |
| 78.5 | 1 |
| 79.5 | 1 |
| 80.5 | 1 |
| 81.5 | 1 |
| 82.5 | 3 |
| 83.5 | 1 |
| 84.5 | 2 |
| 85.5 | 3 |
| 86.5 | 1 |
| 87.5 | 2 |
| 88.5 | 6 |
| 89.5 | 4 |
| 90.5 | 6 |
| 91.5 | 25 |
| 92.5 | 8 |
| 93.5 | 8 |
| 94.5 | 9 |

| Depth (m) | Fracture intensity |
|---|---|
| 95.5 | 4 |
| 96.5 | 1 |
| 97.5 | 0 |
| 98.5 | 1 |
| 99.5 | 4 |
| 100.5 | 7 |
| 101.5 | 9 |
| 102.5 | 5 |
| 103.5 | 12 |
| 104.5 | 10 |
| 105.5 | 2 |
| 106.5 | 2 |
| 107.5 | 1 |
| 108.5 | 0 |
| 109.5 | 3 |
| 110.5 | 2 |
| 111.5 | 2 |
| 112.5 | 3 |
| 113.5 | 0 |
| 114.5 | 0 |
| 115.5 | 1 |
| 116.5 | 3 |
| 117.5 | 3 |
| 118.5 | 0 |
| 119.5 | 1 |
| 120.5 | 0 |
| 121.5 | 3 |
| 122.5 | 0 |
| 123.5 | 0 |
| 124.5 | 2 |
| 125.5 | 2 |