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Geological logging of drill cores from borehole BH 02-13 and BH 03-13 at Jettan, Nordnes mountain in Troms county, Northern Norway

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REPORT

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Summary:

Two drill holes are located at Jettan in the Nordnes mountain in Troms county, named BH 02-2013 and BH 03-2013. The boreholes were drilled during summer/autumn 2013 by Arctic drilling and the drill cores were logged at the Geological Survey of Norway (NGU) in January 2014. Both drill cores are approximately 100 meter long (98.08 and 100.94 m) and due to fracture and/or fault zones the drill hole were cemented and re-drilled several times to keep stable. A short part of BH 03-2013 has a "double set" of the drill core at 44-45.5 m, where the original borehole needed to be abandoned due to stability problems, and a new nearby borehole was drilled.

The drill cores are logged with regards to bedrock type, fracture frequency and zones of interest with respect to sliding plane(s) and movement. The entire drill cores are photographed, in dry and wet, and are documented with pictures and detailed description in this report.

The bedrock occurring in the drill cores is successively banded garnetiferous mica schist, marble, banded garnetiferous mica schist with layers of marble and marble with layers of mica schist. All bedrock types are meta sedimentary rock of medium grade metamorphosis, and the transition between the different bedrock types is gradual. The foliation is pervasive with a sub-horizontal orientation that locally is strongly folded.

In the BH 02-2013 core the main deformation zone is at 36.62 m to 53.15 m. This zone consists of zones with core loss, heavily fractured rock and zones with clay. The zones containing the most clay are regarded as the zones with potentially the most displacement and lie at 46.50-46.62 m and 53-53.11 m. The foliation in these sections is altering from sub-horizontal to sub-vertical (60°-70° dip) and back to sub-horizontal. The change in foliation may cause extra fracturing in the drill core. At 24.72-25.35 and 26.75-27 m core loss occur, with zones of crushed rock before or after, but this may be due to more frequent vertical fractures or many open fractures that cause problems while drilling. Below 55 m a few zones of crushed rock occur, but they are not regarded as essential for the instability of the rock, possibly with the exception of the zone of deformed rocks at ca. 89,5-91 meter where a zone of ca. 13 cm consists of finely crushed rock followed by ca. 20 cm of coarsely crushed rocks. This zone of deformed rocks at ca. 89.5 to 91 meter is located where an old fault with cohesive fault rock is observed.

In BH 03-2013 the main deformation zone is at 42.3-46 m and is represented by core loss and crushed rock. No clear zones of clay are present in the main zone. At 24-39 m occur a narrow zones of crushed rock and occasional core loss, but it is likely that these zones are related to frequent vertical fractures that complicate the drilling process. At 72-72.3 m an old fault occur with fault rock such as cohesive breccia and possibly gouge material. This old fault has later been disturbed and is now crushed rock. At 76.28-76.58 m core loss occurred, that may be due to vertical fractures that are frequent. At 80.80-81.30 m a zone of finely crushed rock, potentially clay, occur in a mica rich bedrock.

Both borehole 02 and 03 is logged with Optical Televiewer and reported by Elvebakk (2014; NGU report 2014.016). In the borehole the fracture frequency is in general lower than in the cores, but the distinctive zones are recognized in both logs; core logs and Optical Televiewer log. Since the drill cores are not oriented the fracture orientation can only be found in the borehole log by Elvebakk (2014). The cores are now stored at Løkken drill core and rock sample storage at the NGU.

Keywords: Core logging	Bedrock	Rock slope
		Report

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1. INTRODUCTION

The drill holes are from Jettan in the Nordnes mountain, named BH 02-13 and BH 03-13. They were drilled during summer/autumn 2013 by Arctic drilling and the drill cores were logged at the Geological Survey of Norway (NGU) in January 2014. The cores are now stored at Løkken drill core and rock sample storage at the NGU. Both drill cores are approximately 100 meter long (98.08 and 100.94 m) and due to fracture and/or fault zones, the drill hole was cemented and re-drilled several times to keep stable. A short part of BH 03-13 has a "double set" of drill core at 44-45.5 m, where the drilling diverted from the original drill hole. Here the original borehole needed to be abandoned due to stability problems, and a new nearby borehole was drilled.

The drill cores are logged with regards to bedrock type, fracture frequency and zones of interest with respect to sliding plane(s). All drill cores are photographed, first dry and then wet, and are documented with pictures and detailed description in this report. A student at the Norwegian University of Science and Technology (NTNU) will use some of these data in his Master of Science thesis (2014).

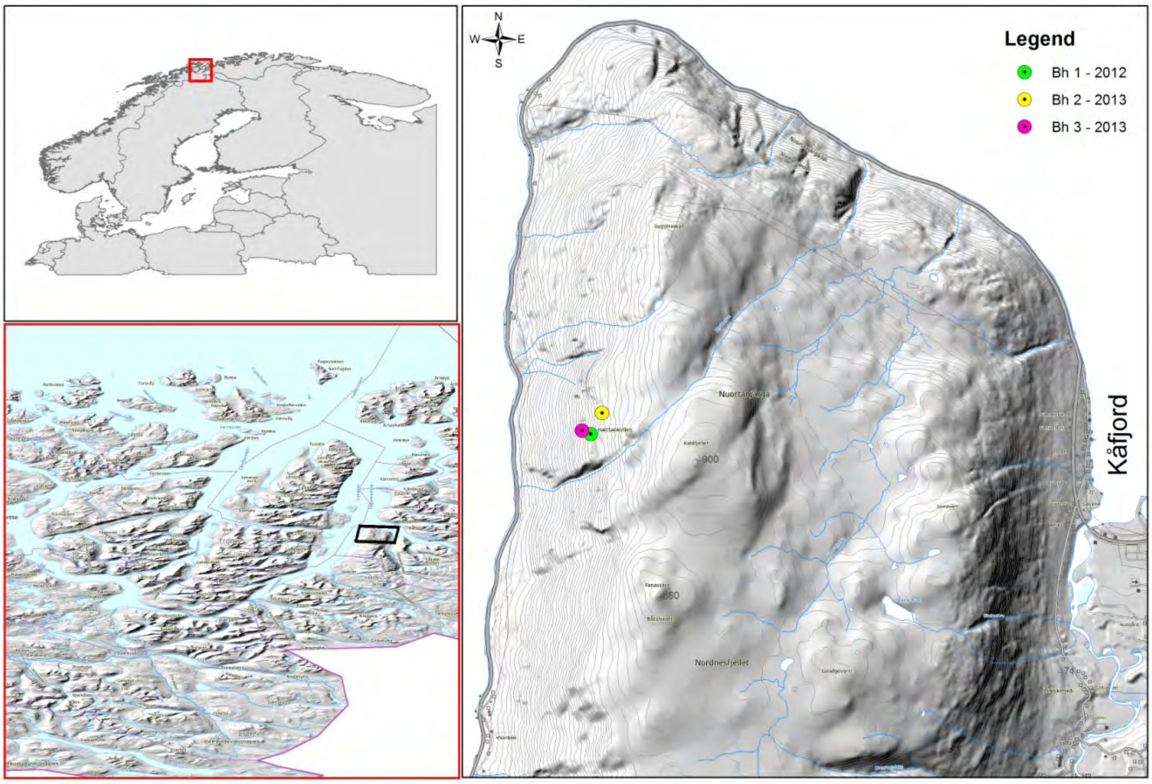

Figure 1. The map shows the location of Jettan at Nordnes mountain in Kåfjord municipality, Troms county, Northern Norway.

2. GEOLOGICAL DRILL CORE LOGGING

The bedrock occurring in the drill cores is successively banded garnetiferous mica schist (Figure 2), mica schist with layers of marble, marble and marble with layers of mica schist. All bedrock types are meta sedimentary rocks of medium grade metamorphosis, and the transition between the different bedrock types is gradual. The foliation is pervasive with a sub-horizontal orientation that locally is strongly folded.

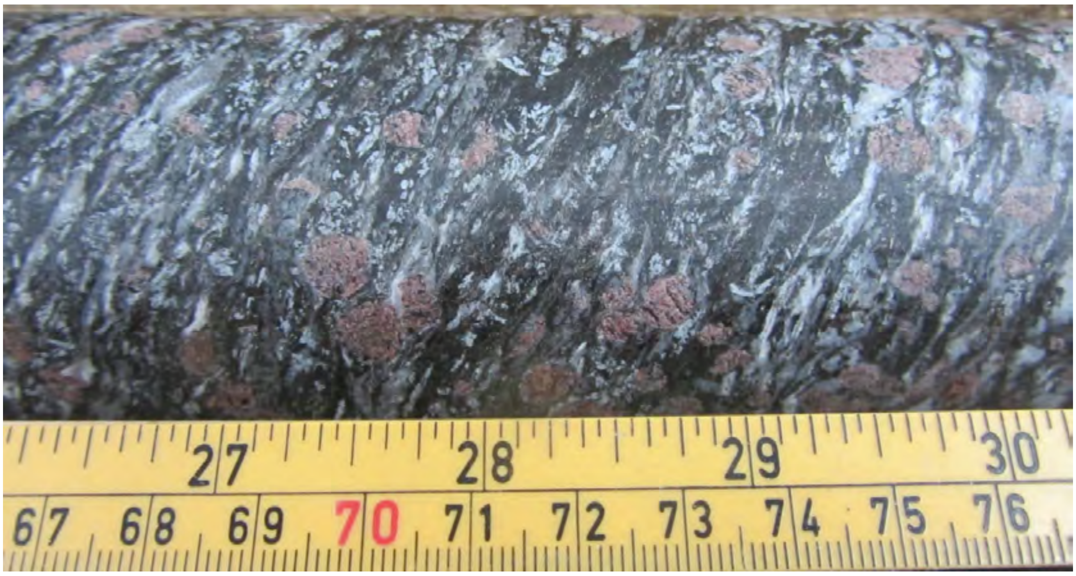

Figure 2. Example of the dominating bedrock type; banded garnetiferous mica schist.

Both borehole 02 and 03 are logged with Optical Televiewer and reported by Elvebakk (2014; NGU report 2014.016). The report by Elvebakk (2014) gives an overview of the orientation of the different fracture sets, as well as fracture frequency per. meter recorded in the bore holes. In the borehole the fracture frequency is in general lower than in the drill cores, but the distinctive zones are recognized in both logs; core logs and Optical Televiewer. Since the drill cores are not oriented the fracture orientation can only be found in the borehole logs by Elvebakk (2014).

Figure 3 shows examples of fractures produced by the drilling process. The top two photos in Figure 3 shows how the drill core is slimmed at one side, second photo when mica schist is in contact with a zone of finer material. It was often observed rounded edge of the drill core, as seen in the left photo in the middle, especially at the transition to zones of crushed rock. Pieces of rock within a zone of crushed rock may be rounded, as seen in the middle, right photo. This is explained by the drillers that pieces of rock get spun round inside the drilling pipe, and hence are "eroded" on the edges. Fractures that are very irregular, as the fracture in the bottom photo is interpreted to be due to the applied drilling force and not natural (Figure 3).

Figure 3. Examples of fractures produced by the drilling process. Top two photos; slimming of drill core. Mid left; rounded edge of drill core. Bottom; irregular fracture.

2.1 BH 02-2013

The location of borehole 2 at Jettan is given in Table 1 and shown in Figure 4. For BH 2-2013 the drill core is 98.08 meter long.

Table 1. Location with coordinates of for borehole 2-2013 at Jettan, Nordnes Mountain.

BH2 is the upper borehole (at Storsteinen by GPS-YN3):	
Map coordinates in local UTM zone	Zone: 34W
X coordinate (east):	0477072.22
Y coordinate (north):	7716612.67

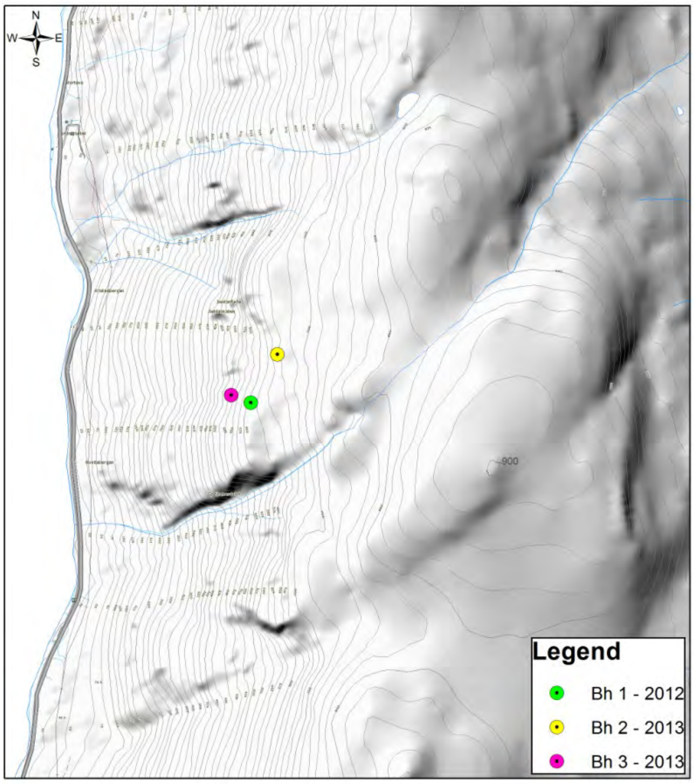

Figure 4. Location of bore hole 2 at Jettan, Nordnes mountain.

Table 2: Overview of bedrock types and zones occurring in the drill core for BH 02-2013.

Depth (m)	Bedrock type	Description
0-0.46		Core loss ca. 0.46 m
0.46-73.6	Banded garnetiferous mica schist	Banded garnetiferous mica schist
24.52-27.17		Zone with crushed rock and core loss
36.62-53.15	**Main fracture zone**	Zone with crushed rock, core loss and some clay filled zones
73.6-83.95	Marble	Marble with layers of schist
75.4-75.65		Zone of finely crushed rock
83.95-98.08	Mica schist with layers of marble	
89.95-90.4	Old fault	Zone of finely crushed rock, old fault (25-35 cm) with fault rock such as cohesive breccia
98.08	End of drill core	

In the upper 0.5 to 12 meter there is a high fracture frequency of foliation parallel fractures. In the uppermost 0.5 to 4 meters the mica rich schist is highly oxidised and weathered due to water flow through the fractured and crushed rock (Figure 5). Iron mineralisation is evident on fractures in the drill core (an example from 2.5 to 4 meters is given in Figure 5).

Figure 5. Photo shows an example from the upper 2.5-4 m where the mica rich schist is heavily fractured, weathered and oxidized.

The first zone of extensive crushed rock and core loss is at ca. 24.5 to 27 m (Figure 6). The core loss correlates well with cavity in the bedrock due to open fractures and possible movement.

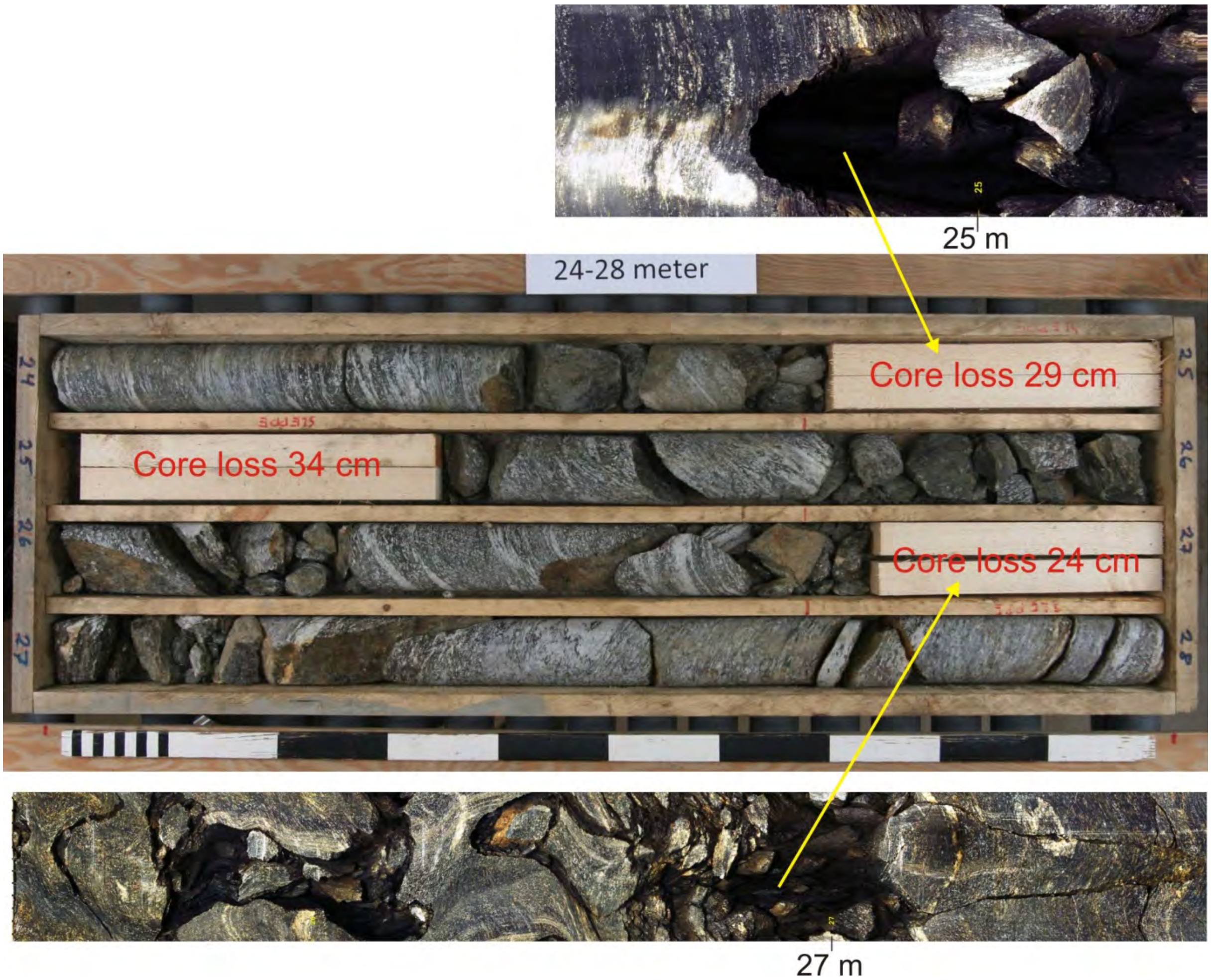

Figure 6. At ca. 24.5 to 27.5 m is the first zone of core loss and crushed rock occur (scale is 1 m). The images at top and bottom are from the Optical Televiewer (Elvebakk, 2014) and show that core loss often correlates to cavity in the bedrock due to open fractures interpreted as possible movement.

For BH 02-13 the main zone of deformed rocks is from 36.62 to 53.15 meters, containing several intervals of core loss, repeating zones of crushed rock and distinct zones with clay (Figure 7). The clay zones are mica rich and the thickest clay zone is ca. 13 cm thick at ca. 46.50-46.63 meter. The fracture at the upper boundary of this clay zone has a dip of 45°. The pervasive, sub-horizontal foliation is seen by thin lines in the bedrock. The core loss in the drill cores correlate with cavity in the bedrock observed with the Optical Televiewer (Figure 8; Elvebakk, 2014).

The bedrock is folded which is indicated by the change in foliation, from sub-horizontal to sub-vertical. As seen in Figure 3 the bedrock has small folds that alters the foliation from ca. 20° dip to ca. 45° dip. Foliation parallel fractures and fractures with different orientation are represented in the drill core (for example in Figure 6 and Figure 7). Orientation of fractures is reported by Elvebakk (2014; NGU report 2014.016)

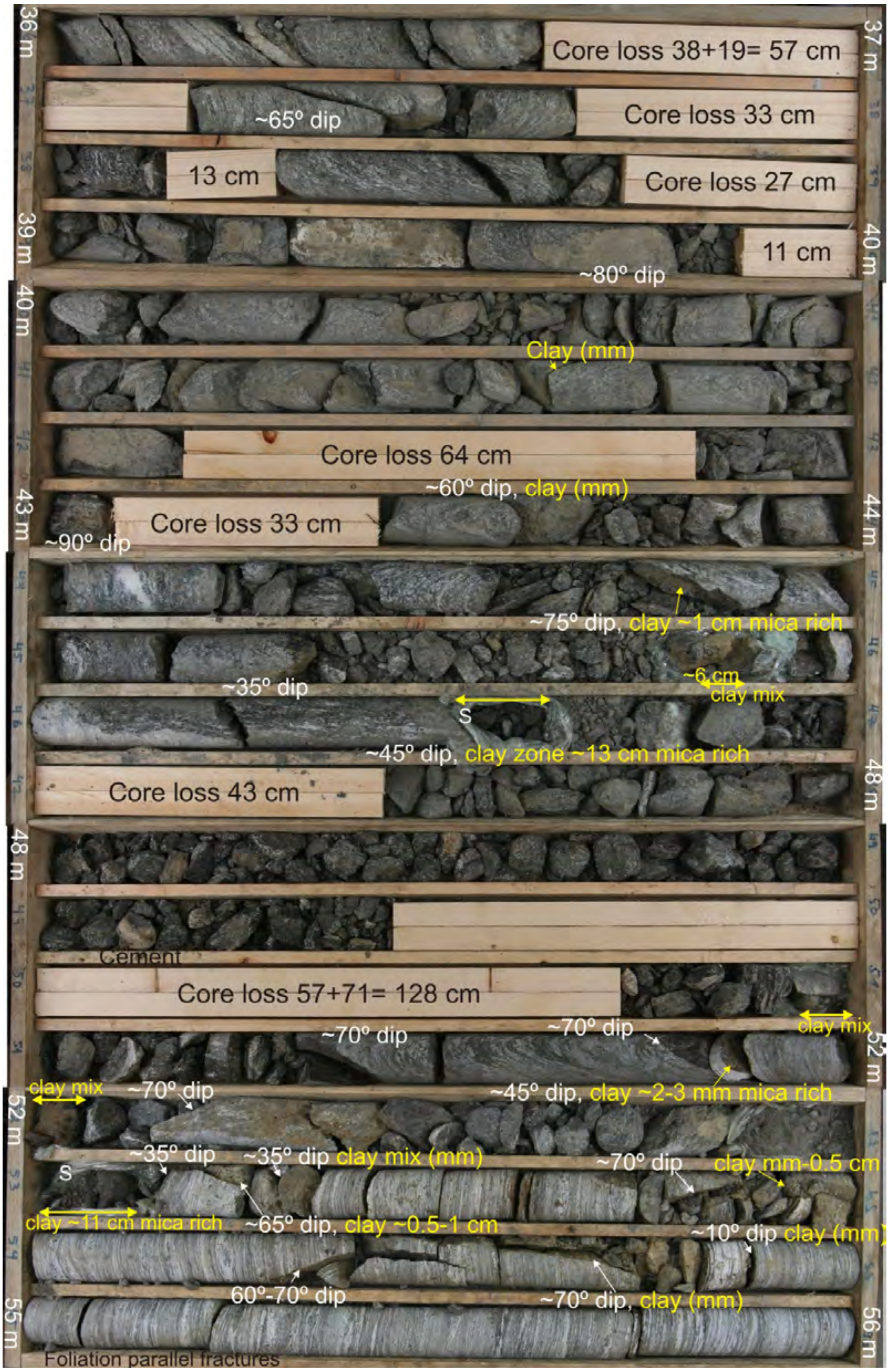

Figure 7. Pictures of the main zone of crushed rock, containing highly fractured and crushed rock with clay and core loss at 36.62-53.15 meter. S = sample; sample of clay for XRD and swelling test at NTNU. White writing indicate dip in degrees measures on fractures; inclination from horizontal where horizontal = 0° and vertical = 90°. Yellow text indicate where clay is observed.

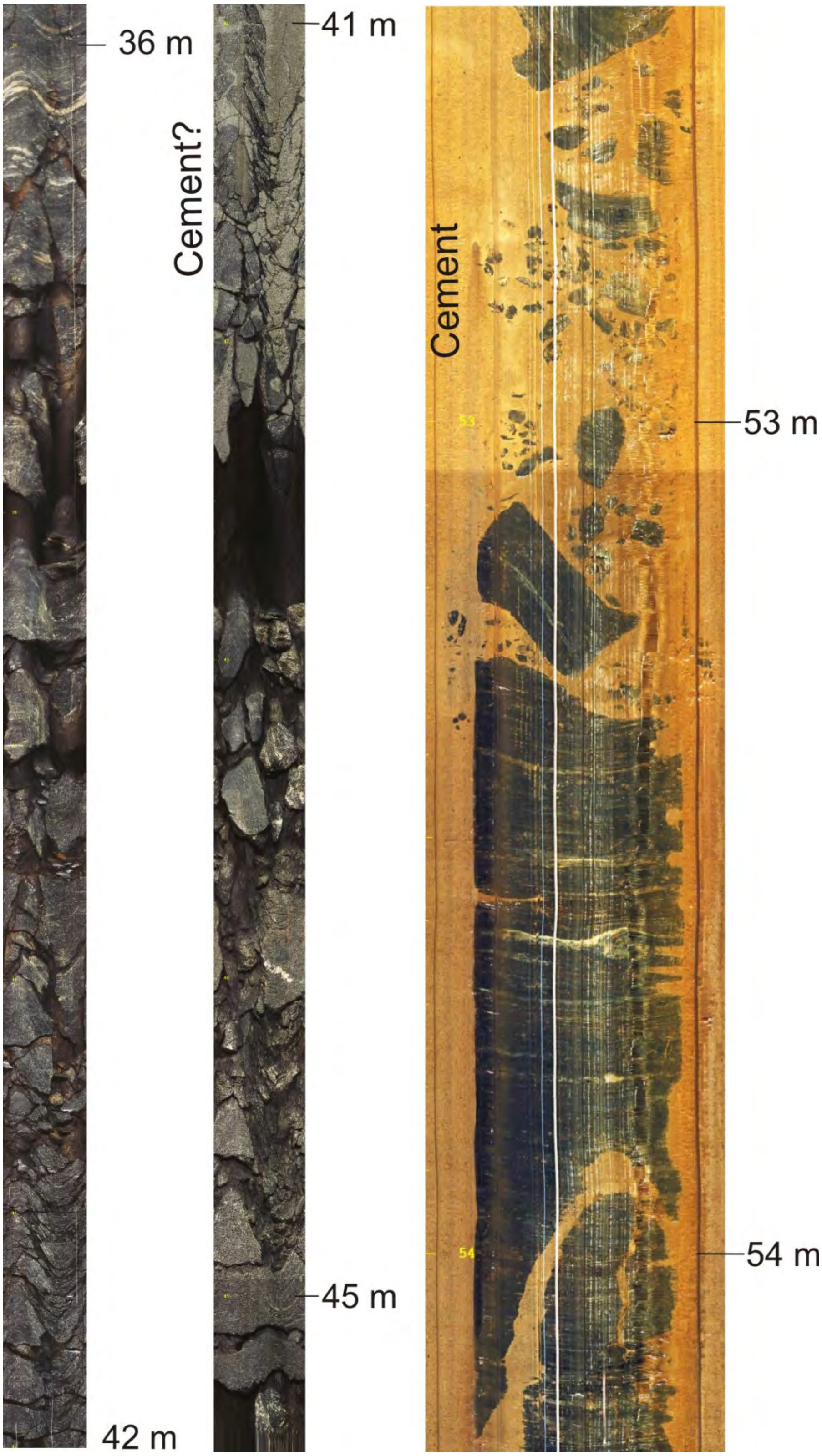

Figure 8. Images from Optical Televiewer in the borehole that show zones of crushed rock that correlate with the zones in the drill core and cavity in the bedrock that is recorded as core loss in the drill core. The imaging is poorer when the borehole has been filled with cement and re-drilled, as seen from ca. 52.5 to 54.2 m (right image).

At 69-71 meter vertical fractures occur and they are long; 2-2.5 m. Vertical fractures commonly causes higher fracture frequency than natural, and what is seen in the bore hole

(Elvebakk, 2014) due to fracturing during the drilling process (Figure 9). When the drilling pipe hits a vertical fractures with long extension smaller fractures are commonly produced, especially between the drill pipe wall and the vertical fracture.

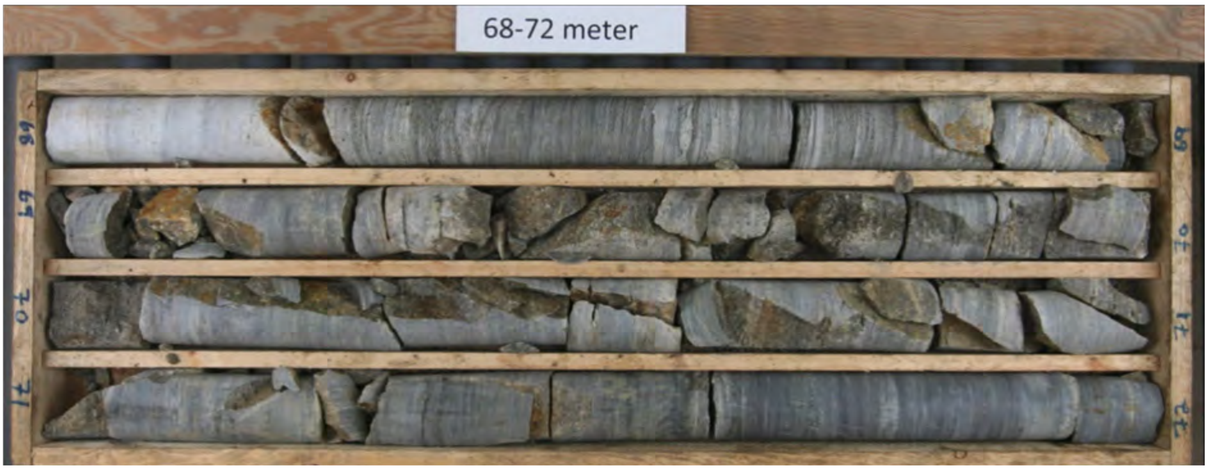

Figure 9. At 69-71 m vertical fractures occur. High fracture frequency is common related to vertical fractures, where smaller fractures are produced between the drill pipe wall and the vertical fracture, as seen at ca. 70. 20-70.30 m.

At 89.95 to ca. 90.40 meter a 25-35 cm wide fault zone with cohesive breccia and cohesive gouge is located (Figure 10). This interpreted as an old fault that has been reworked, where clasts of breccia is found in the zone of finely crushed rock below. In the borehole this zone consist of crushed rock that is either filled with fine, natural material or cement (Figure 10). The foliation in this section is sub-horizontal altering from 5°to 25° dip. This is showed in Figure 37 and Figure 38 as well as in the graph of foliation by Elvebakk (2014).

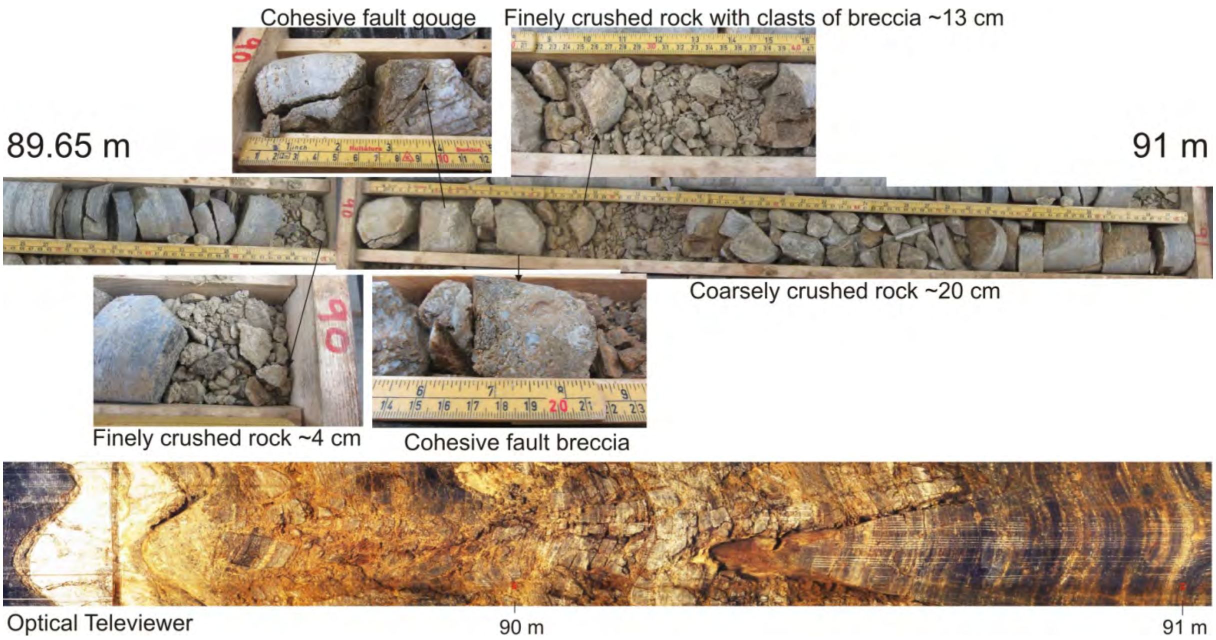

Figure 10. At ca. 89.95-90.40 m depth there is an old fault containing 25-35 cm thick cohesive breccia and cohesive gouge. The fault has been reworked and clasts of breccia is found in the zone of finely crushed rock that is directly below the fault. Bottom: Image from Optical Televiewer from ca. 89.5 to 91 meter depth (Elvebakk, 2014). It is difficult to distinguish if the fractures are filled with fine (natural) material or cement.

An overview of the core log for BH 02-13 is given in Figure 9, where the different bedrock types are coloured. The larger zones of crushed rock are marked, core loss and zones containing clay are indicated by colour.

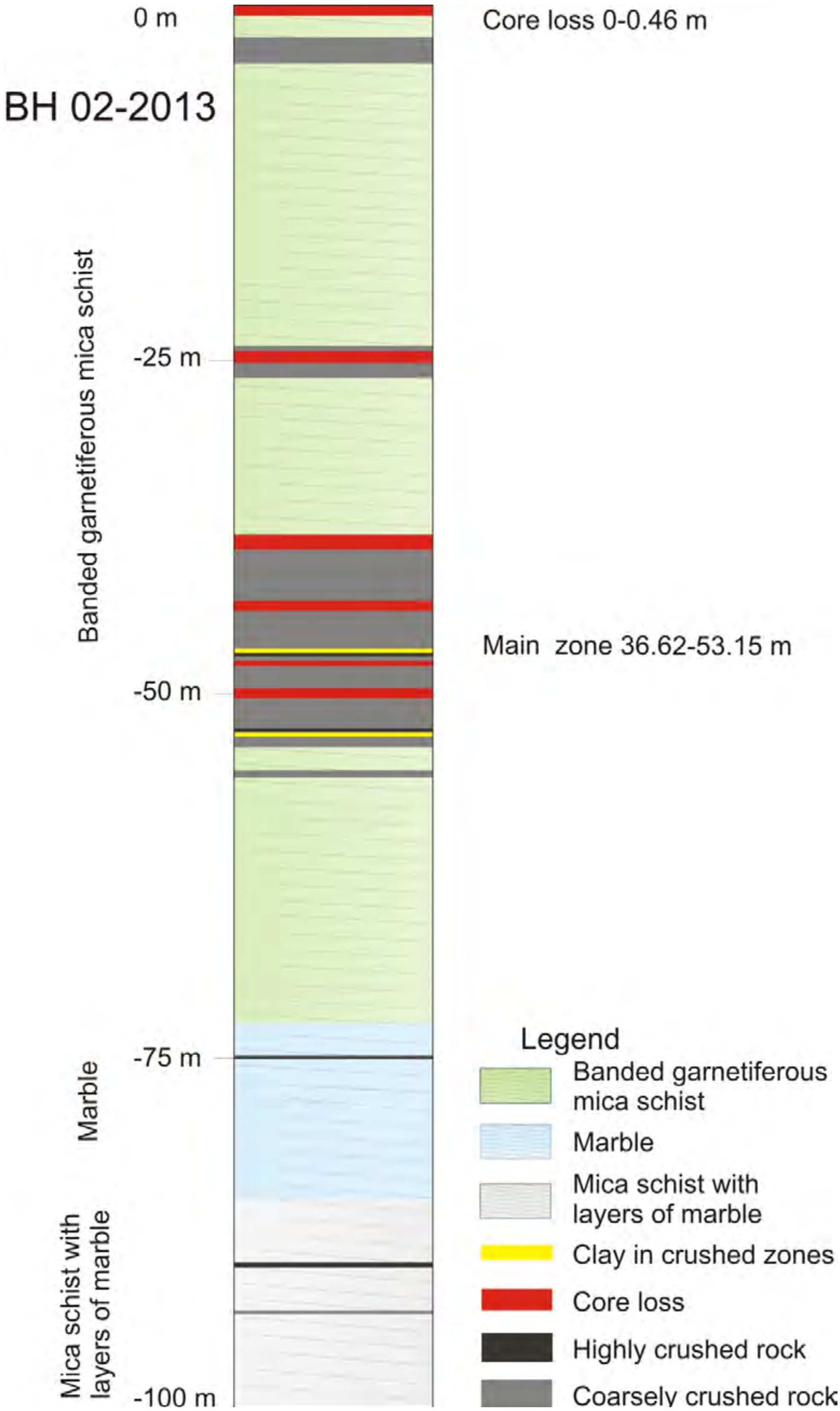

Figure 11. Overview of the core log from BH 02-2013 where the main bedrock sections and zones of crushed rock, core loss and zones with clay are indicated by colour.

Figure 12 and Figure 13 show graphs of fracture frequency, extent of zones of crushed rock, extent of core loss, foliation parallel fractures, drilling produced fractures and vertical fractures. For the fracture frequency there are given two graphs; total fracture frequency that contains numbers of fractures and an estimated value of fractures that reflect the zones of crushed rock and core loss. In addition a fracture frequency regarding only actual fractures, without the zones of crushed rock and core loss is given, which is thereby lower than the total fracture frequency. To show a graph of fracture frequency per. meter that is closer to natural values the fractures that are interpreted as produced by the drilling process (examples in Figure 3) are subtracted, as shown in the graph of actual fracture frequency (Figure 12 and Figure 13). Foliation parallel fractures are most likely to be produced with applied force, since they follow an already existing preferred orientation and weakness in the bedrock. Where vertical fractures occur the drill core tend to be more fractured than otherwise, this is considered to be due to drilling produced fractures made between the vertical fracture and the borehole wall. An example of vertical fracturing and high fracture frequency is given in Figure 9.

When the core logging is compared to logging with Optical Televiewer in the borehole (Elvebakk, 2014; NGU report 2014.016), the borehole logging shows considerably lower fracture frequency.

The foliation reflects a folded bedrock where the orientation varies through the drill core. The orientation of the foliation is documented by Elvebakk (2014, NGU report 2014.016), which show that at the top the foliation has 15° to 20° dip towards SW, increasing to 60° to 70° dip towards W-SW between 38. and 53 meter. From ca. 53 meter and deeper the foliation varies between 10° and 35° dip with a general orientation towards SSW. This alternation in foliation is also seen in the drill cores (chapter 3.).

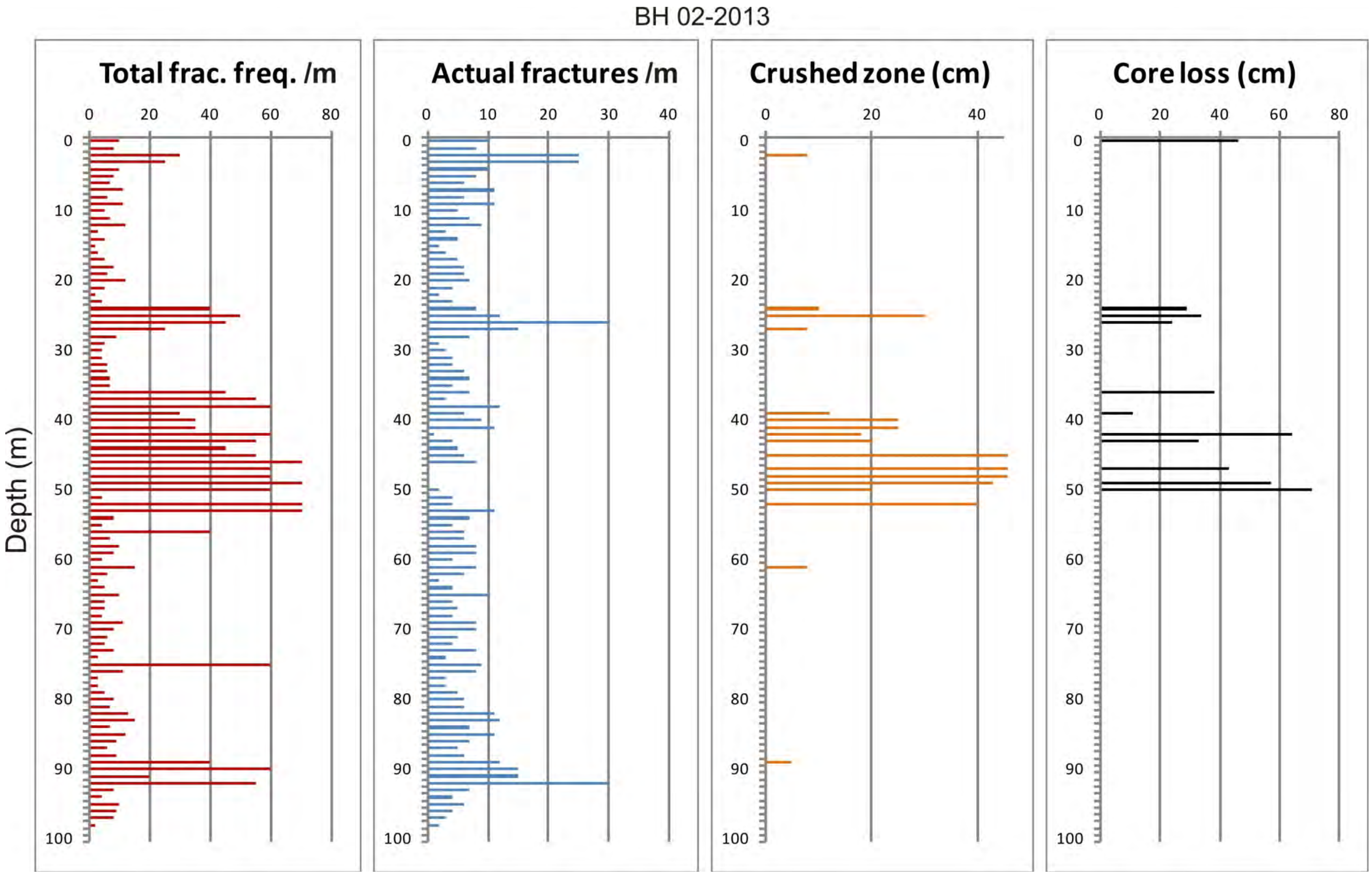

Figure 12. Graphs from core logging for BH 02-13 with total fracture frequency including fractures and crushed zones (left), actual fractures observed, crushed zones with length given in cm and core loss given in cm to the right.

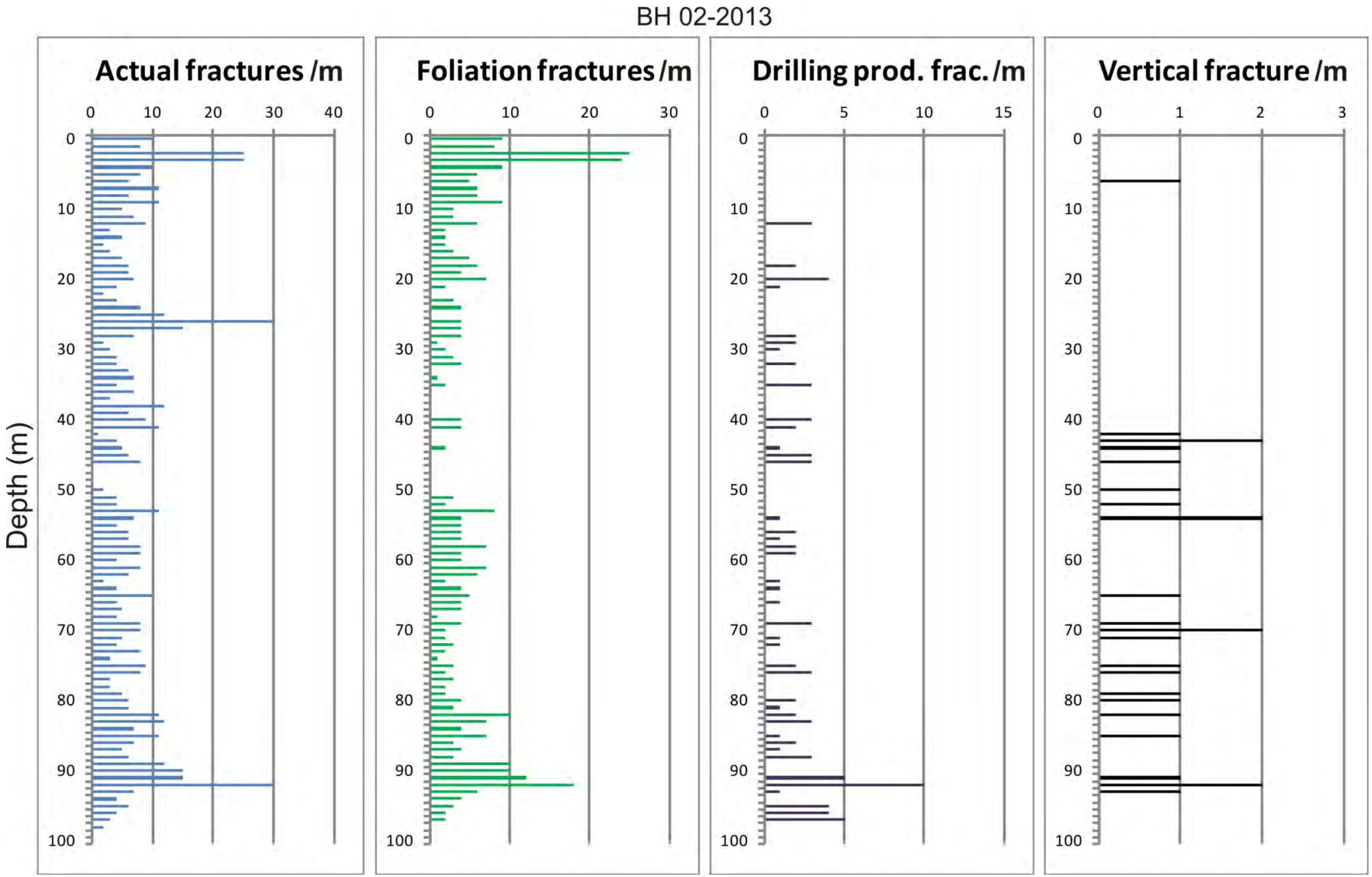

Figure 13. Graphs from core logging for BH 02-13 showing frequency of actual fractures observed (left), of those fractures are foliation fractures, drill produced fractures and vertical fractures (right) registered.

2.2 BH 03-2013

The location of borehole 3-2013 at Jettan is given in Table 3 and Figure 14. For BH 3 the drill core is 100.94 meter long.

Table 3. Location with coordinates of for borehole 3-2013 at Jettan, Nordnes Mountain.

BH3-2013 is the lower borehole (close to GPS-YN8)	
Map coordinates in local UTM zone	Zone: 34W
X coordinate (east):	0476859.58
Y coordinate (north):	7716459.32

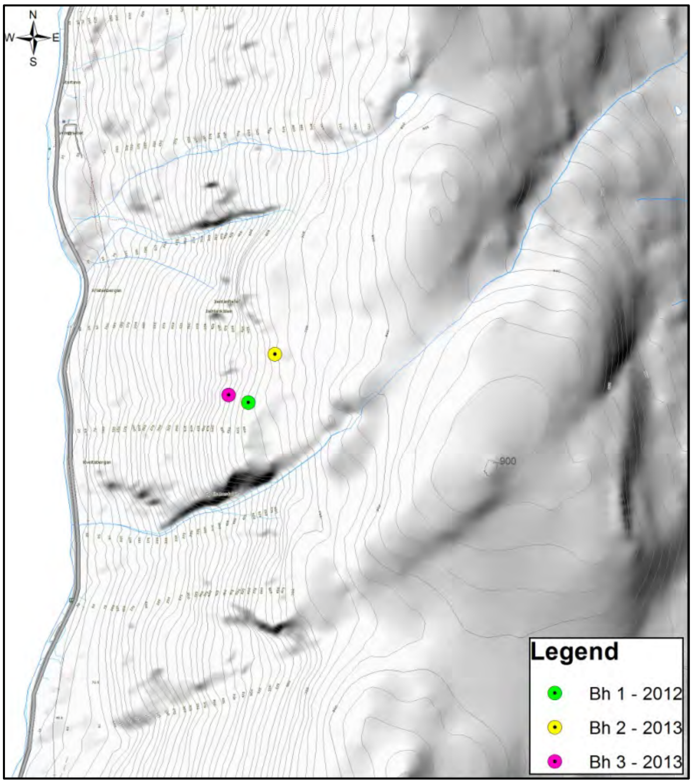

Figure 14. Location of bore hole 3 at Jettan, Nordnes mountain.

In this drill core the bedrock changes between banded garnetiferous mica schist and marble. There are several zones of crushed rock and core loss. At 24 to ca. 36 meter depth vertical fractures are abundant. The main zone of deformed rocks is regarded to be at 42.3 to 46 meter, where high fracture frequency, abundant zones of crushed rock and core loss occur. BH 03-2013 has no distinct zone of clay. An overview of zones and bedrock types is given in Table 4.

Table 4: Overview of bedrock types and zones occurring in the drill core in BH 03-2013.

Depth (m)	**Bedrock type**	**Description**
0-2.5		Core loss ca. 1.5 m, casing 1.5-2.5 m
2.5-43.4	Banded garnetiferous mica schist	Banded garnetiferous mica schist
24-37		Zones of crushed rock and core loss
42.3-46	**Main fracture zone**	Zone with crushed rock and core loss
43.4-74.3	Marble	Marble with zones inter-bedded with schist
74.3-92.25	Banded garnetiferous mica schist with layers of marble	Banded garnetiferous mica schist with layers of marble
72-72.2	Old fault	Old fault with fault rock such as cohesive breccia and cohesive gouge
46.2-82.7		Zone with crushed rock and minor zones of core loss
92.25-100.94	Marble	Marble with layers of schist
100.94	End of drill core	

Mineral coating of iron on fractures is common throughout the drill core (Figure 15). This may indicate water flow in fractures or good drainage of rainwater.

Figure 15. Example of iron oxidation (middle) and clay (mica) coating (left) on fractures. Here at ca. 23.50 m.

From ca. 24 to ca. 36.80 meter the bedrock is heavily fractures and zones of crushed rock and some core loss are evident. Especially 24 to 26.5 meter is crushed with altogether 50 cm core loss (Figure 16). Vertical fractures do occur in this section, which may cause extra fracturing due to drilling difficulties (Figure 17). The core loss observed in the drill core (Figure 16) correlate well with cavity in the bedrock that is observed in the Optical Televiewer (Figure 17; Elvebakk, 2014). As seen in the comparison of Figure 13 and Figure 14 is that the fine material, potential clay, is often lost during the drilling process and not preserved in the drill cores.

Figure 16. Zone of crushed rock from ca. 24 to ca. 36.80 m where the bedrock is crushed and core loss occurred. Core segment is 1 m.

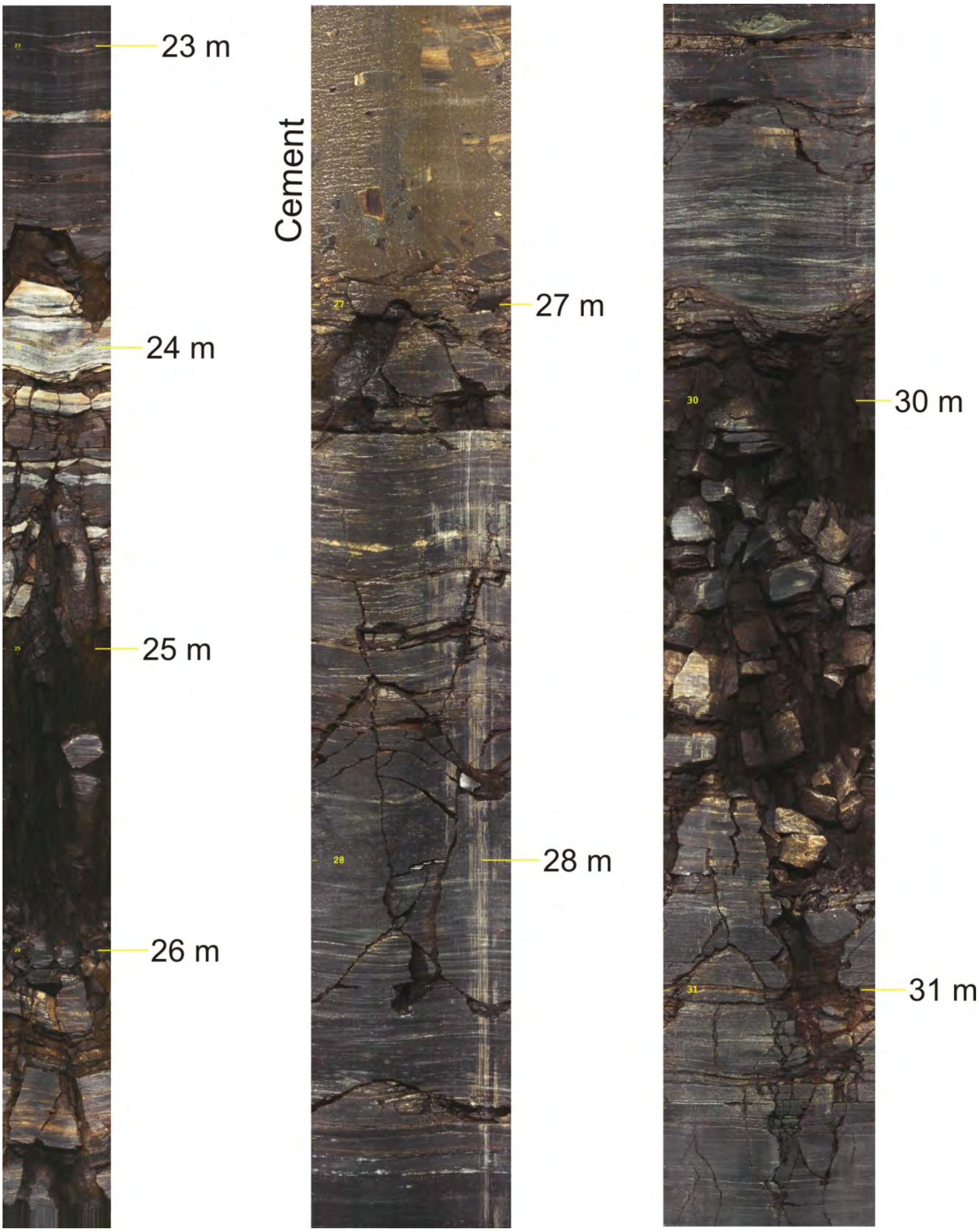

Figure 17. Pictures form the Optical Televiewer (Elvebakk, 2014) where zones of crushed rock and cavity in the bedrock is distinct. Core loss in the drill core correlates with cavity in the bedrock, as seen between 25 and 26 m (left image).

The main zone of deformed rocks in borehole 3 is at ca. 42.3 to 46 meters depth and consists of crushed rock (Figure 18). In the drill core loss of core is noted (Figure 18), but when compared to images from the Optical Televiewer the same interval, 42-43 m, show a bedrock with good quality and few fractures (Figure 19).

Figure 18. Main zone in BH 3 at 42.3 to 46 meter. The beginning of this zone is lost due to core loss, where the rest of the 3.7 m wide zone is dominated by crushed rock. The bedrock alters between mica schist to marble from top to bottom.

Core loss in the drill core correlate well with open fractures in the borehole, as seen in Figure 19 from the Optical Televiewer (Elvebakk, 2014).

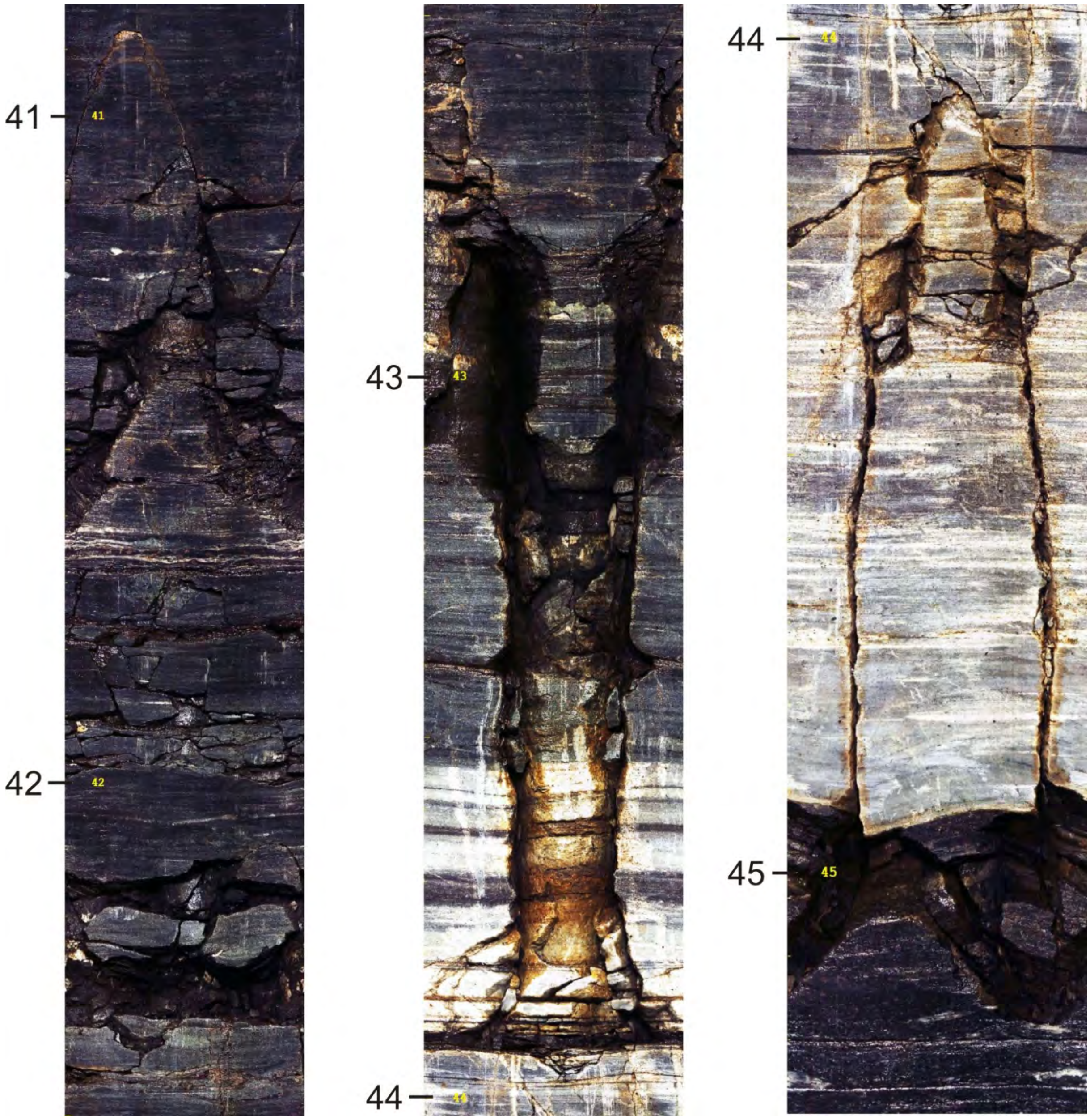

Figure 19. Images from Optical Televiewer (Elvebakk, 2014) that show open fractures and zones of heavily fractured rock, including vertical fractures.

At ca. 72.10 to 72.20 m a zone consisting of fault rock such as cataclasite is observed (Figure 20). Cataclasite is a cohesive, semi ductile, fault rock that has equivalent strength as the bedrock. This is interpreted to be an old fault. Below the fault zone, a zone of coarsely crushed rock is observed, but there is no evidence that the old fault has been reactivated.

Figure 20. Old fault at 72.10 to 72.20 meter showing displacement along sealed fractures and appurtenant fault rock such as cataclasite; cohesive and cemented fault rock.

At ca. 80.90 to 81.10 meters depth a zone of finely crushed rock is observed (Figure 21). The fine material is rich on mica that reflect the bedrock, which is mica rich schist, but clay is not observed. In the image from the Optical Televiewer the same zone is seen as cavity in a crushed zone where the fine material might be washed out (bottom in Figure 21).

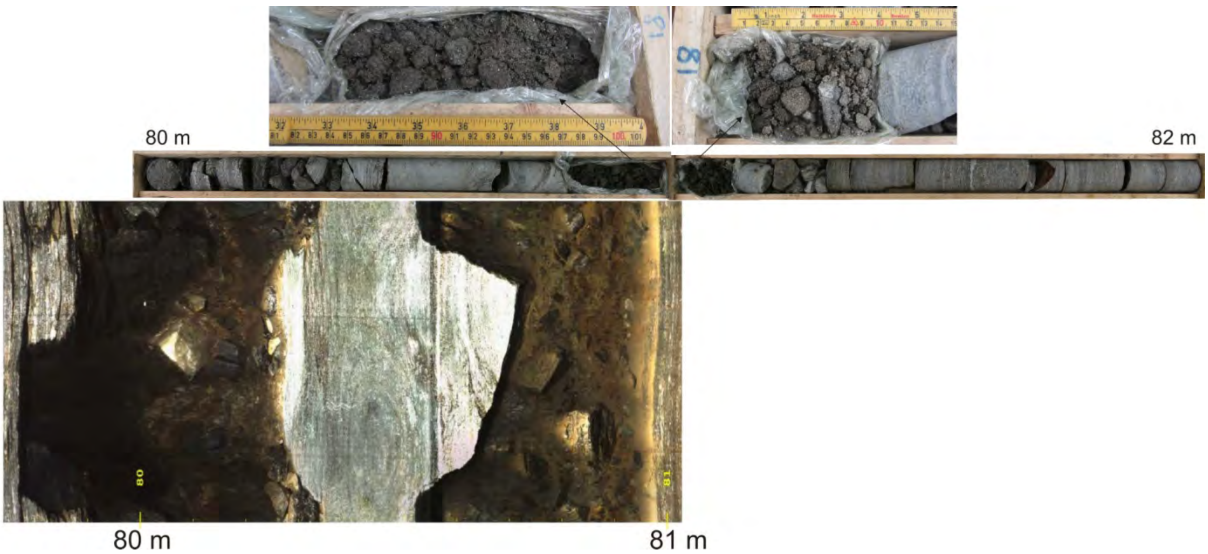

Figure 21. Zone of finely crushed rock at ca. 80.80 to 81.15 m. The Picture at the bottom is from Optical Televiewer form the borehole, which is described in NGU report 2014.016 by Elvebakk (2014). The zone of finely crushed rock in the drill core correlate well with a zone of crushed rock with fine material in the borehole. There is a divagation of ca. 10 cm between the depth in the borehole and the drill core.

An overview of the core log for BH 03-13 is shown in Figure 22, where the different bedrock types are symbolised with colour, the larger zones of crushed rock are mapped, and zones containing clay are indicated.

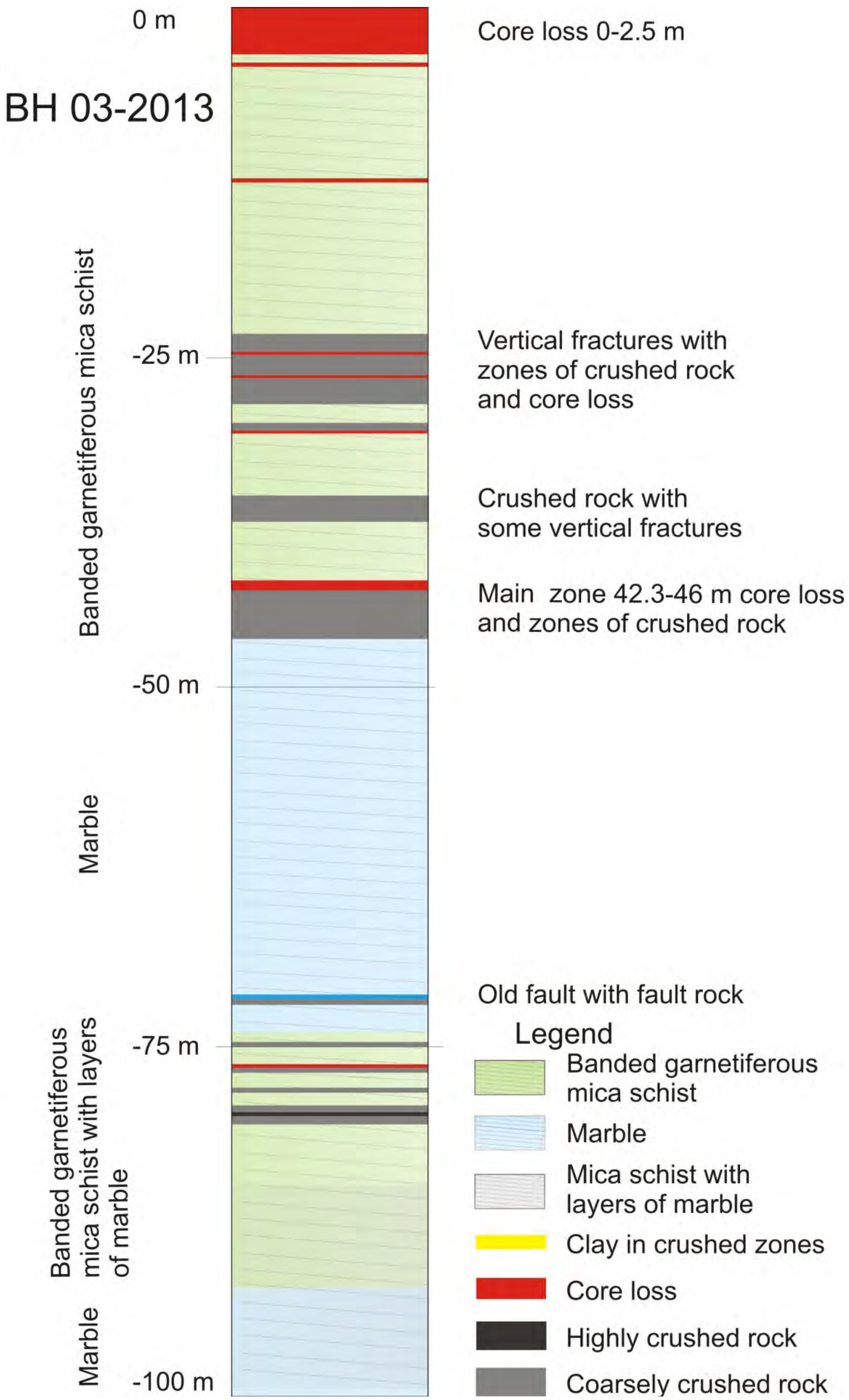

Figure 22. Overview of the core log from BH 03-2013 with main bedrock sections and zones of crushed rock indicated.

Figure 23 and Figure 24 show graphs of fracture frequency, extent of zones of crushed rock, extent of core loss, foliation parallel fractures, drilling produced fractures and vertical fractures from BH 3. For the fracture frequency there are given two graphs; total fracture frequency that contains numbers of fractures and an estimated value of fractures that reflect the zones of crushed rock and core loss. In addition a fracture frequency regarding only actual fractures, without the zones of crushed rock and core loss is given, which is thereby lower than the total fracture frequency. To show a graph of fracture frequency per. meter that is closer to natural values the fractures that are interpreted as produced by the drilling process (examples in Figure 3) are subtracted, as shown in the graph of actual fracture frequency (Figure 23 and Figure 24). Foliation parallel fractures are most likely to be produced with applied force, since they follow an already existing preferred orientation and weakness in the bedrock. Where vertical fractures occur the drill core tend to be more fractured than otherwise, this is considered to be due to drilling produced fractures made between the vertical fracture and the drill pipe wall. An example of vertical fractures and high fracture frequency is given in Figure 9.

When the core logging is compared to logging with Optical Televiewer in the borehole (Elvebakk, 2014; NGU report 2014.016), the Optical Televiewer logging shows considerably lower fracture frequency. In the Optical image of the borehole the zones of crushed rock seem to be less crushed or the zone is narrower compared to the drill core.

The foliation reflects a folded bedrock where the orientation varies through the drill core. The orientation of the foliation is documented by Elvebakk (2014, NGU report 2014.016), which shows that at the top the foliation dips 5° to 20° towards SE. Between ca. 45 to 70 meter the dip is shallow, ca. 5° with orientation towards east. From ca. 75 meter and deeper the foliation varies between 5° and 35° dip angle with rapidly changing orientation, indicating that the bedrock is folded. This alternation in foliation is also seen in the drill cores (chapter 4.).

In parts of the drill core the fracture frequency is as low as 1-5 fractures per meter. This is close to background fracturing in nature that is ca. 3 fractures per meter (Braathen & Gabriele, 2000). The zones of crushed rock indicate where possible movement may occur in the rock mass. When the drill cores are compared to the images from optical televiewer in the borehole the zones of deformation; i.e. crushed rock or heavily fractured, are less or narrower in the bore hole than in the drill core. This is interpreted to be due to the applied drilling force that can increase the fracture frequency and crush the rock.

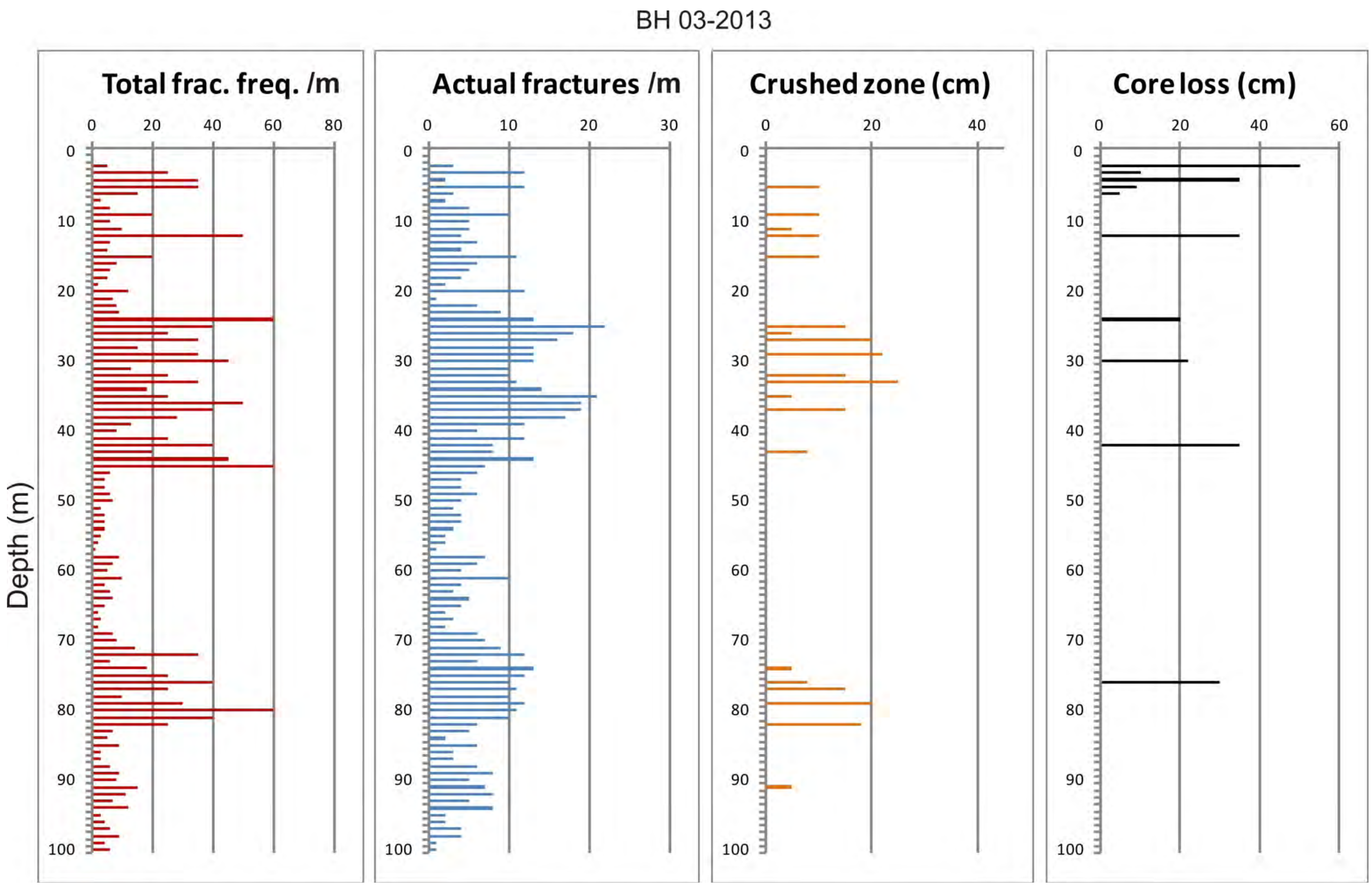

Figure 23. Graphs from core logging for BH 03-13 with total fracture frequency including fractures and crushed zones (left), actual fractures observed, crushed zones with length given in cm and core loss given in cm to the right.

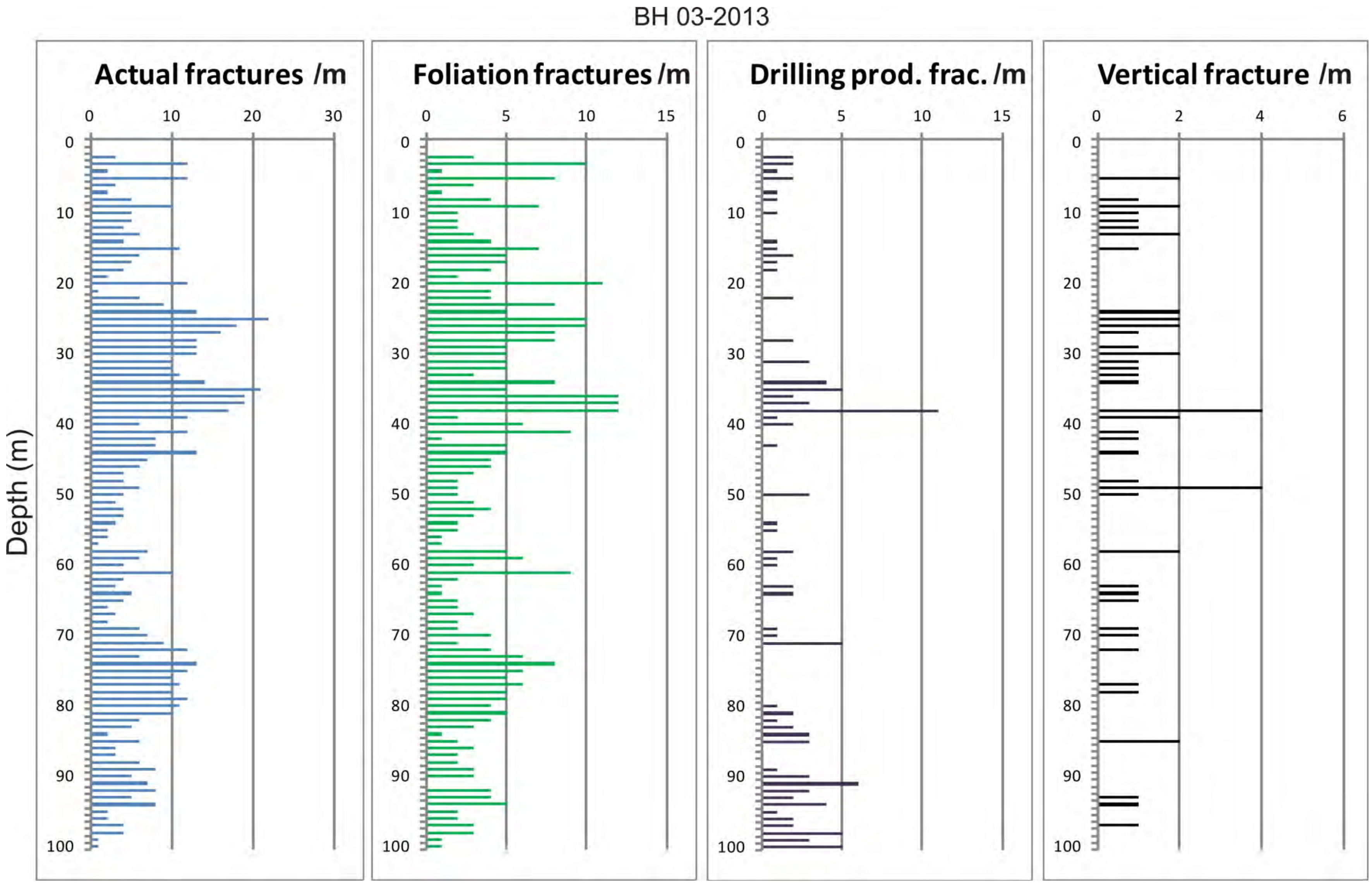

Figure 24. Graphs from core logging for BH 03-13 showing frequency of actual fractures observed (left), of those fractures are foliation fractures, drill produced fractures and vertical fractures (right) registered.

3. CORE LOGGING BH 2- 2013

In this chapter the drill cores from BH 2 is documented with pictures and logged with detailed information such as bedrock type and zones of interest for stability.

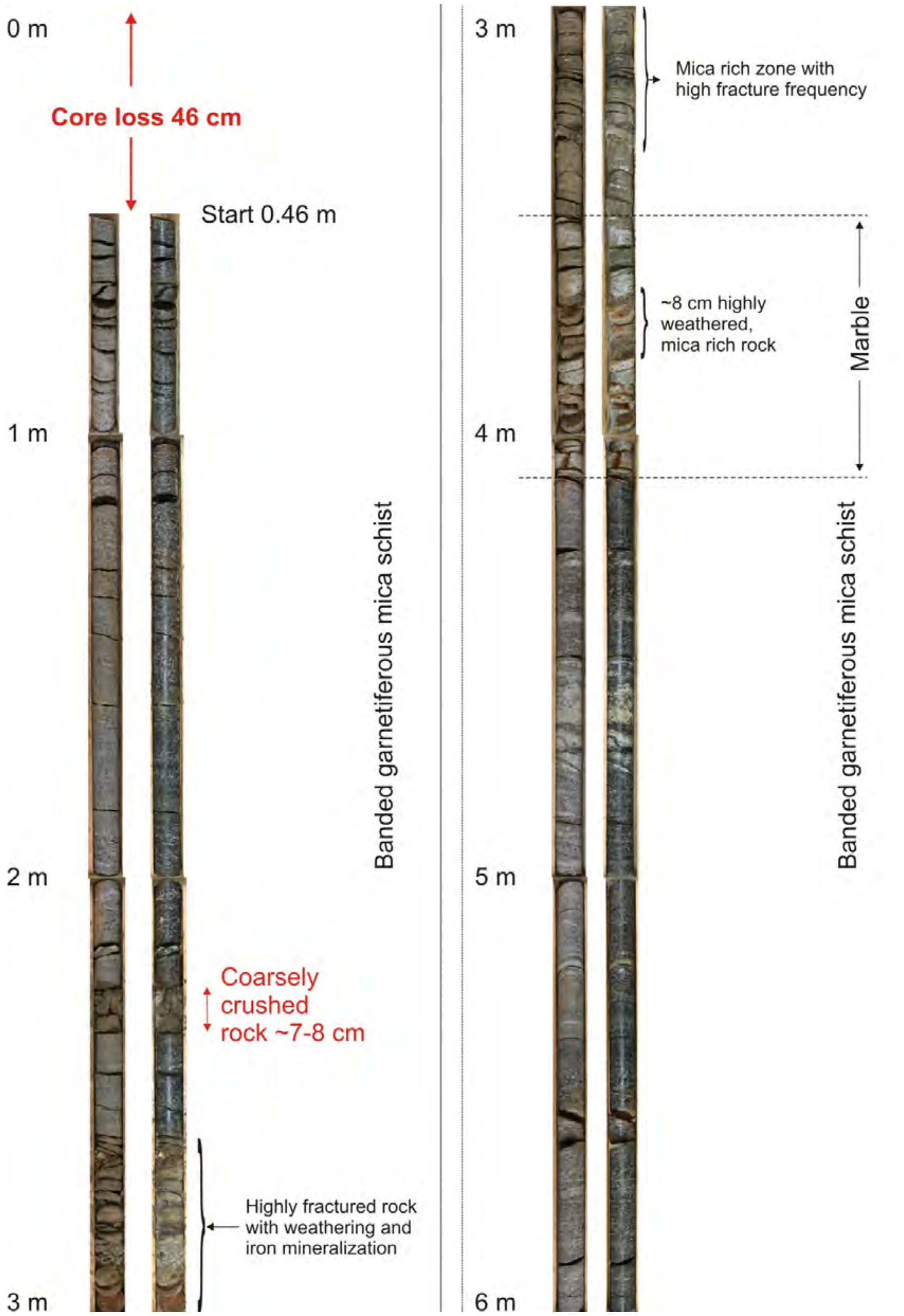

Figure 25. Core logging of drill core BH 02-13 at 0-6 m. Photo of dry core to the left and wet core to the right.

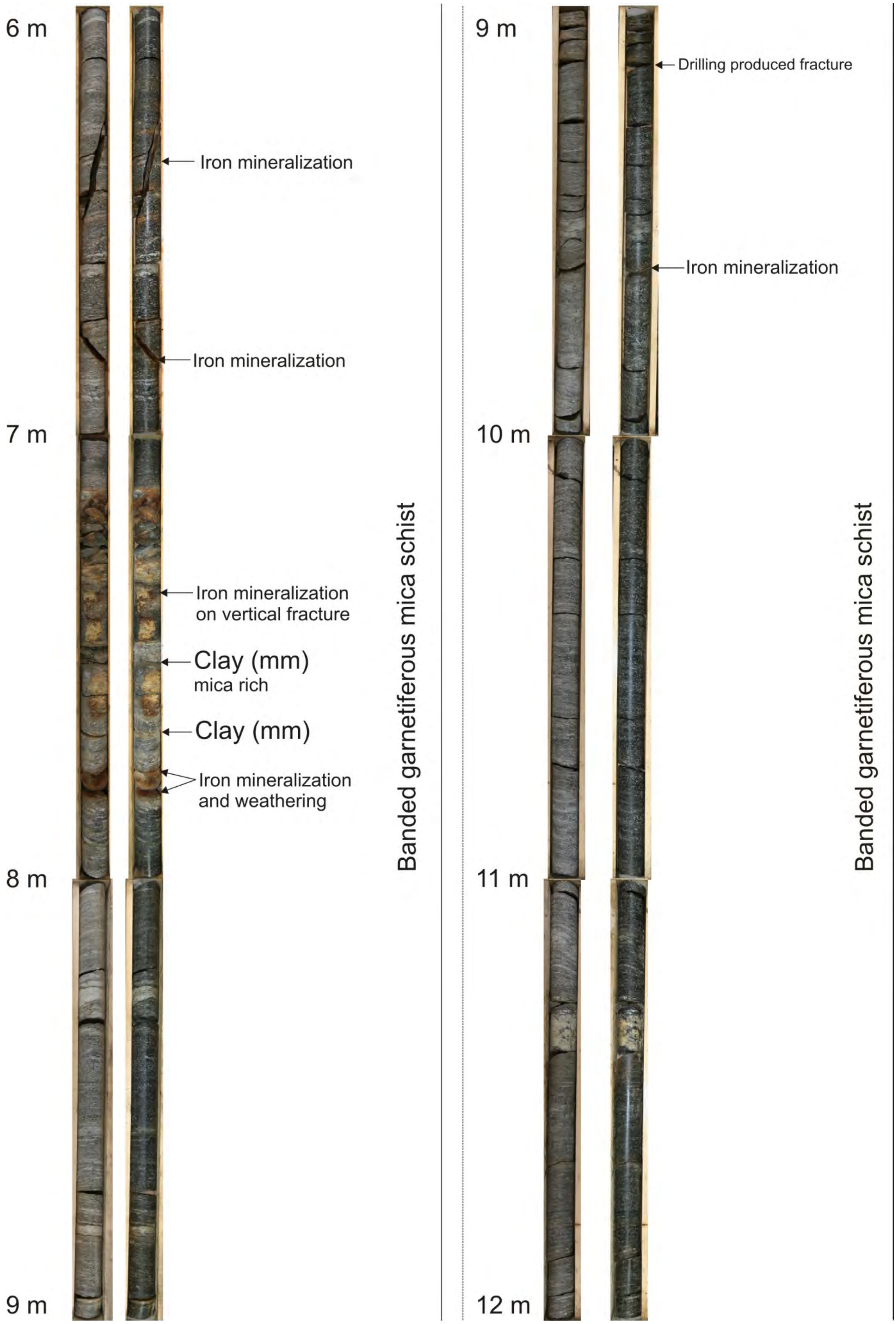

Figure 26. Core logging of drill core BH 02-13 at 6-12 m. Photo of dry core to the left and wet core to the right.

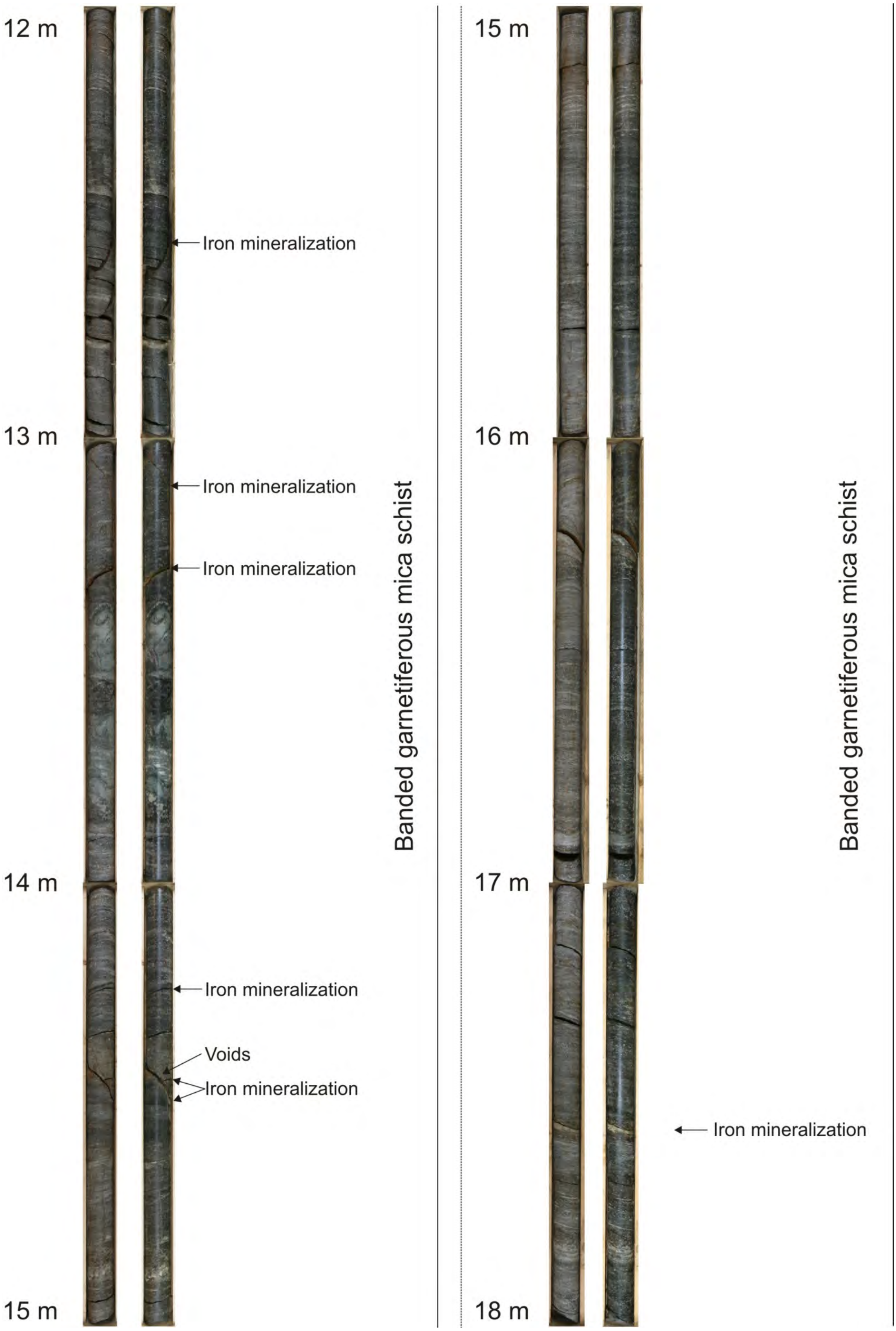

Figure 27. Core logging of drill core BH 02-13 at 12-18 m. Photo of dry core to the left and wet core to the right.

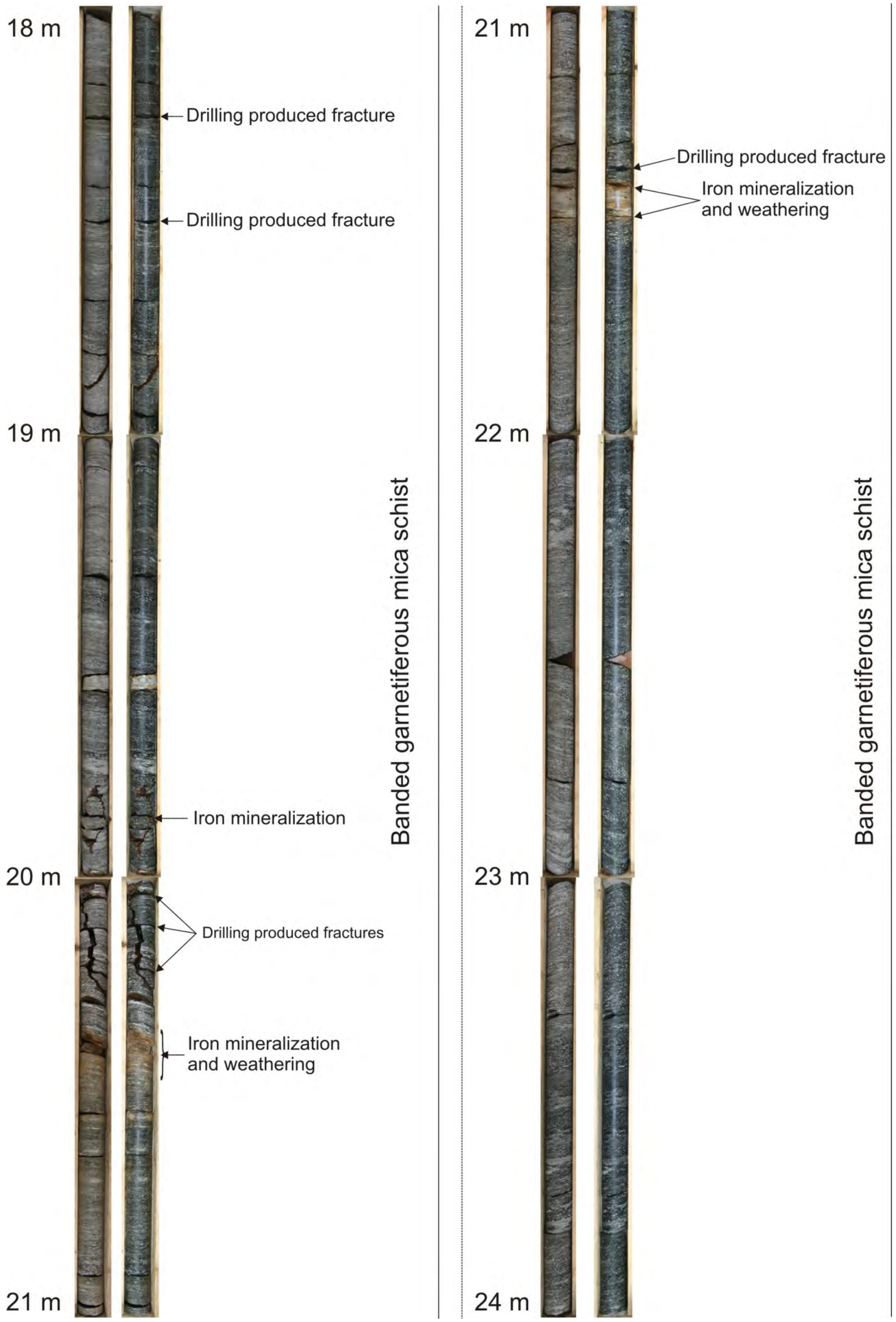

Figure 28. Core logging of drill core BH 02-13 at 18-24 m. Photo of dry core to the left and wet core to the right.

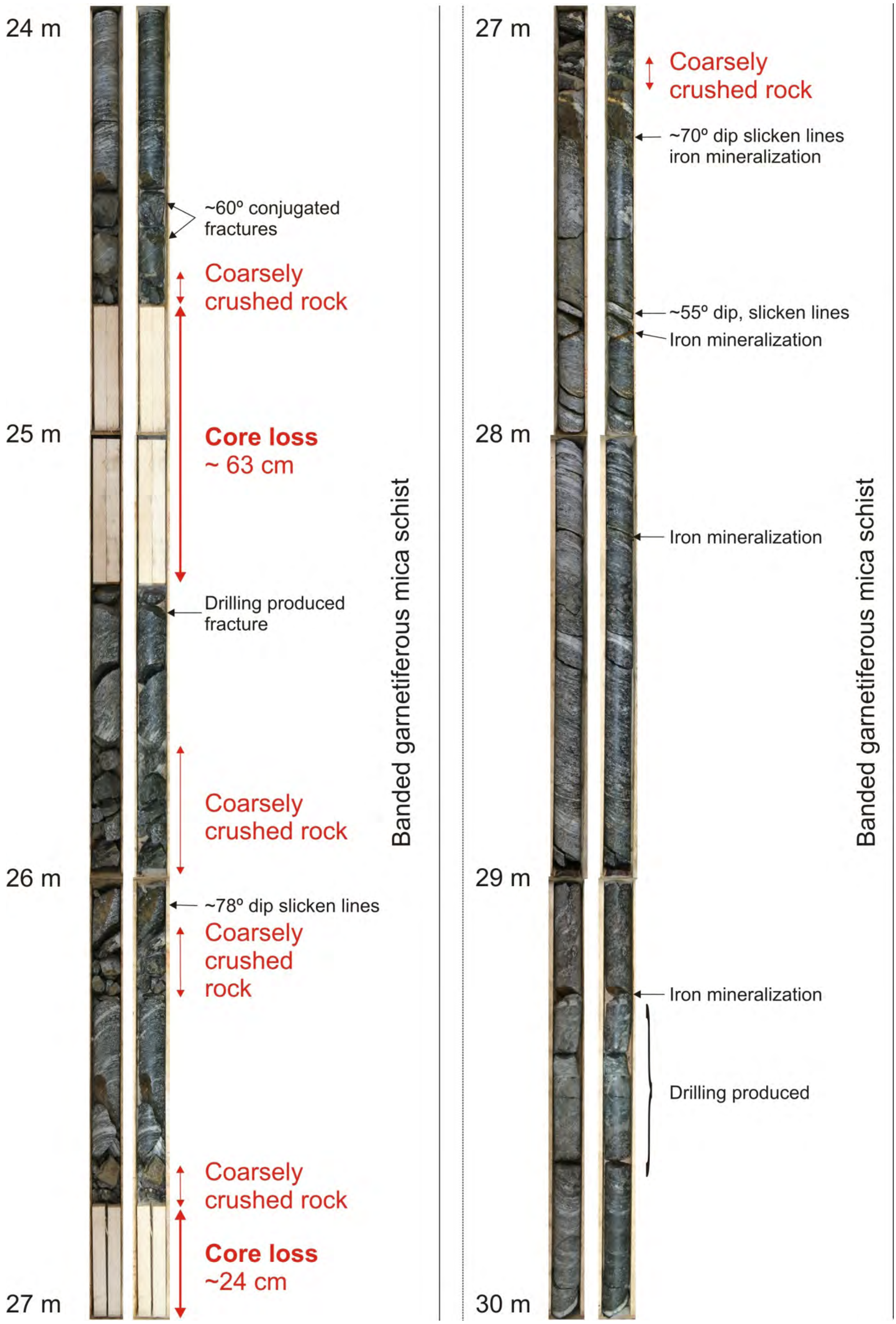

Figure 29. Core logging of drill core BH 02-13 at 24-30 m. Photo of dry core to the left and wet core to the right.

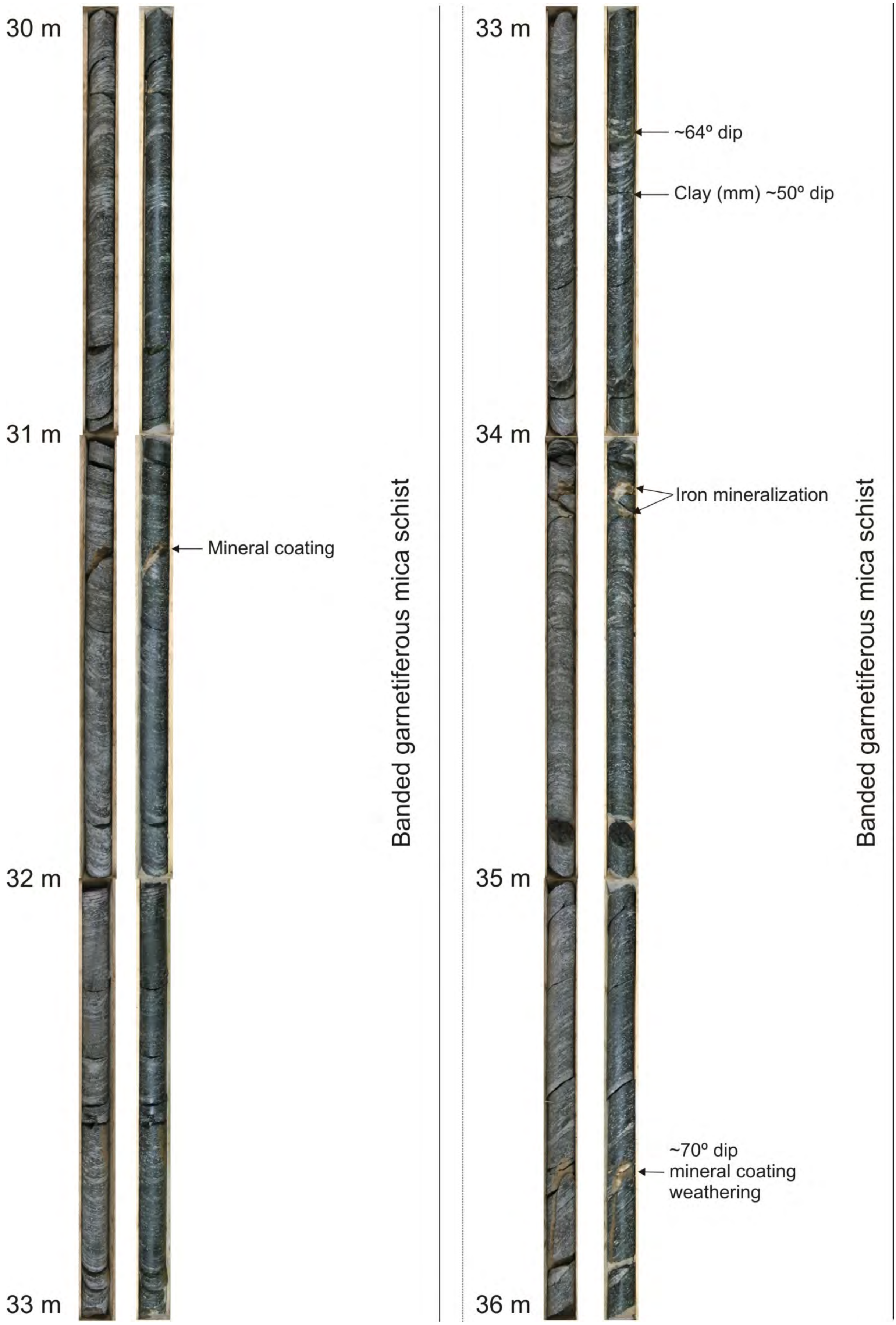

Figure 30. Core logging of drill core BH 02-13 at 30-36 m. Photo of dry core to the left and wet core to the right.

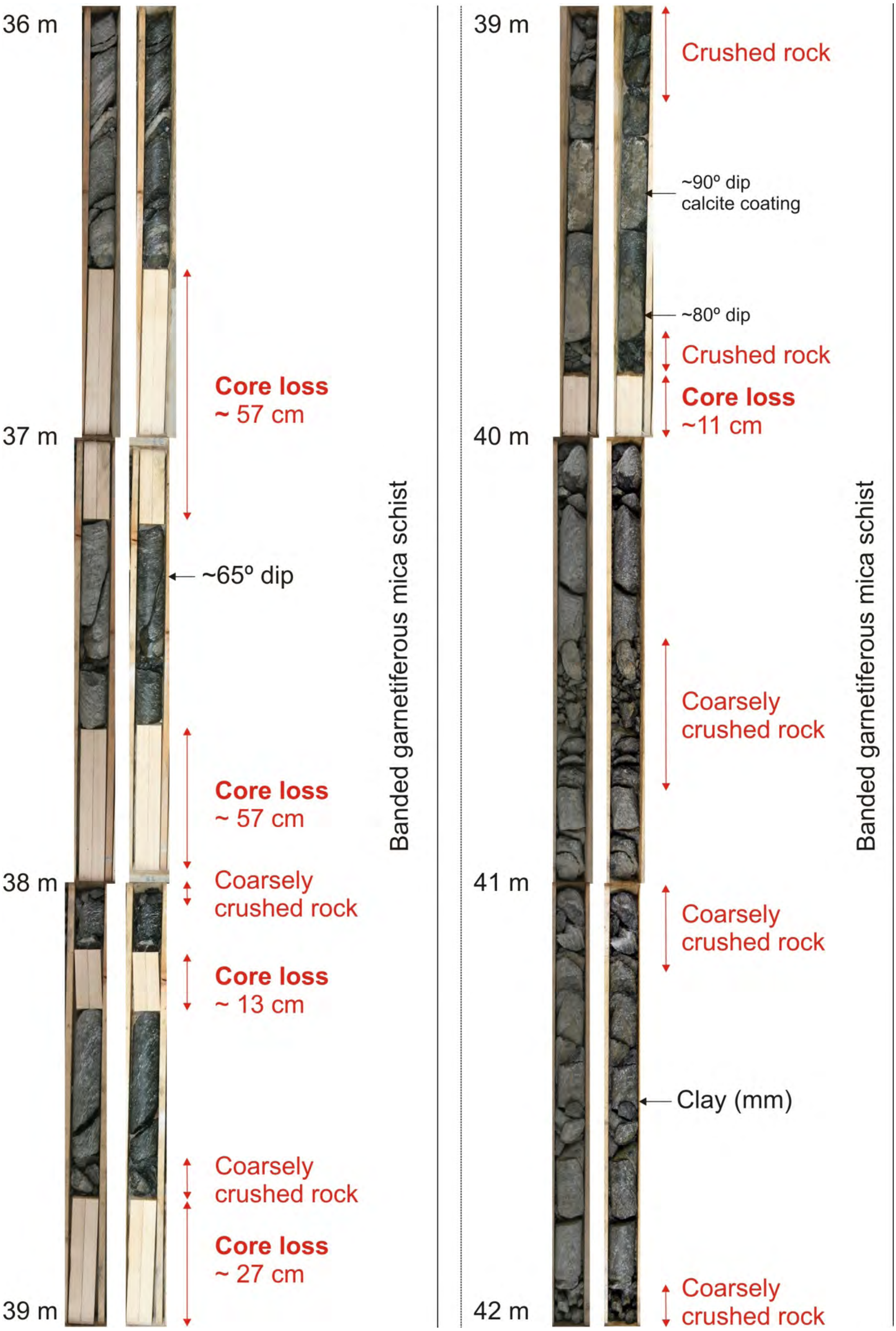

Figure 31. Core logging of drill core BH 02-13 at 36-42 m. Photo of dry core to the left and wet core to the right. Clay (mm) means appearance of clay material that is less than 5 mm thick.

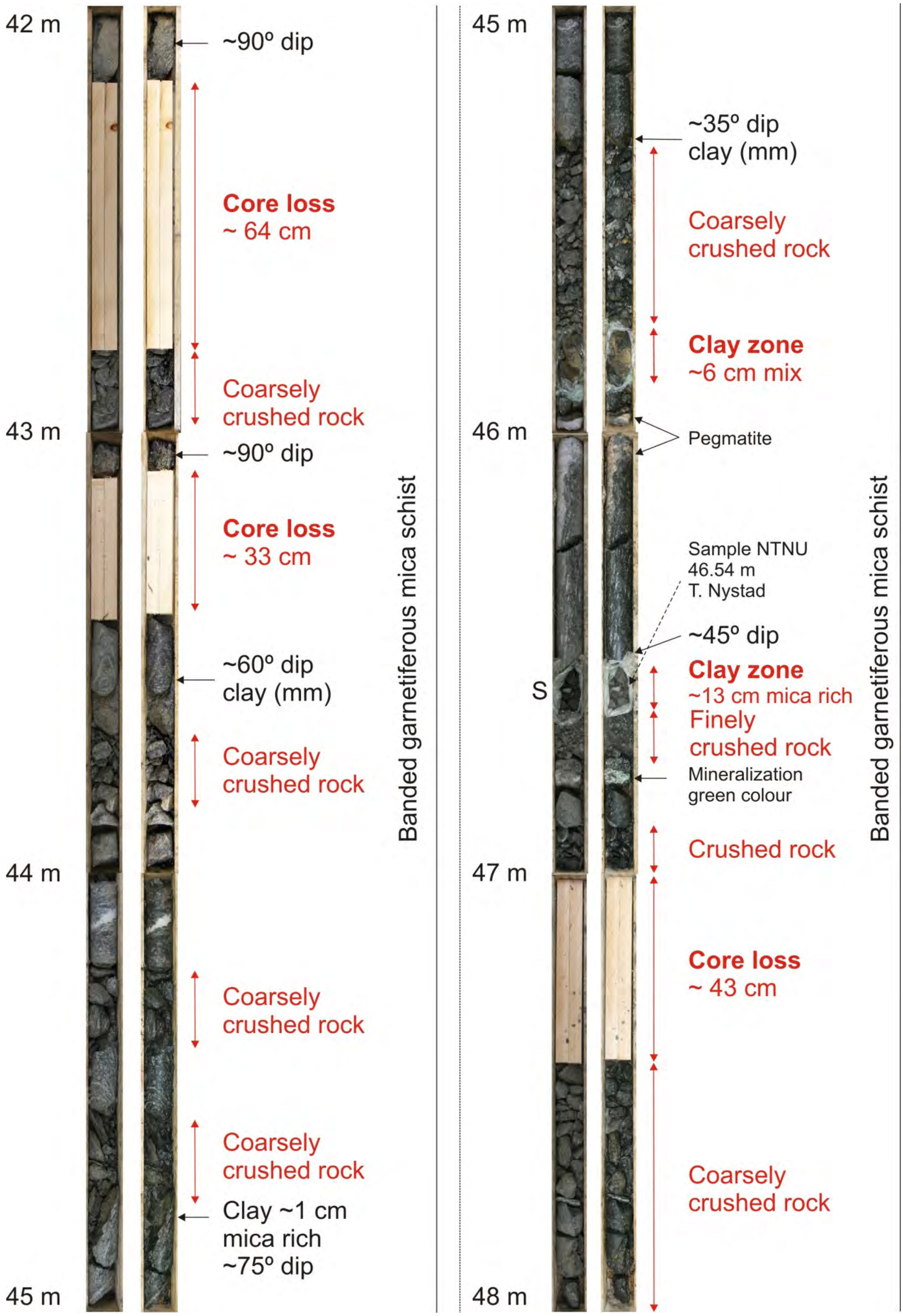

Figure 32. Core logging of drill core BH 02-13 at 42-48 m. Photo of dry core to the left and wet core to the right. Clay (mm) means appearance of clay material that is less than 5 mm thick.

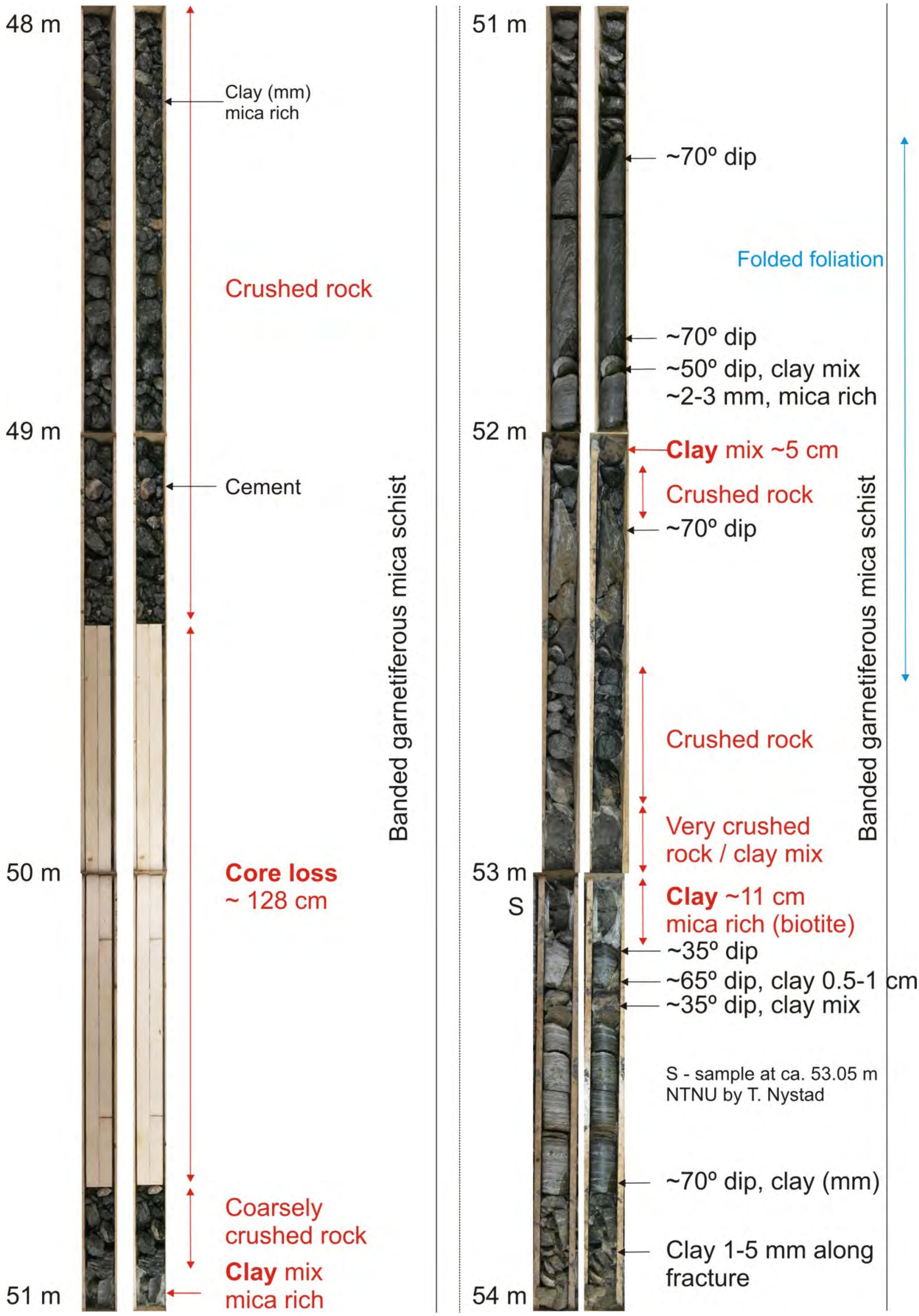

Figure 33. Core logging of drill core BH 02-13 at 48-54 m. Photo of dry core to the left and wet core to the right. Clay (mm) means appearance of clay material that is less than 5 mm thick.

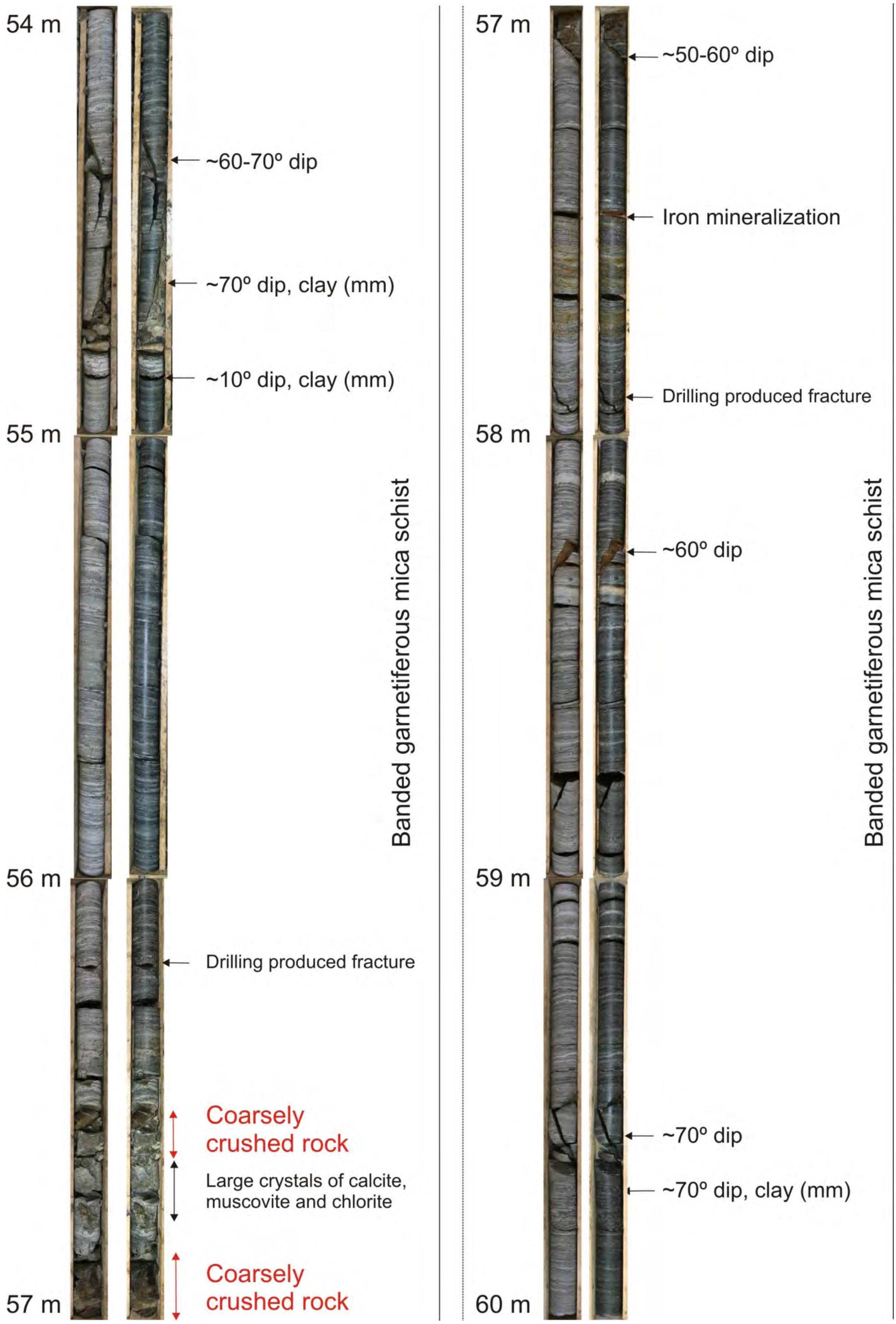

Figure 34. Core logging of drill core BH 02-13 at 54-60 m. Photo of dry core to the left and wet core to the right. Clay (mm) means appearance of clay material that is less than 5 mm thick.

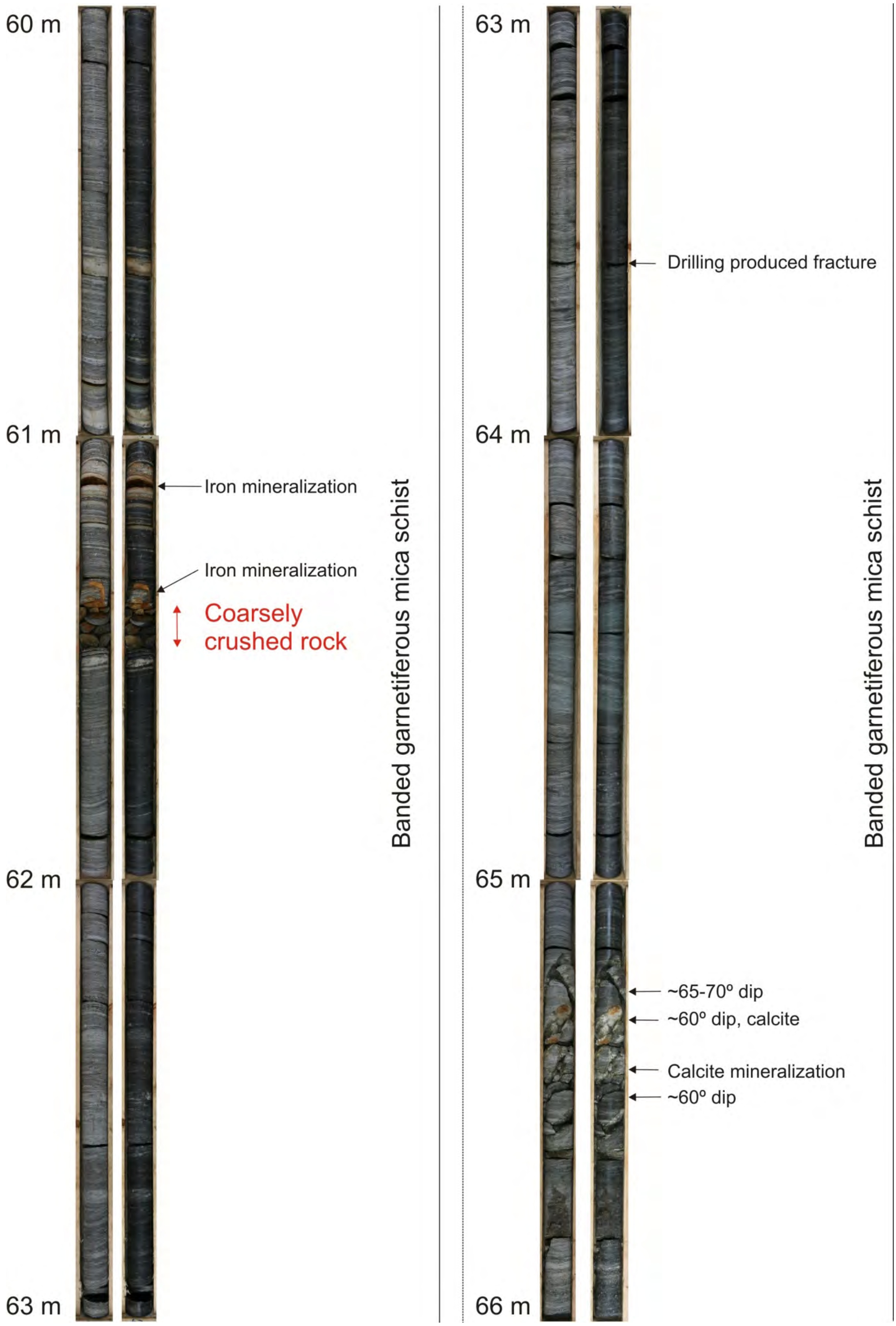

Figure 35. Core logging of drill core BH 02-13 at 60-66 m. Photo of dry core to the left and wet core to the right.

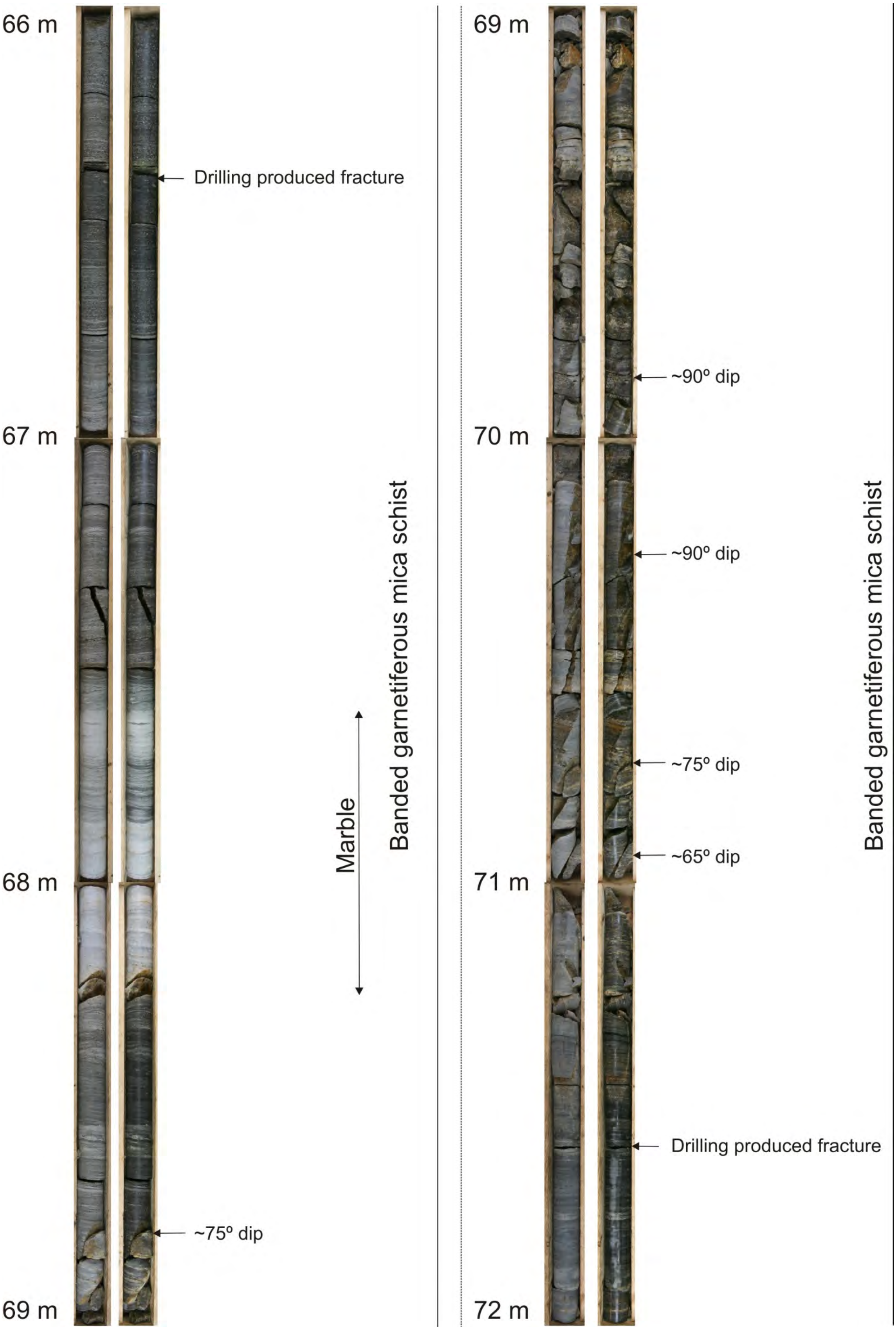

Figure 36. Core logging of drill core BH 02-13 at 66-72 m. Photo of dry core to the left and wet core to the right.

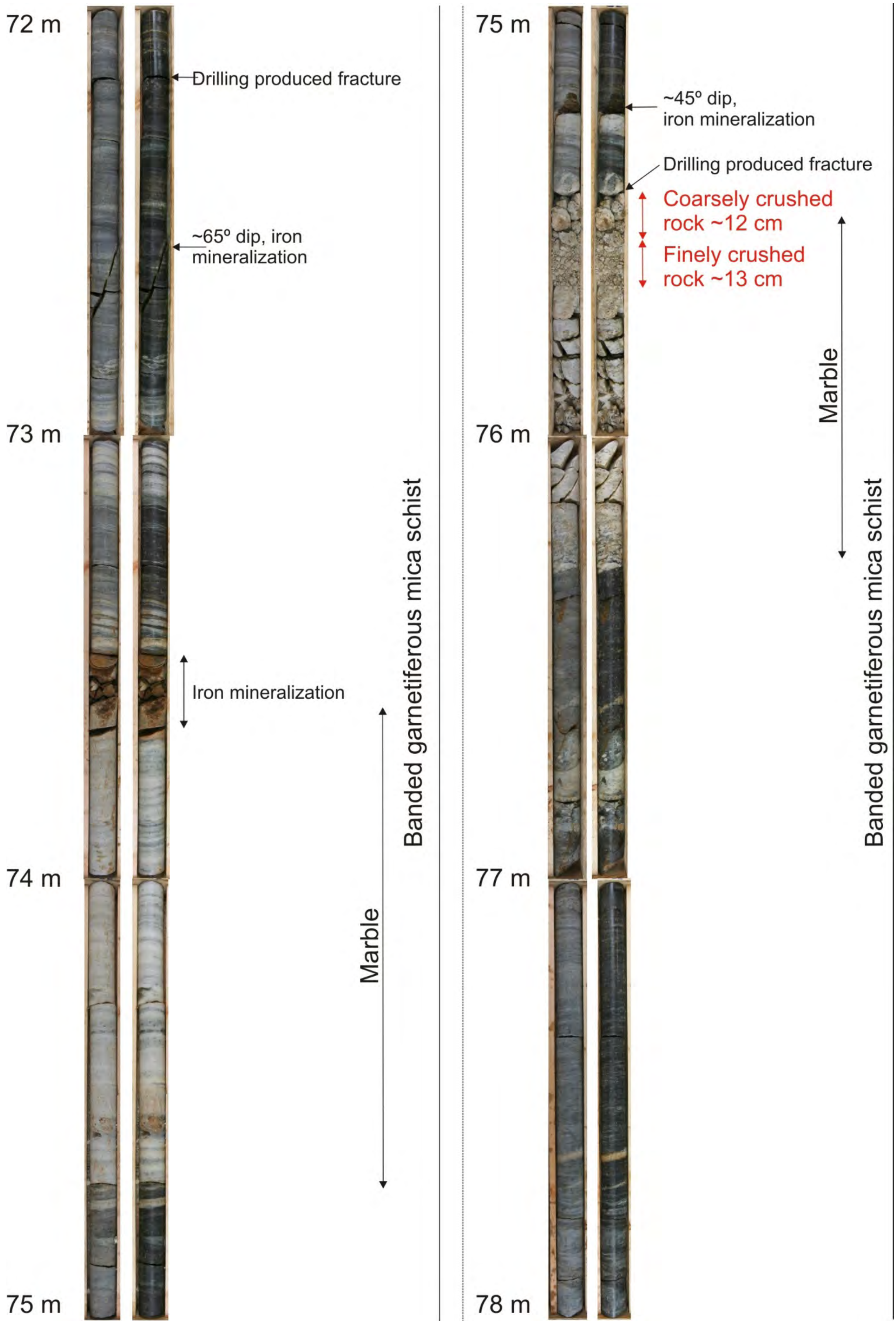

Figure 37. Core logging of drill core BH 02-13 at 72-78 m. Photo of dry core to the left and wet core to the right.

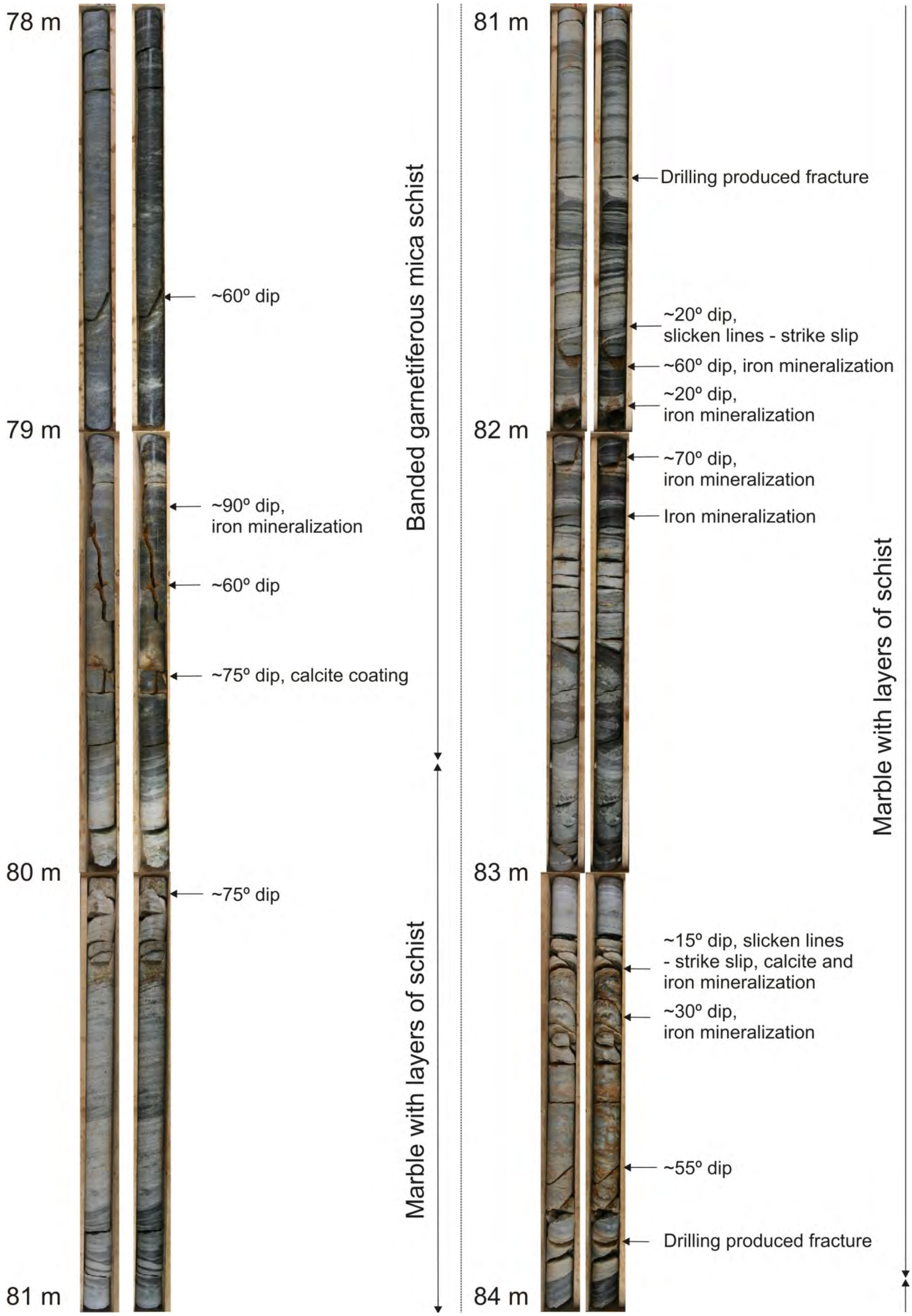

Figure 38. Core logging of drill core BH 02-13 at 78-84 m. Photo of dry core to the left and wet core to the right.

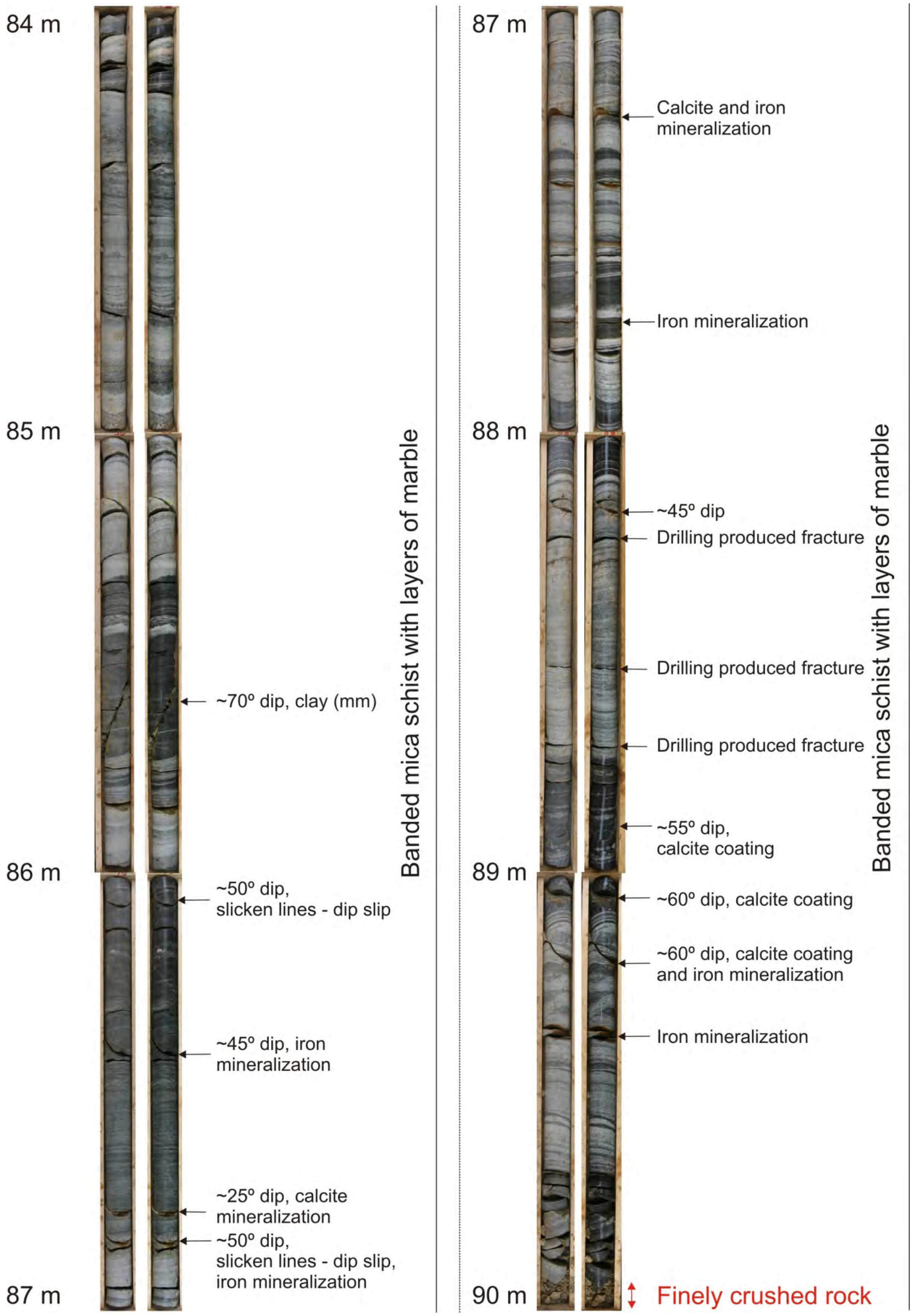

Figure 39. Core logging of drill core BH 02-13 at 84-90 m. Photo of dry core to the left and wet core to the right. Clay (mm) means appearance of clay material that is less than 5 mm thick.

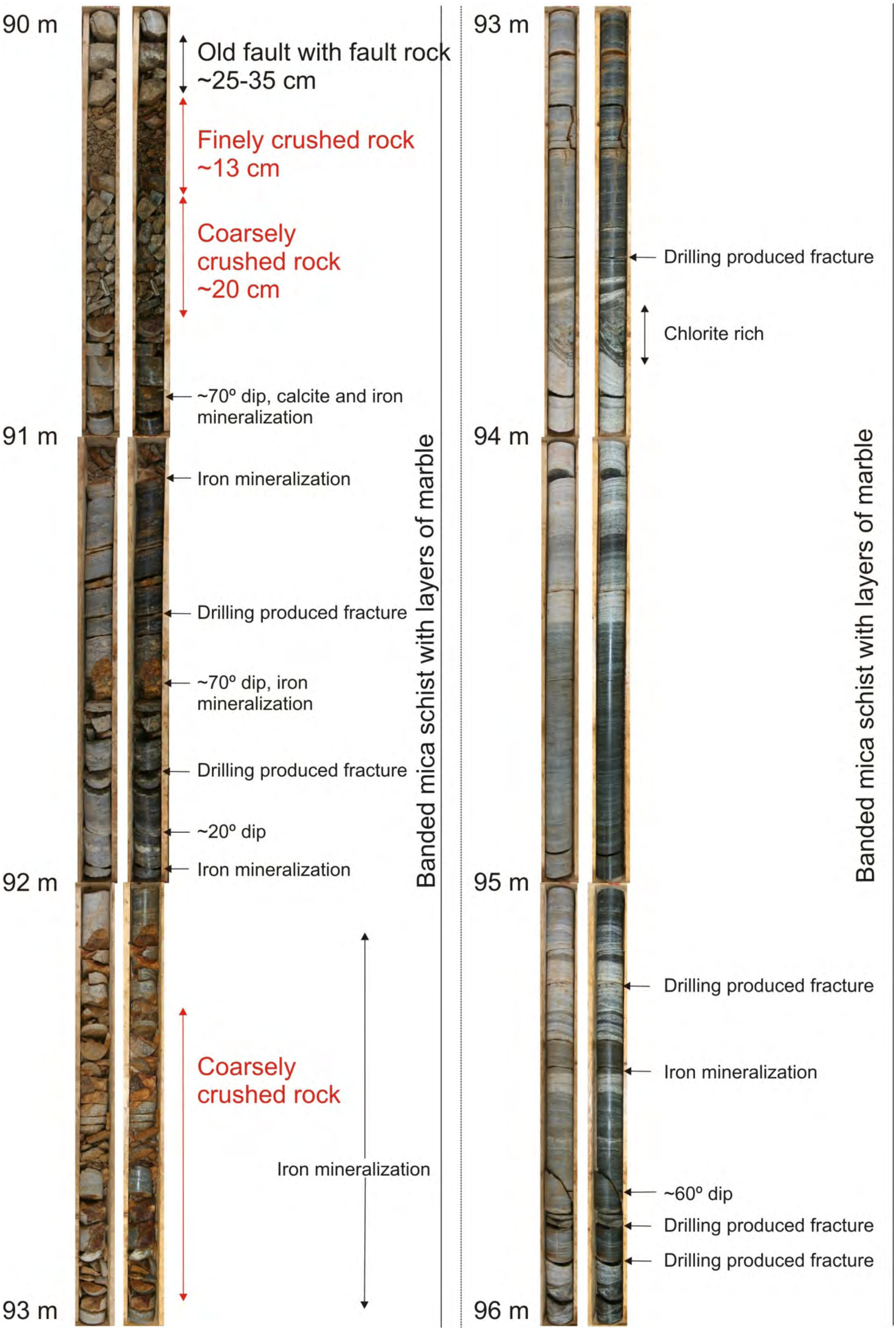

Figure 40. Core logging of drill core BH 02-13 at 90-96 m. Photo of dry core to the left and wet core to the right.

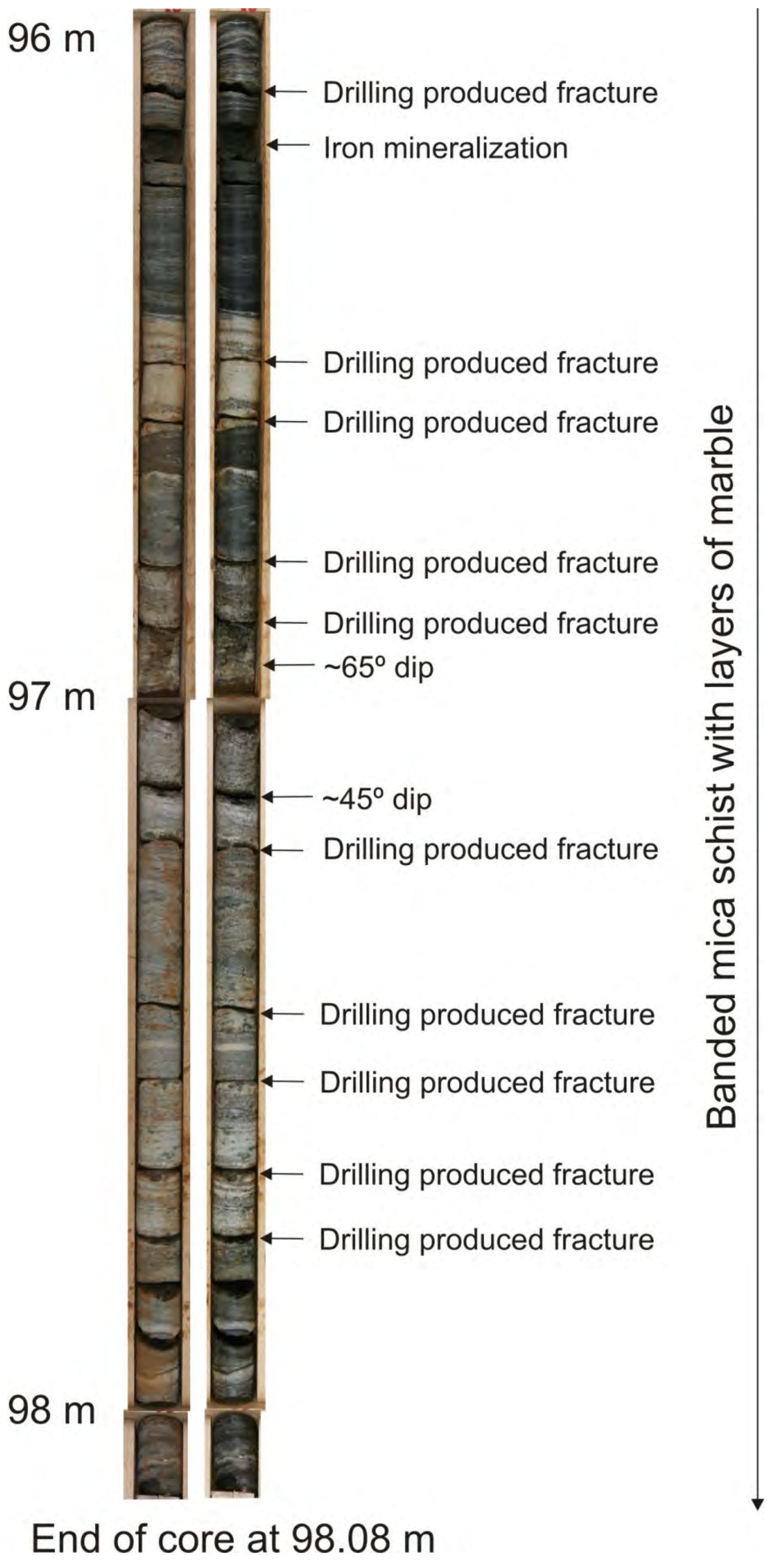

Figure 41. Core logging of drill core BH 02-13 at 96-98.08 m. Photo of dry core to the left and wet core to the right.

4. CORE LOGGING BH 3- 2013

In this chapter the drill cores from BH 3 is documented with pictures and logged with detailed information such as bedrock type and zones of interest for stability.

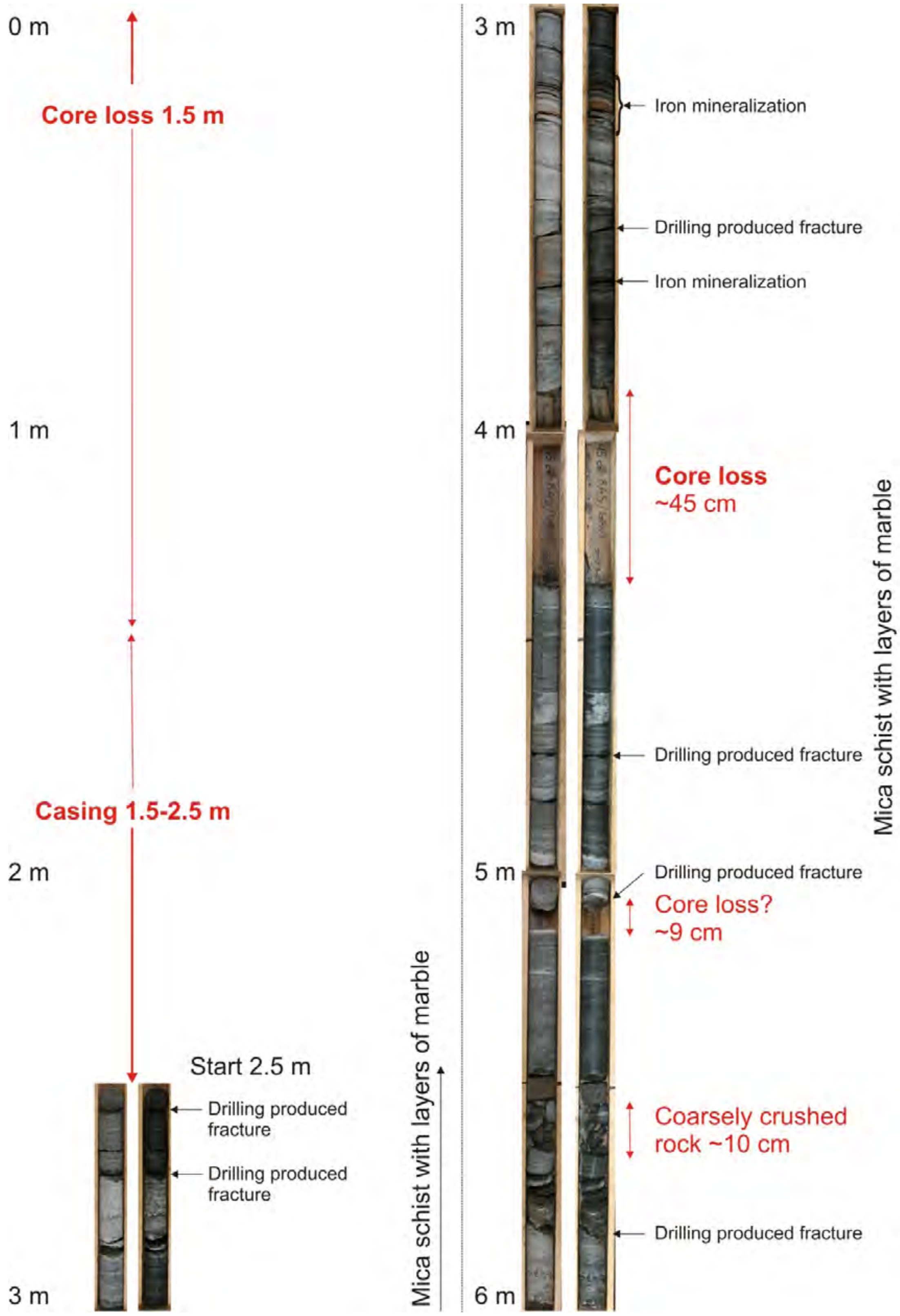

Figure 42. Core logging of drill core BH 03-13 at 0-6 m. Photo of dry core to the left and wet core to the right.

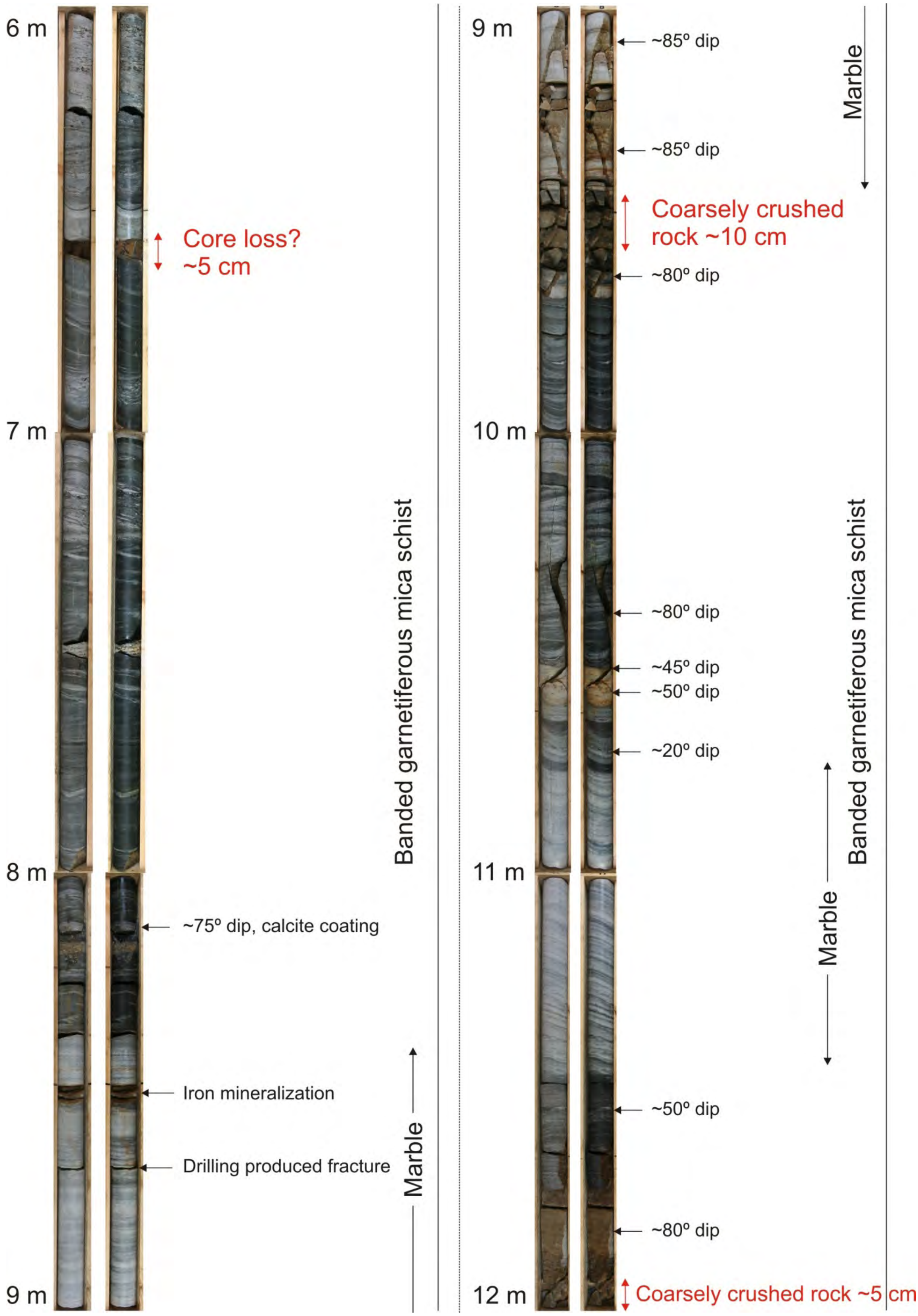

Figure 43. Core logging of drill core BH 03-13 at 6-12 m. Photo of dry core to the left and wet core to the right.

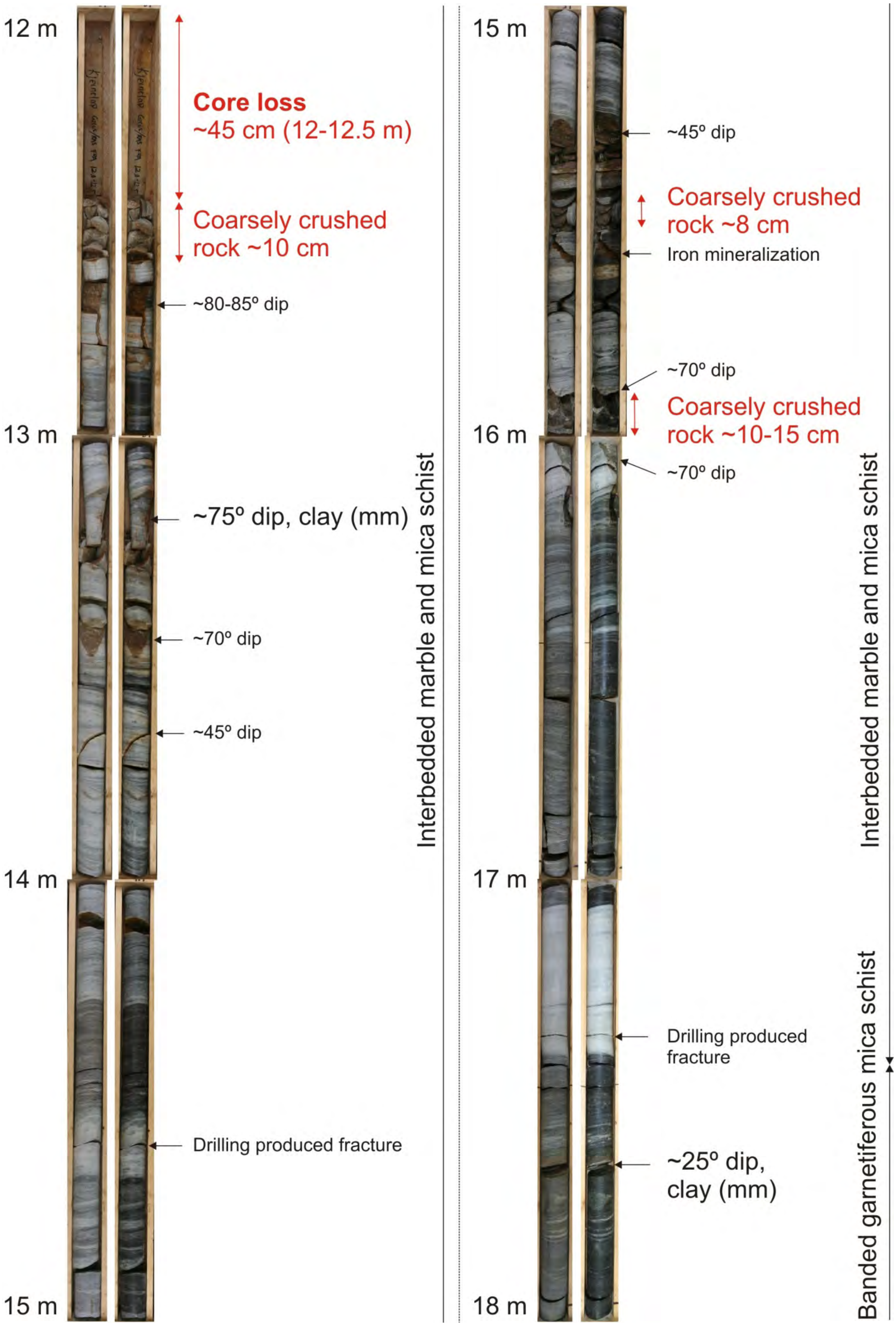

Figure 44. Core logging of drill core BH 03-13 at 12-18 m. Photo of dry core to the left and wet core to the right. Clay (mm) means appearance of clay material that is less than 5 mm thick.

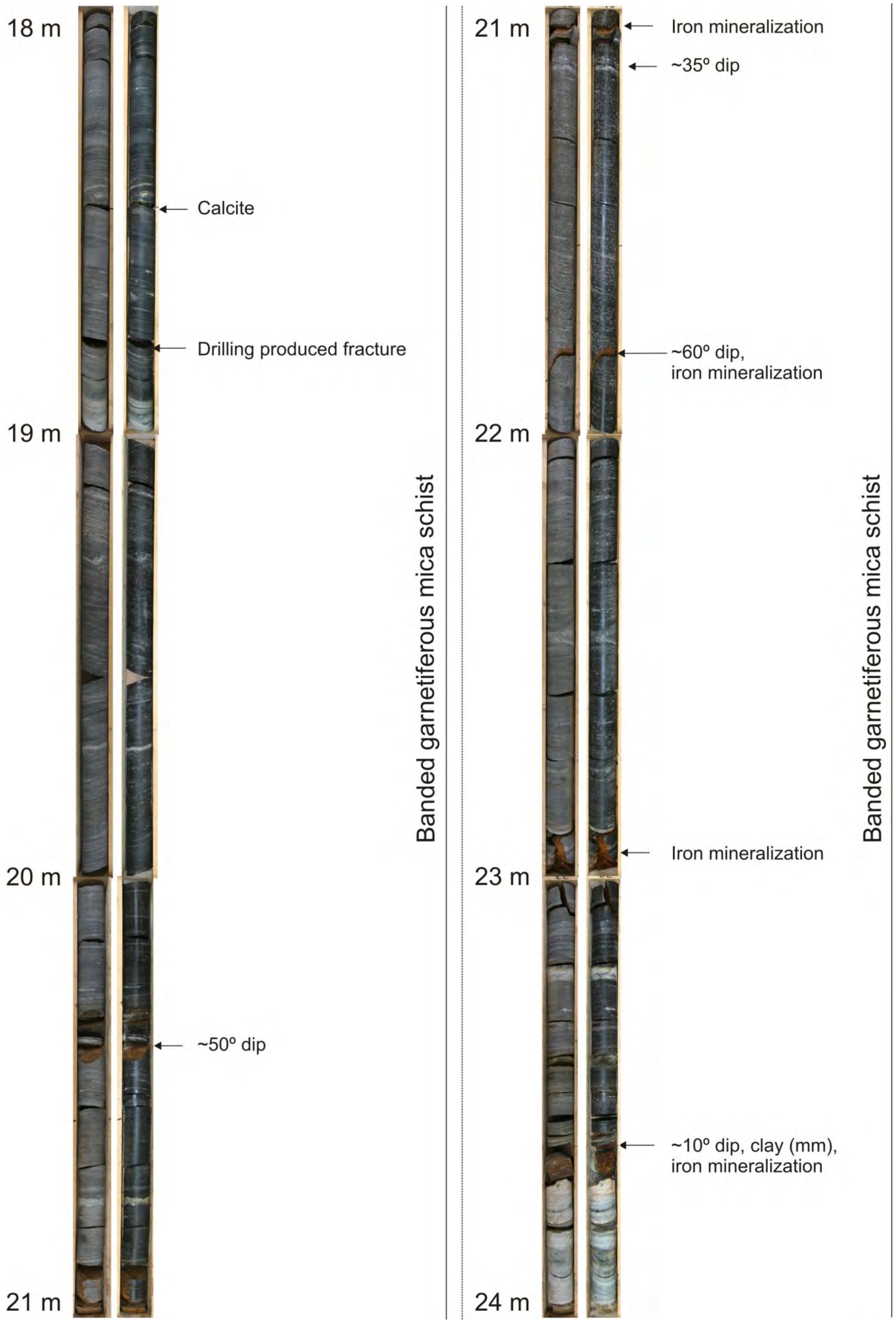

Figure 45. Core logging of drill core BH 03-13 at 18-24 m. Photo of dry core to the left and wet core to the right. Clay (mm) means appearance of clay material that is less than 5 mm thick.

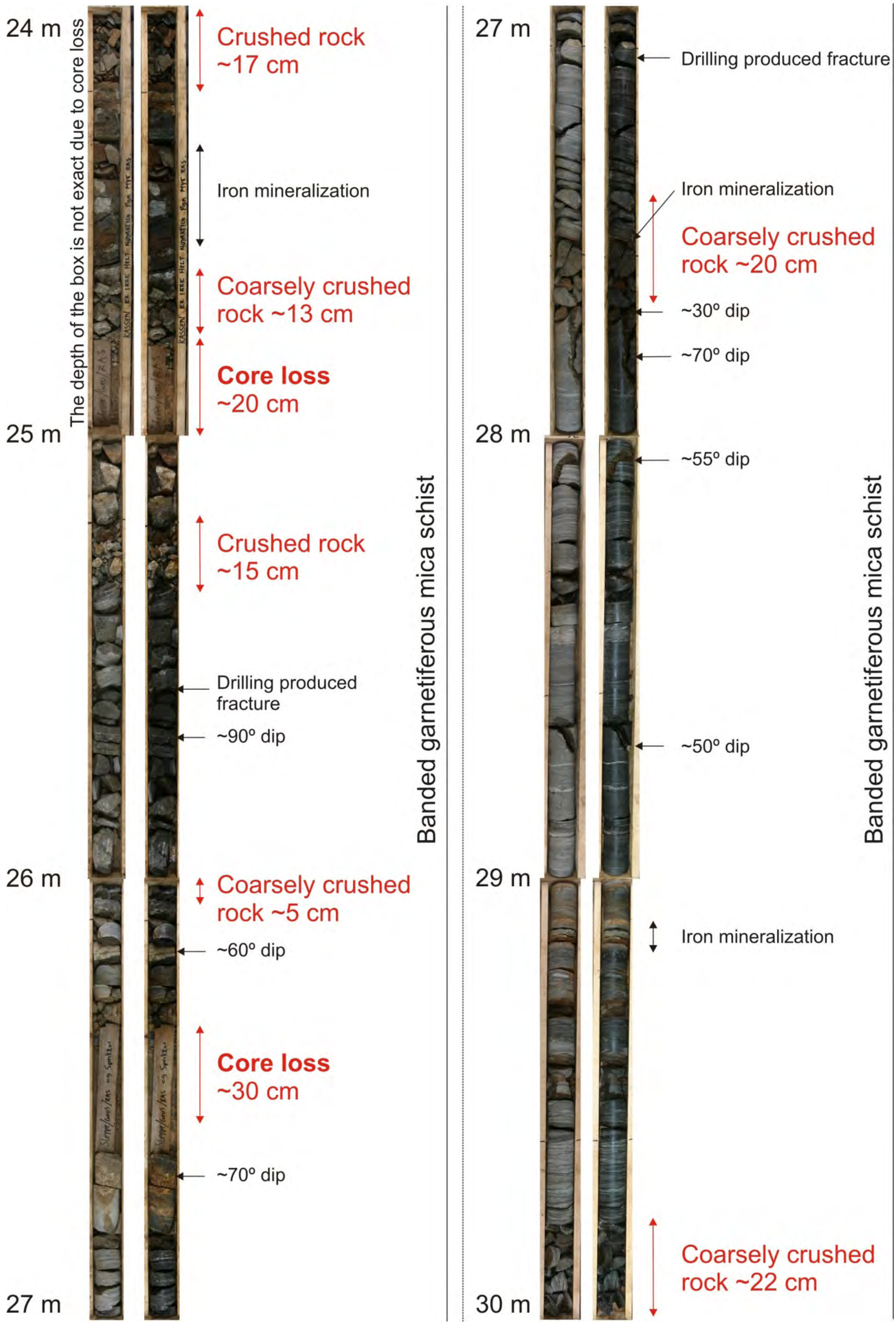

Figure 46. Core logging of drill core BH 03-13 at 24-30 m. Photo of dry core to the left and wet core to the right.

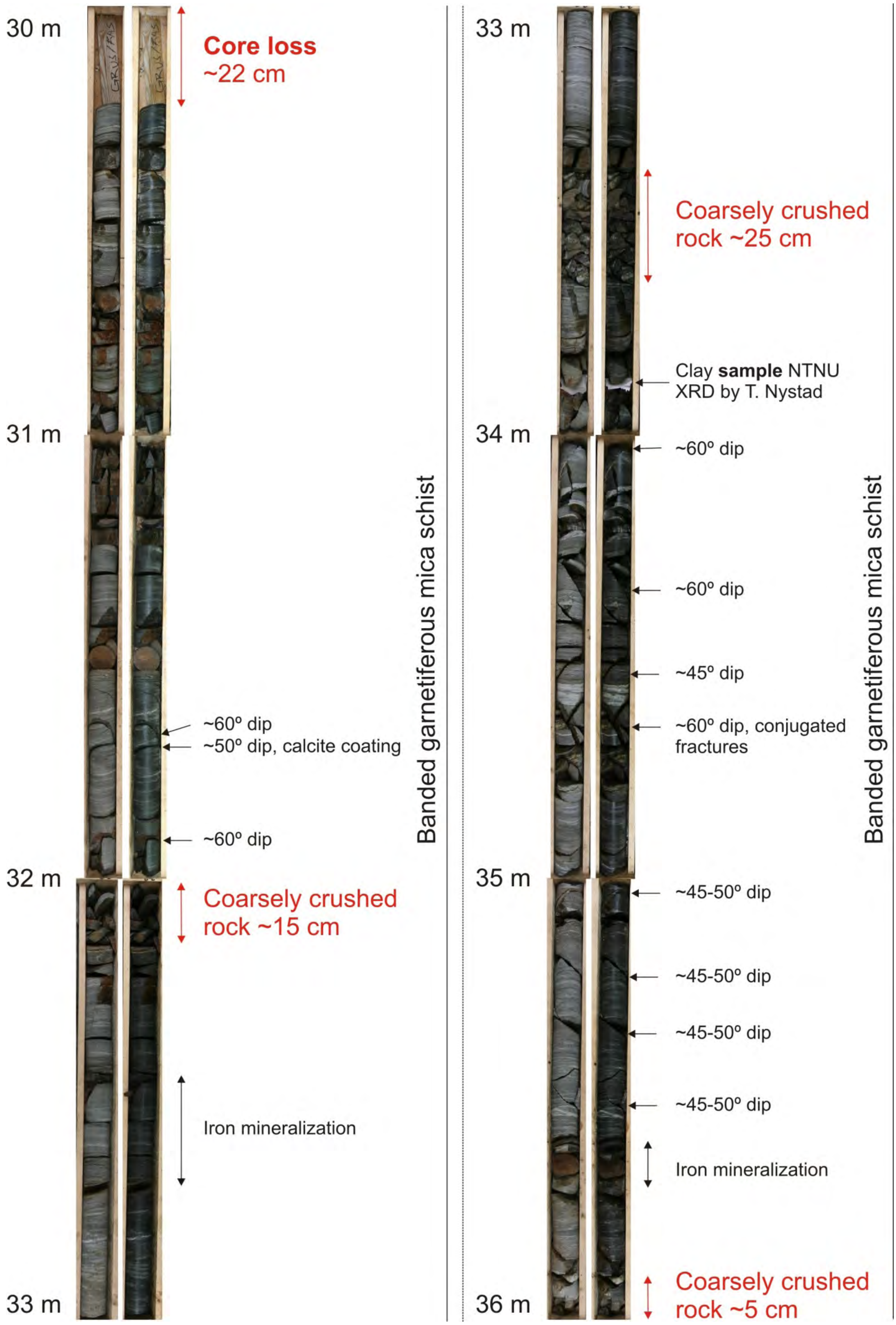

Figure 47. Core logging of drill core BH 03-13 at 30-36 m. Photo of dry core to the left and wet core to the right.

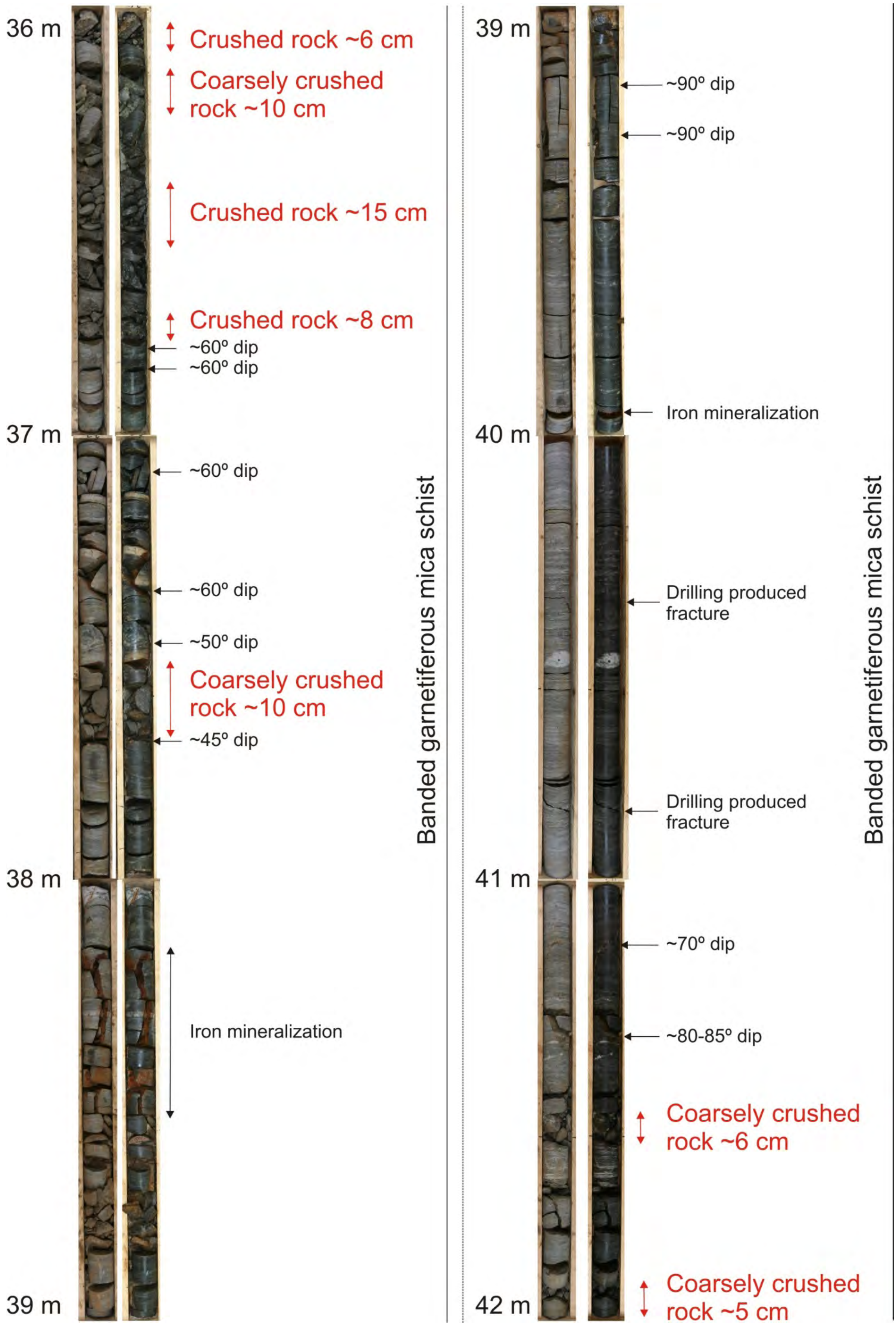

Figure 48. Core logging of drill core BH 03-13 at 36-42 m. Photo of dry core to the left and wet core to the right.

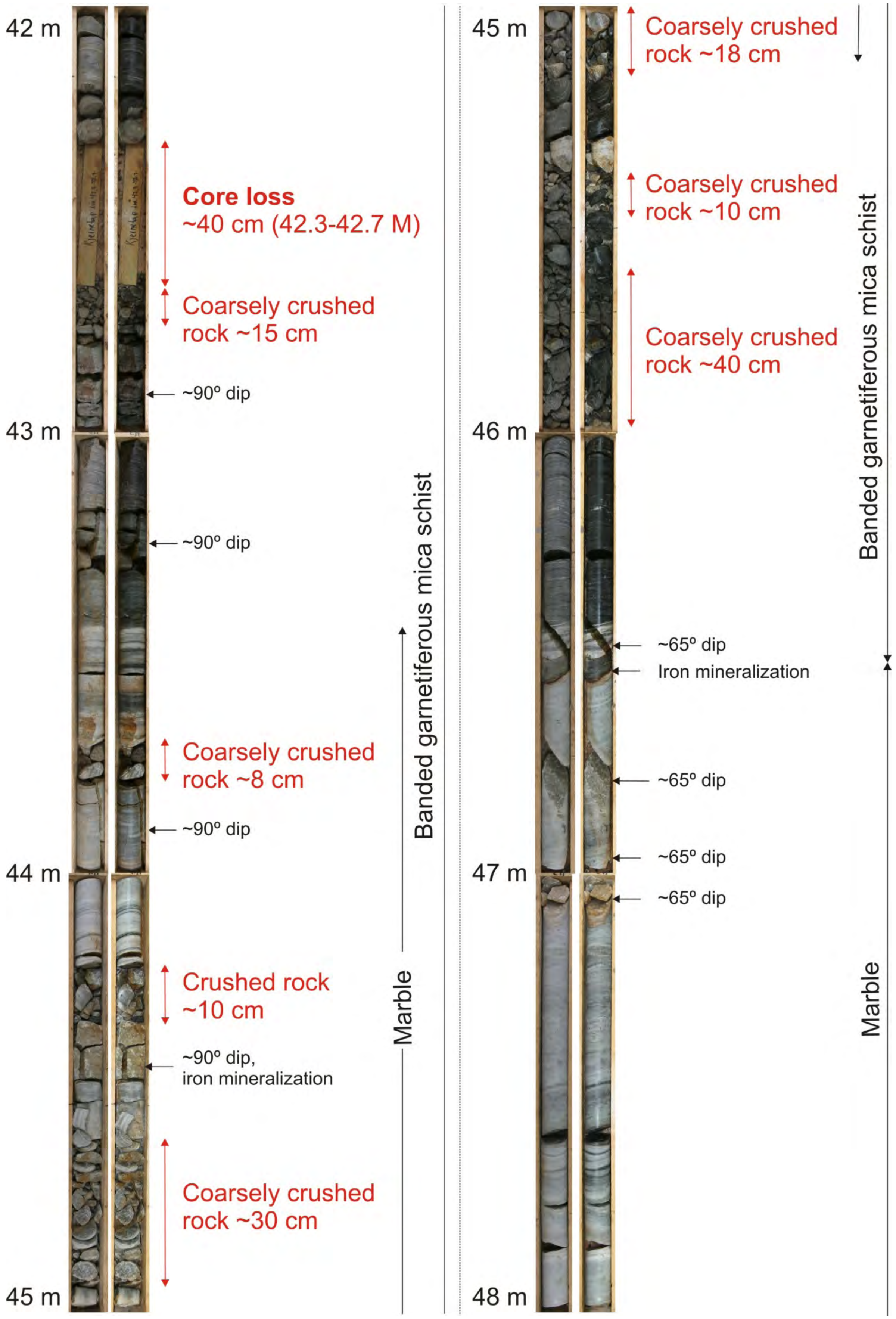

Figure 49. Core logging of drill core BH 03-13 at 42-48 m. Photo of dry core to the left and wet core to the right.

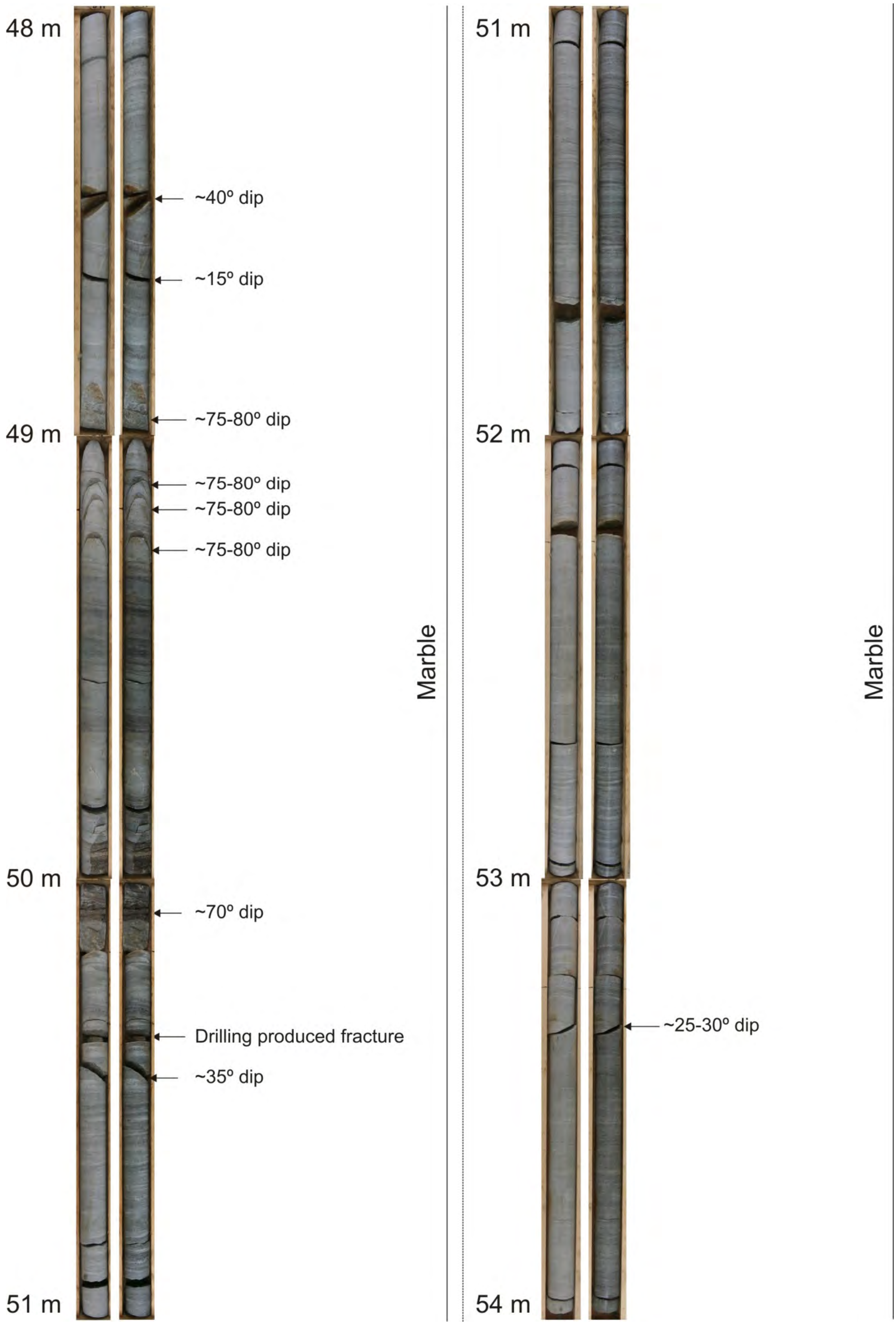

Figure 50. Core logging of drill core BH 03-13 at 48-54 m. Photo of dry core to the left and wet core to the right.

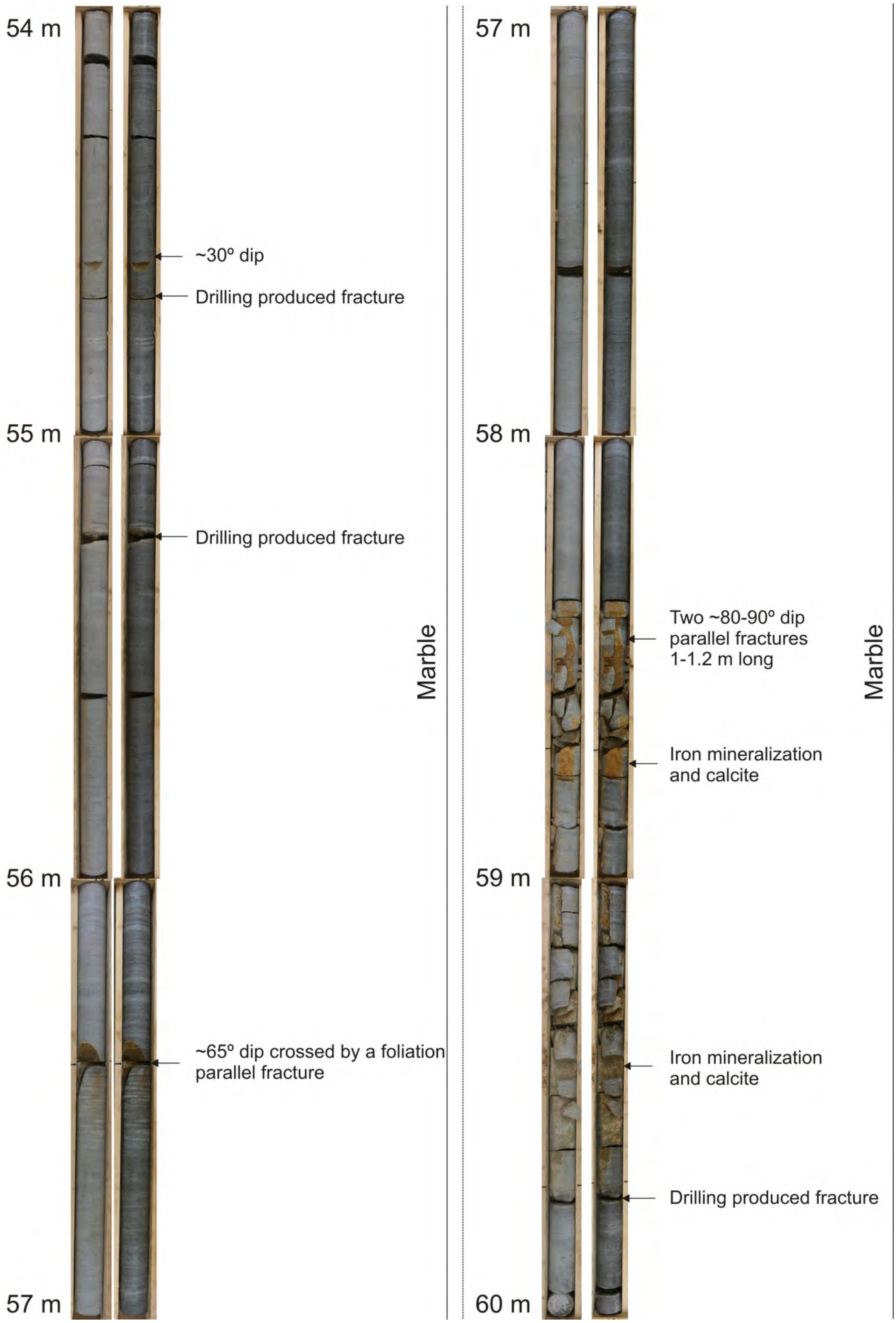

Figure 51. Core logging of drill core BH 03-13 at 54-60 m. Photo of dry core to the left and wet core to the right.

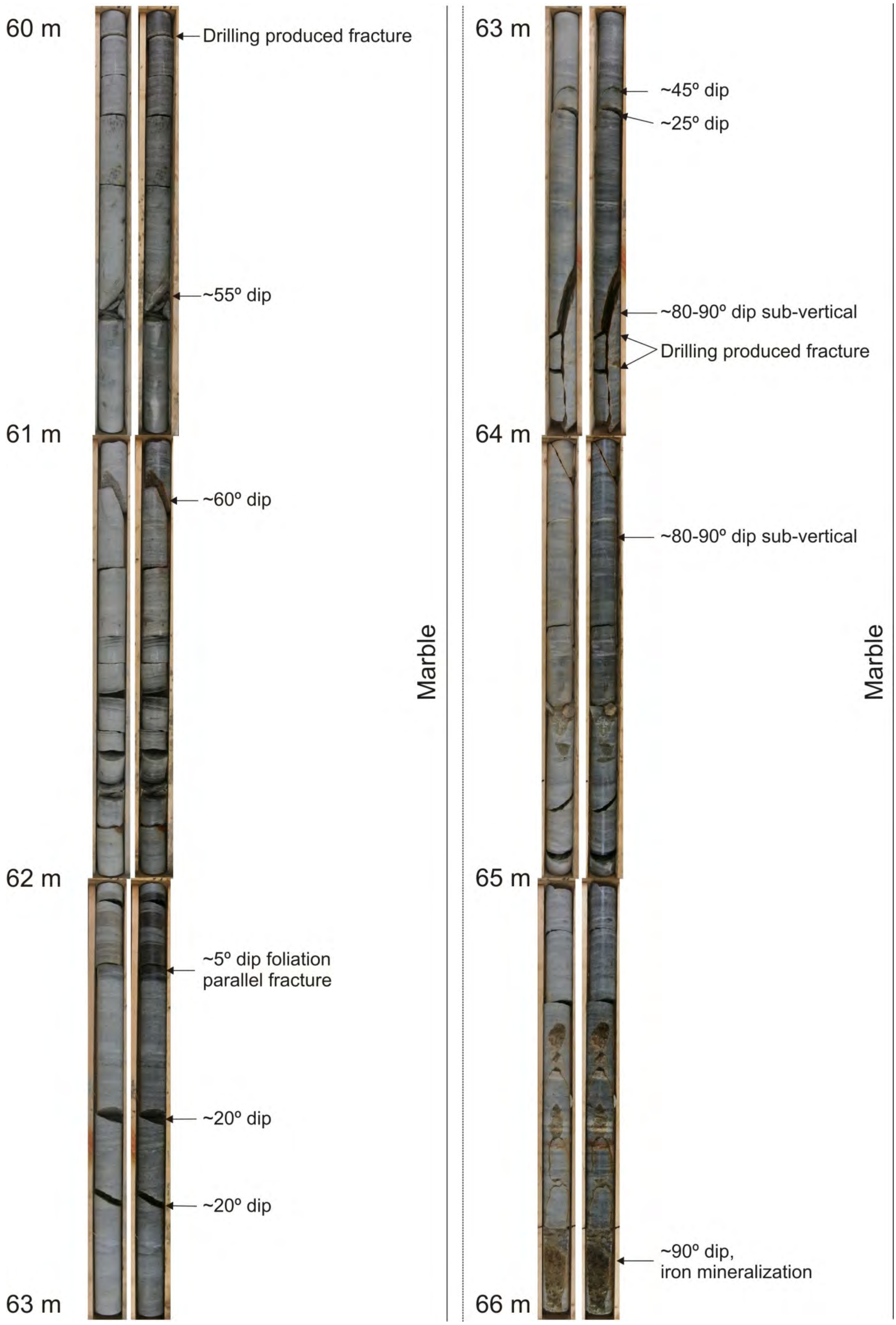

Figure 52. Core logging of drill core BH 03-13 at 60-66 m. Photo of dry core to the left and wet core to the right.

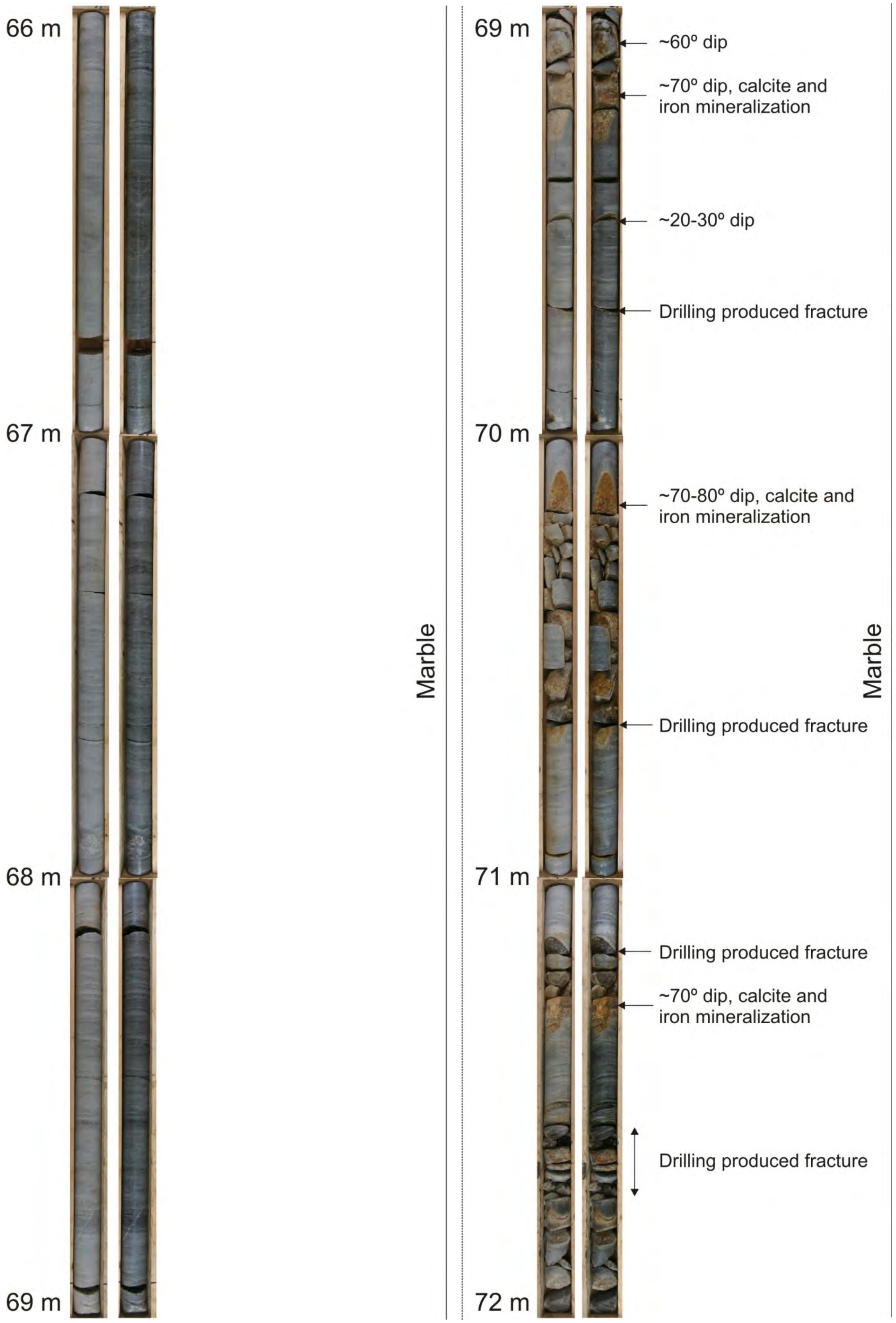

Figure 53. Core logging of drill core BH 03-13 at 66-72 m. Photo of dry core to the left and wet core to the right.

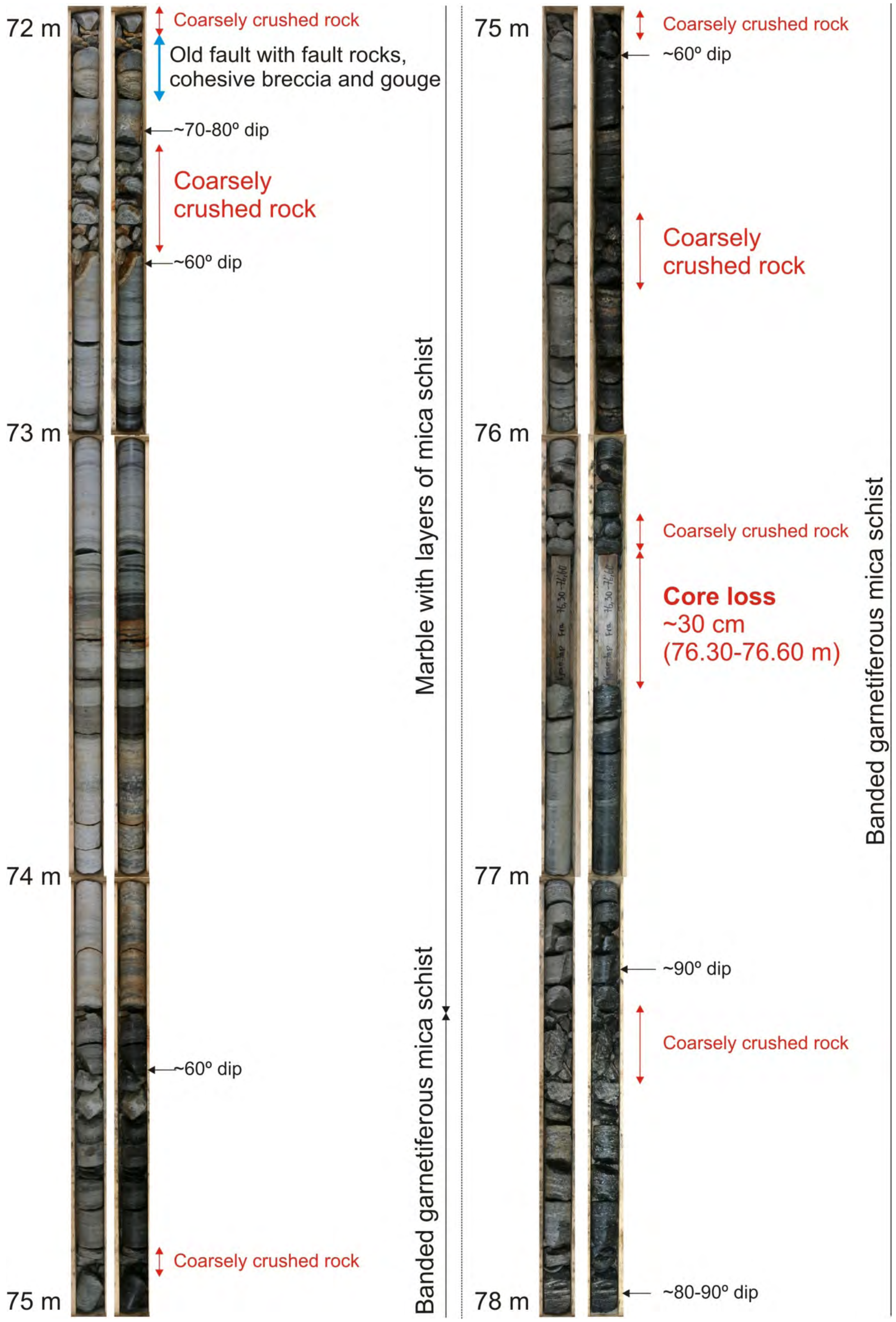

Figure 54. Core logging of drill core BH 03-13 at 72-78 m. Photo of dry core to the left and wet core to the right.

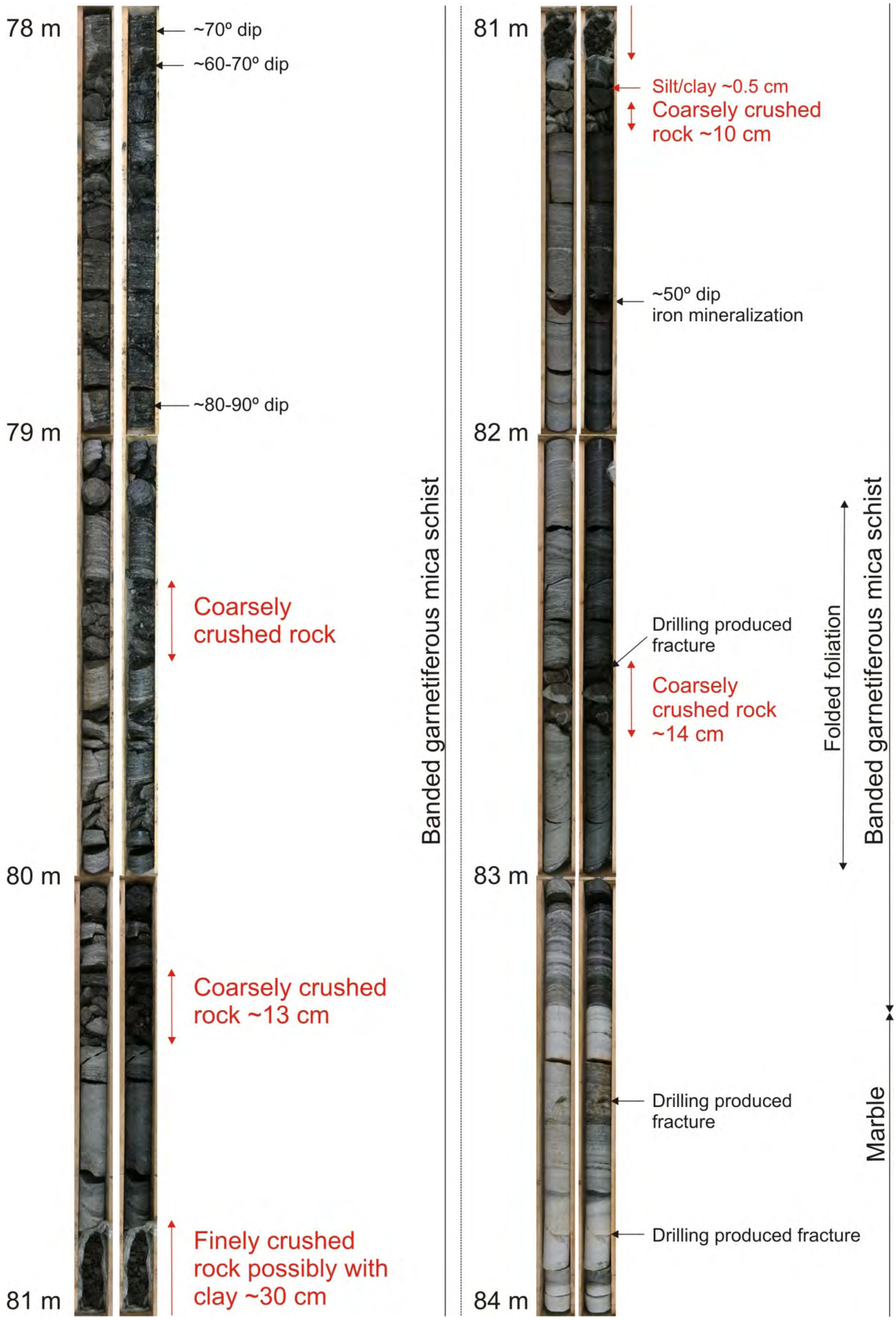

Figure 55. Core logging of drill core BH 03-13 at 78-84 m. Photo of dry core to the left and wet core to the right.

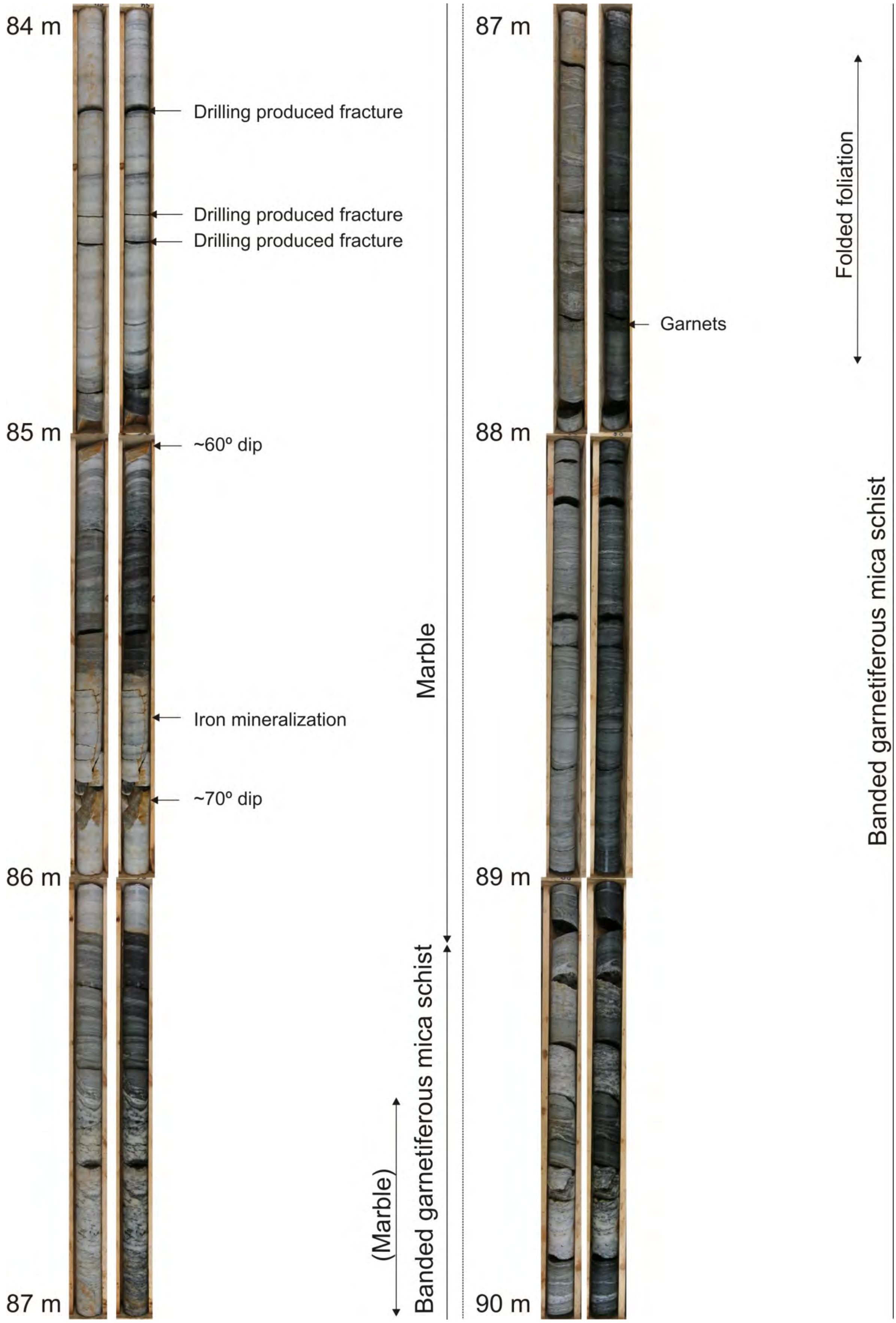

Figure 56. Core logging of drill core BH 03-13 at 84-90 m. Photo of dry core to the left and wet core to the right.

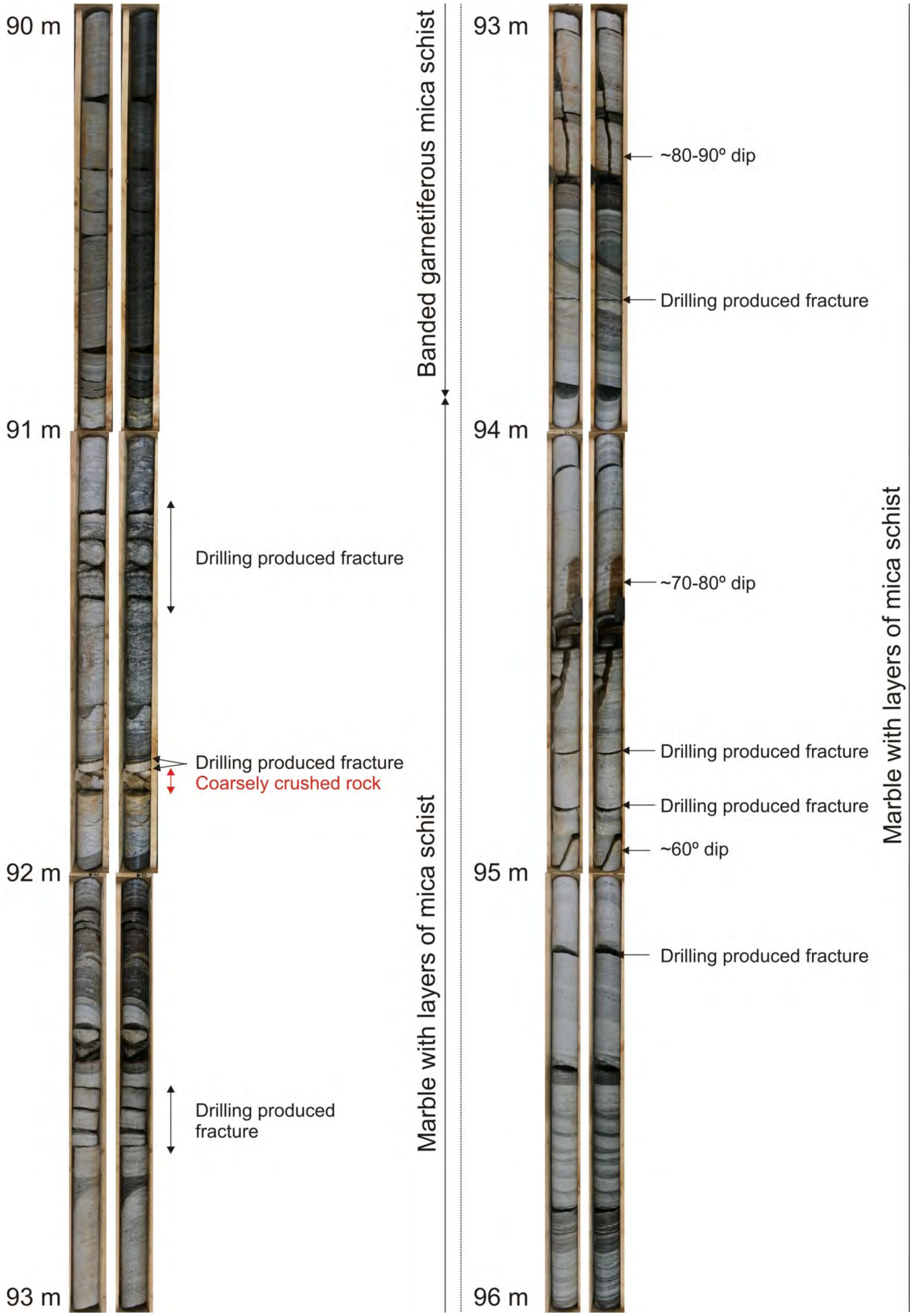

Figure 57. Core logging of drill core BH 03-13 at 90-96 m. Photo of dry core to the left and wet core to the right.

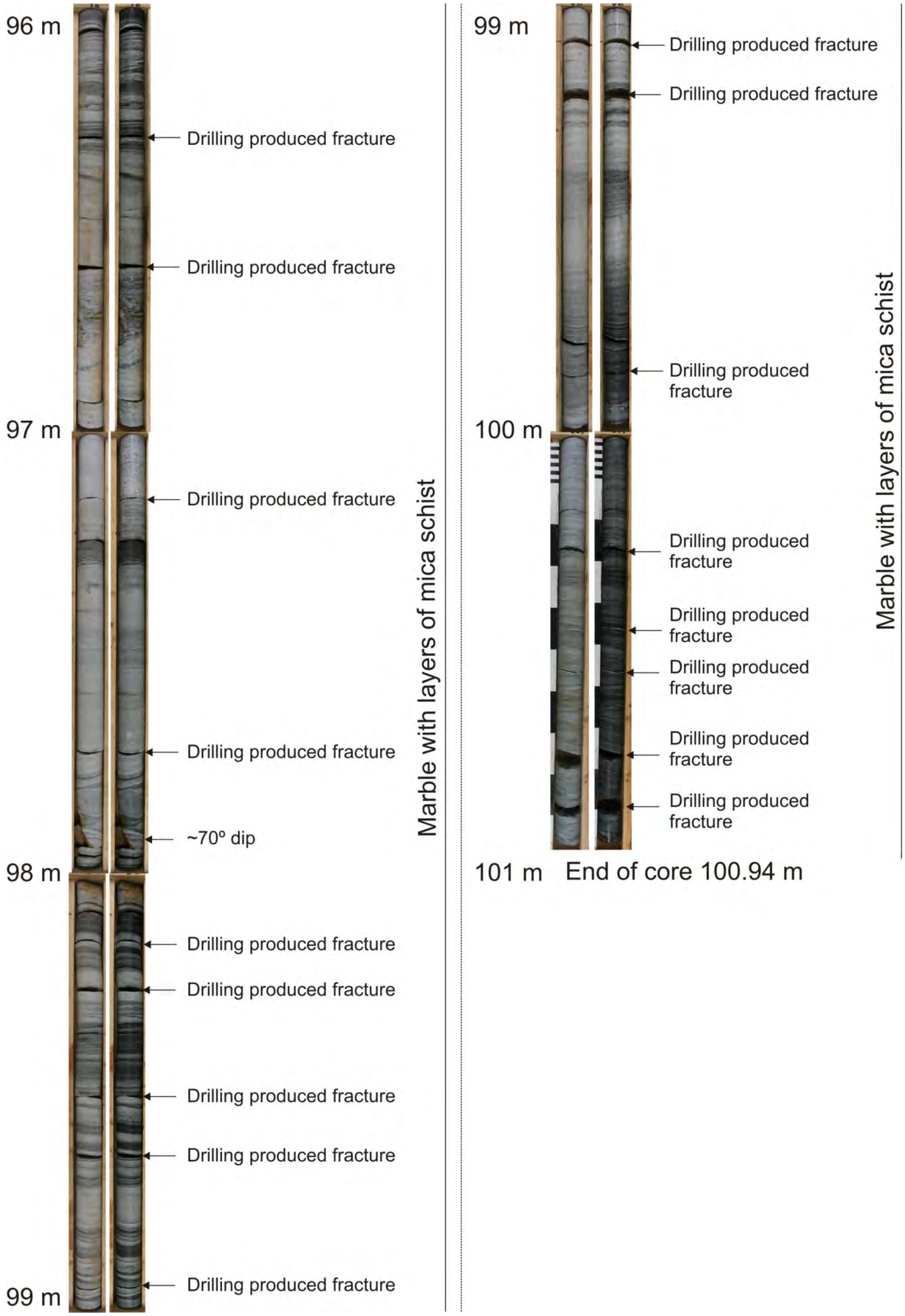

Figure 58. Core logging of drill core BH 03-13 at 96-100.94 m. Photo of dry core to the left and wet core to the right.

4.1 Double core from 44 m to 45.5 m

A section of 1.5 meter in BH 3 consist of double drill core, where the original borehole needed to be abandoned due to stability problems, and a new nearby borehole was drilled.

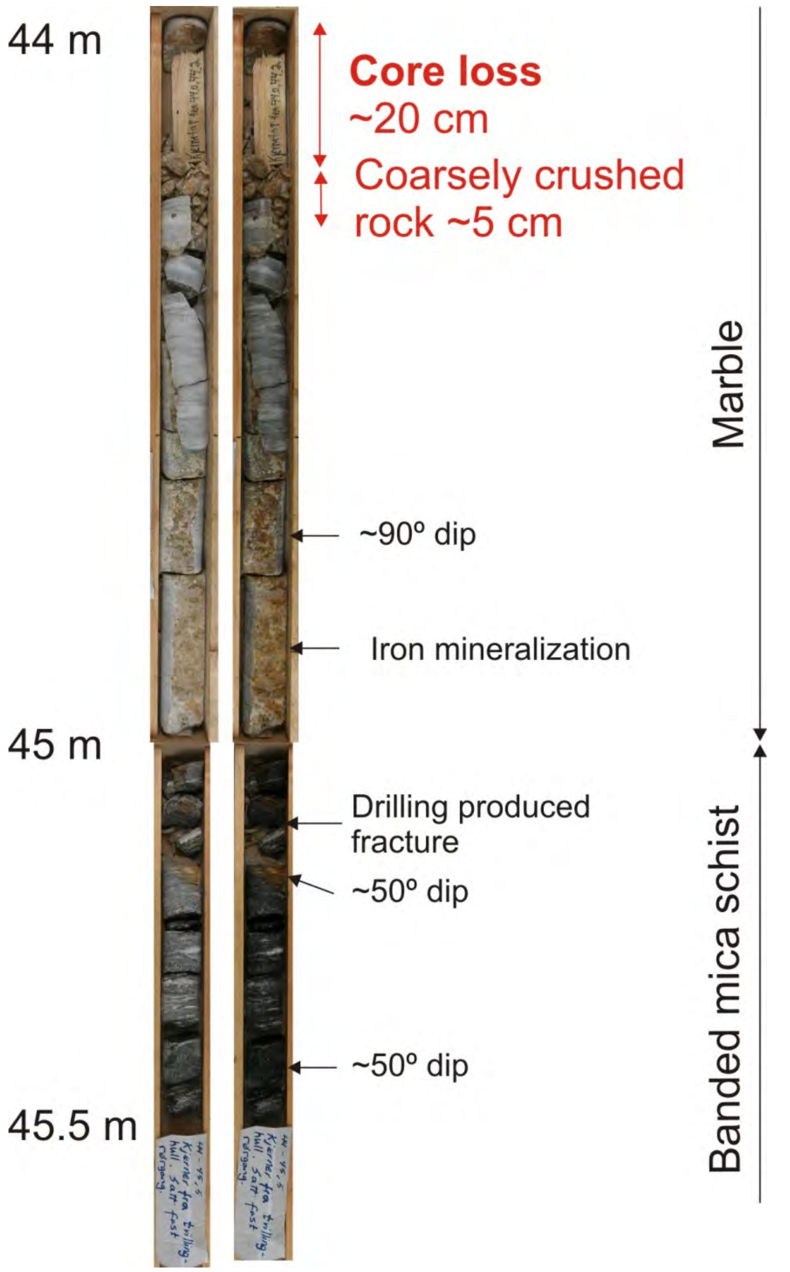

Figure 59. Core logging of drill core BH 03-13B at 44-45.5 m, double set of cores. Photo of dry core to the left and wet core to the right.

5. SUMMARY

The bedrock in the drill core consists generally of banded garnetiferous mica schist, banded mica schist with layers of marble, marble and marble with layers of mica schist. All bedrock types are meta sedimentary rock of medium grade metamorphosis. The foliation is pervasive and sub-horizontal, with local intense folding, throughout the drill cores. The orientation of the foliation and fractures are documented in NGU report 2014.016 by Elvebakk (2014).

5.1 Summary for BH 02-2013

Borehole BH 2 and the coherent drill cores are characterized by zones of crushed rock, core loss and narrow zones containing clay. The first zone of extensive crushed rock and core loss is at ca. 24.5 to 27 m (Figure 6). The core loss correlates well with cavity in the bedrock due to open fractures that possibly represent zones of gravitational movement.

The main zone of deformation is from 36.62 to 53.15 meters, containing several intervals of core loss, repeating zones of crushed rock and distinct zones with clay (Figure 7). The clay zones are mica rich and the thickest clay zone is ca. 13 cm at ca. 46.50-46.63 meter. The fracture at the upper boundary of this clay zone has a dip of ~45°. The core loss in the drill cores correlate with cavity in the bedrock observed with the Optical Televiewer (Figure 5; Elvebakk, 2014).

At 69-71 meter vertical fractures cause higher fracture frequency than natural due to fracturing during the drilling process (Figure 9). When vertical fractures with long extension occur the fracture frequency commonly increases due to drilling difficulties and increased drilling produced fractures.

At 89.95 to ca. 90.40 meter a 25-35 cm wide fault zone with cohesive breccia and cohesive gouge is located (Figure 10). The zone is interpreted as an old fault that has been reworked, where clasts of breccia is found in the zone of finely crushed rock below. In the borehole this zone consist of crushed rock that is either filled with fine, natural material or cement (Figure 10).

Graphs of fracture frequency for BH 2 is given in Figure 12 and Figure 13. The zones described above commonly have both zones of crushed rock and core loss.

The pervasive, sub-horizontal foliation is seen by thin lines in the bedrock. The foliation reflects a folded bedrock where the orientation varies through the drill core. The orientation of the foliation is documented by Elvebakk (2014, NGU report 2014.016), which shows that the foliation at the top has 15° to 20° dip towards SW, increasing to 60° to 70° dip towards W-SW between 38. and 53 meter. From ca. 53 meter and deeper the foliation varies between 10° and 35° dip with a general orientation towards SSW. This alternation in foliation is also seen in the drill cores (chapter 3.).

5.2 Summary for HB 03-2013

This drill hole is characterized by zones of crushed rock and core loss, and the lack of fine material such as clay. This does not indicate that fine material does not exist, but rather that it was not recovered during the drilling process. In images for the borehole logged by Elvebakk (2014) there is observed fine material that is not recovered in the drill core as seen in Figure 17 and Figure 19.

From ca. 24 to ca. 36.80 meter the bedrock is heavily fractures and zones of crushed rock and some core loss are evident. Especially the zone between 24 to 26.5 meter is crushed it also shows altogether 50 cm of core loss (Figure 16). Vertical fractures do occur in this section, which may cause extra fracturing due to drilling difficulties (Figure 17). The core loss observed in the drill core (Figure 16) correlate well with cavity in the bedrock that is observed in the Optical Televiewer (Figure 17; Elvebakk, 2014). As seem when Figure 16 and Figure 17 are compared is that the fine material, potential clay, is often lost during the drilling process and not preserved in the drill cores.

The main zone of deformation in borehole 3 is at ca. 42.3 to 46 meters depth and consists of crushed rock (Figure 18). In the drill core loss of core is noted (Figure 18), but when compared to images from the Optical Televiewer of the same interval (42-43 m) the bedrock is visible with good quality and few fractures (Figure 19).

An old fault is observed at ca. 72.10 to 72.20 m consisting of fault rock such as cataclasite (Figure 20). Cataclasite is a cohesive, semi ductile, fault rock that has equivalent strength as the bedrock. Below the old fault a zone of coarsely crushed rock is observed, but there is no evidence that the old fault has been reworked.

At ca. 80.90 to 81.10 meters depth a zone of finely crushed rock is observed (Figure 21). The fine material is rich in mica that reflect the bedrock, which is mica rich schist, but clay is not observed. In the image from the Optical Televiewer the same zone is seen as cavity in a crushed zone where the fine material might has been washed out (bottom in Figure 21).

Graphs of fracture frequency for BH 3 are shown in Figure 23 and Figure 24. The fracture frequency reflect the zones of crushed rock and core loss that are described above.

The foliation reflects a folded bedrock where the orientation varies through the drill core. The orientation of the foliation is documented by Elvebakk (2014, NGU report 2014.016): at the top the foliation has 5° to 20° dip towards SE. Between ca. 45 to 70 meter the dip is shallow, ca. 5° with orientation towards east. From ca. 75 meter downward the foliation varies between 5° and 35° dip with rapidly changing orientation, indicating that the bedrock is folded. This alternation in foliation is also seen in the drill cores (chapter 4.).

A discussion of the results in comparison to geological data earlier published on Jettan was not performed.

Acknowledgements

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