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Geological logging of drill core from borehole NN-01-12 at Jettan, Nordnes mountain in Troms county, Northern Norway

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REPORT

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Geological logging of drill core from borehole NN-01-12 at Jettan, Nordnes mountain in Troms county , Northern Norway

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Summary:
This drill hole is the first at Jettan in the Nordnes mountain, named NN-01-12. The borehole was drilled during summer/autumn 2012 by Arctic drilling and the drill core was logged at the Geological Survey of Norway (NGU) in May 2013. The cores are now stored at Løkken drill core and rock sample storage at the NGU. The drill core is approximately 200 metre long (198.8 m) and due to fracture and/or fault zones the drill hole was cemented and re-drilled several times to keep stable. Therefore, a short part for the drill core has a "double set" of ca. 20 metre, where the drilling diverted from the original drill hole. The drill cores are logged with regards to bedrock type, fracture frequency and zones of interest with respect to sliding plane(s) and movement. All drill cores are photographed, first dry and then wet, and are documented with pictures and detailed description in this report.

The bedrock occurring in the 200 metre long drill core is successively banded garnetiferous mica schist, 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. The orientation of the foliation and fractures occurring in the borehole is well documented in the NGU report 2013.20 by Elvebakk describing results from Optical Televiewer. The depth of the drill core is poorly reported, therefore the depths given are approximate and tried correlated to the depths recorded by the drillers on the way, but with some difficulty.

The main zone of crushed rock is at ~37.3 metre to ~42 metre with highly fractured rock and zone with potential clay filling. A ~25 cm zone with carbonate breccia containing clasts of mica schist and possibly clay is located at ~45.2-45.5 metre related to an old fault constricted at the bottom by a sliding plane with fault breccia. This zone is considered as the main zone of displacement.

The drill core has in general a low fracture frequency of ~5 fractures/meter when the zones of crushed rock is not regarded. In the interval ~37 to ~46 metre is where the rock is most intensely crushed with potential clay. The other zones of crushed rock that occur in the drill core consist of coarsely crushed rock. Such zones of coarsely crushed rock is frequent from ~148 metre to ~181 metre. The only exception is the zone at ~148.5 to ~152 metre, where the rock is crushed with possible clay occurrence.

Keywords: Core logging	Bedrock	Rock slope

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1. INTRODUCTION

This drill hole is the first at Jettan in the Nordnes mountain, named NN-01-12. The borehole was drilled during summer/autumn 2012 by Arctic drilling and the drill core was logged at the Geological Survey of Norway (NGU) in May 2013. The cores are now stored at Løkken drill core and rock sample storage at the NGU. The drill core is approximately 200 metre long (198.8 m) and due to fracture and/or fault zones, the drill hole was cemented and re-drilled several times to keep stable. Therefore, a short part for the drill core has a "double set" of ca. 20 metre, where the drilling diverted from the original drill hole.

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) joined the logging to carry out engineering geological parameters that are to be used in his Master of Science.

2. GEOLOGICAL DRILL CORE LOGGING

The bedrock occurring in the 200 metre long drill core is successively banded garnetiferous mica schist, 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. The orientation of the foliation and fractures occurring in the borehole is well documented in the NGU report 2013.020 by Elvebakk describing results from Optical Televiewer.

The depth of the drill core is poorly reported, therefore the depths given are approximate and tried correlated to the depths recorded by the drillers on the way, and depths from the borehole logging by Optical Televiewer, given in NGU report 2013.20.

Table 1: Overview of bedrock types and zones occurring in the drill core.

Depth (m)	Bedrock type	Description
0-1.35		Core loss ca. 1.35 m
1.35-31	Mica schist	Banded garnetiferous mica schist
29.45-30.1		Zone with coarsely crushed rock
30.7-31.7		Zone with coarsely crushed rock
31-55	Marble with layers of mica schist	
37.3-42	**Main fracture zone**	Zone with crushed rock
45.2-45.5	**Main zone of displacement**	Fault with carbonate breccia
55-125.3	Mica schist with layers of marble	
125.3-198.9	Marble with layers of mica schist	
149.3-150.2		Zone with crushed rock
156.6-157.75		Zone with crushed rock
165.8-166.2		Zone with coarsely crushed rock
177-178		Zone with coarsely crushed rock
180.9-181.2		Zone with coarsely crushed rock
198.8	End of drill core	

The main zone of crushed rock is at ~37.3 to ~42 metre with highly fractured rock and zone with potential clay filling.

Figure 1. Pictures of the main zone of crushed rock, containing highly fractured and crushed rock with possibly clay at ~37.3-~42 metre.

A ~25 cm zone with carbonate breccia containing clasts of mica schist and possibly clay is located at ~45.2 to 45.5 metre. This zone is considered as the main zone of displacement (Figure 2). This zone is regarded as a reactivated old fault that has breccia along the sliding plane with an estimated dip of 65-70° (Figure 2 and Figure 3). The top fracture of the fault zone has a dip of ~40° (Figure 4).

Figure 2. At ~45.2-45.5 m depth there is an old fault containing ca. 25 cm thick carbonate breccia with possible clay, where the fault plane, with estimated dip of 65-70°, defines the lower depth of the fault zone. This zone is considered as the main zone of displacement.

Figure 3. The old fault has a layer of breccia along the sliding plane, and is likely to contain calcite with deformed schist clasts at ~45.5 m. The fault plane is steep and the dip is estimated to 65-70°.

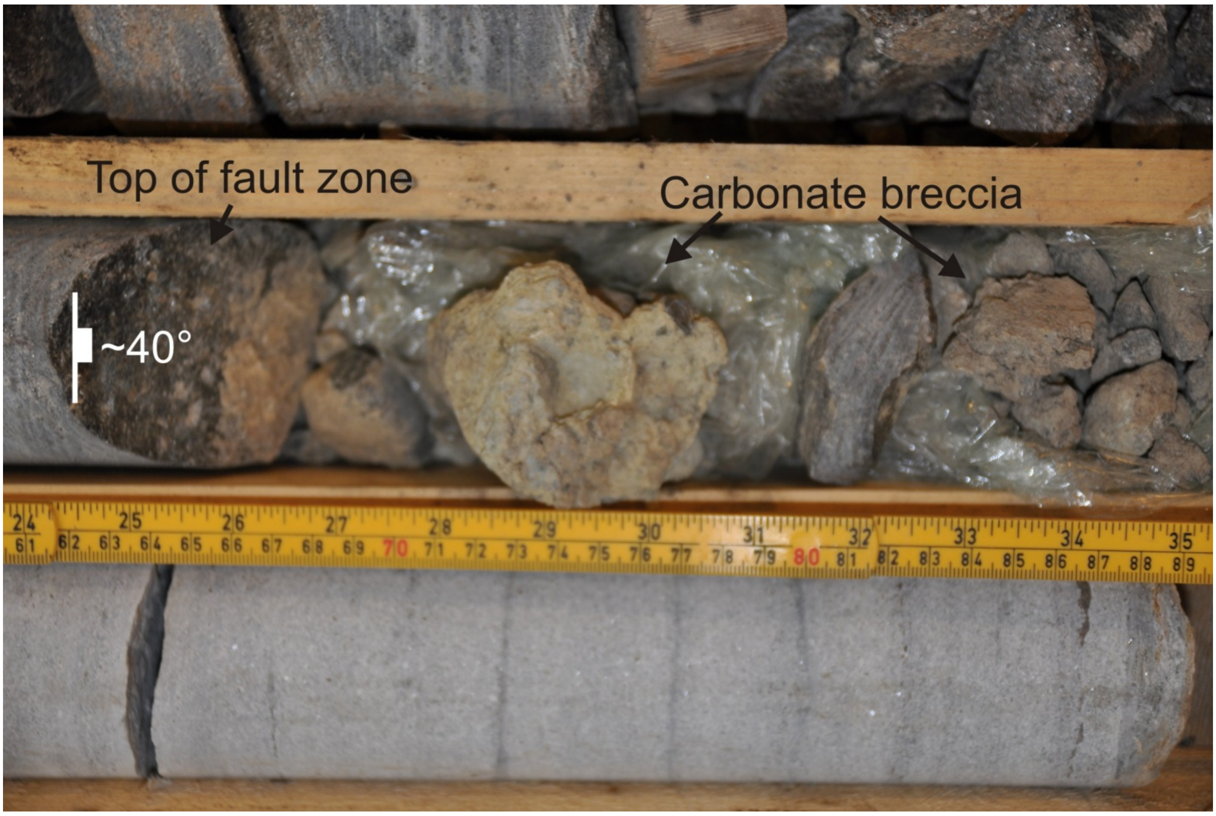

Figure 4. The fracture at the top of the fault zone has an estimated dip of ~40°, and the strike is not determined. The fault zone consists of carbonate breccia possibly with clay.

In-fill of sediments most likely of Quaternary age is found along a fracture at ~18.30 to ~18.40 metres depth (Figure 4). The sediment has clay/silt matrix and small clasts. There is a sharp transition from sediment to bedrock, which reflects that the sediments are in-filled and not in situ.

Figure 5. At ~18.30-18.40 m sediments most likely of Quaternary age is filled in along a fracture. The sediments contain small pebbles in clay/silt matrix.

An overview of the core log is given in Figure 5, where the different bedrock types are symbolised with colour, the larger zones of crushed rock are mapped, and zones possibly containing clay are indicated. The zone at ~45.2-45.5 metres is regarded as the main zone of movement (Figure 2). The other zones of crushed rock that occur in the drill core consist of coarsely crushed rock. Such zones of coarsely crushed rock, is frequent from ~148 metre to ~181 metre. The only exception is the zone at ~148.5 to ~152 metre, where the rock is crushed with possible clay occurrence. The pervasive, sub-horizontal foliation is symbolised by thin lines in the bedrock (Figure 5).

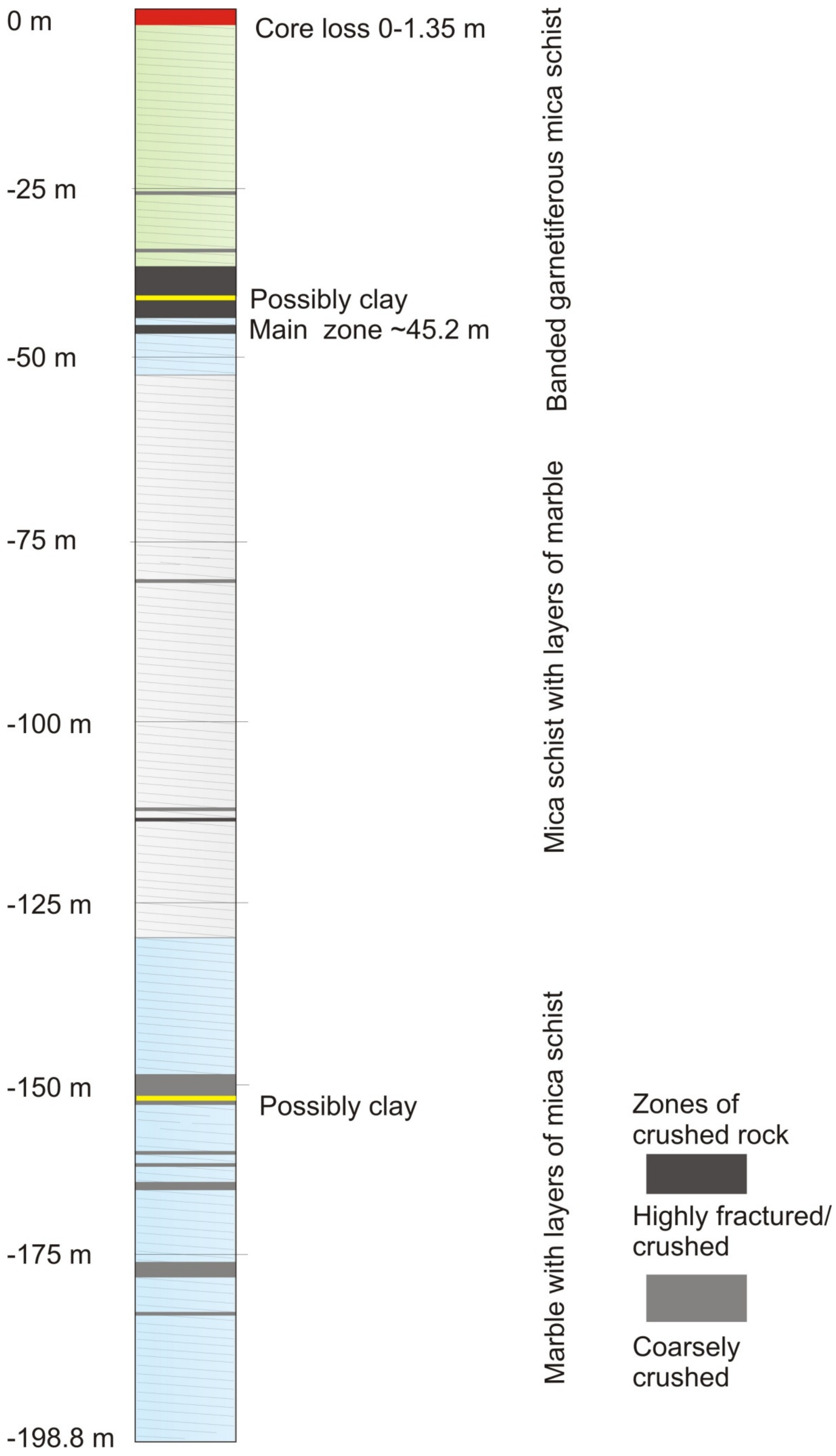

Figure 6. Overview of the core log with main bedrock sections and zones of crushed rock indicated.

The depth of the drill core is not consistent, but the drilling company has tried to record the drilling depth on the way. This recording of depths starts first at 32 metre. The divergence in recorded depth is illustrated in Table 2 where numbers in bold letters are those depths recorded by the drillers, and the gray shading is where the depth recording is not consistent. The error is not necessarily where the gray shading is indicated, but somewhere between the recorded depths; bold numbers. As seen from Table 2, there is no logic in the error of recorded depths. There is possible core loss, which is not documented in the core, such as where the depth of 149.3 to 151 metres is recorded as 20 cm in the core (Figure 34 and Figure 35). Similarly at 164.3 to 166.4 metre depth, which is recorded as ~20 cm in the drill core (Figure 37). Table 2 tries to illustrate the deviation in recorded depth in the drill cores, similar to the column of "corrected depth" on the left hand side in Figure 6 to 8.

Table 2. Illustration of deviation of depth in the drill cores. The depth of the drill core is not consistent, but drilling depth has been recorded on the way. Numbers in bold letters are those depths recorded by the drillers, and the gray shading is where the depth recording is not consistent. Each cell symbolizes a ~meter in the drill core box. The recording of depths starts first at 32 metres depth.

	51					
	52	76	**101**	126		176
	53	**77**	102	127		177
	54	**78**	103	**128**	**152**	178
	55	79	**104**	129	153	**179**
32	**56**	**80**	105		154	180
33	57	81	106	**130**	**155**	181
34	58	82	107	131	156	**182**
35		**83**	108	132	157	183
36	**59**	84		**134**	158	184
37	60	85	**109**	135	159	**185**
38	61	**86**	110	136	160	186
39	**62**	87	111	**137**	**161**	187
40	63	88	**113**	138	162	**188**
	64	**89**	114	139	163	189
	65	90	115	**140**	**164**	190
41	66	91	**116**	141	**166**	191
42	67		117	142	167	192
43	68	**92**	118	**143**		193
44	69	93	**119**	144	**168**	**194**
45	70	94	120	145	169	
46	**71**	**95**	121		170	**195**
		96	122	**146**	171	196
47	**72**	97	123	147	172	197
48	73	**98**	124	158	173	**198**
49	74	99		**149**	**174**	
50	75	100	**125**	**151**	175	

Figure 6 and Figure 7 shows 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. In addition a fracture frequency only regarding actual fractures, without the zones of crushed rock, is given and which is thereby lower than total fracture frequency. Both graphs of fracture frequency include what is regarded as drilling produced fractures, where the applied drilling force has forced potential fractures to open. 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 occurs the drill core tend to be more fractured than otherwise, this is considered to be due to drilling produced fractures made from the vertical fracture to the borehole wall. When the core logging is compared to logging with Optical Televiewer in the borehole, the borehole logging shows considerably lower fracture frequency.

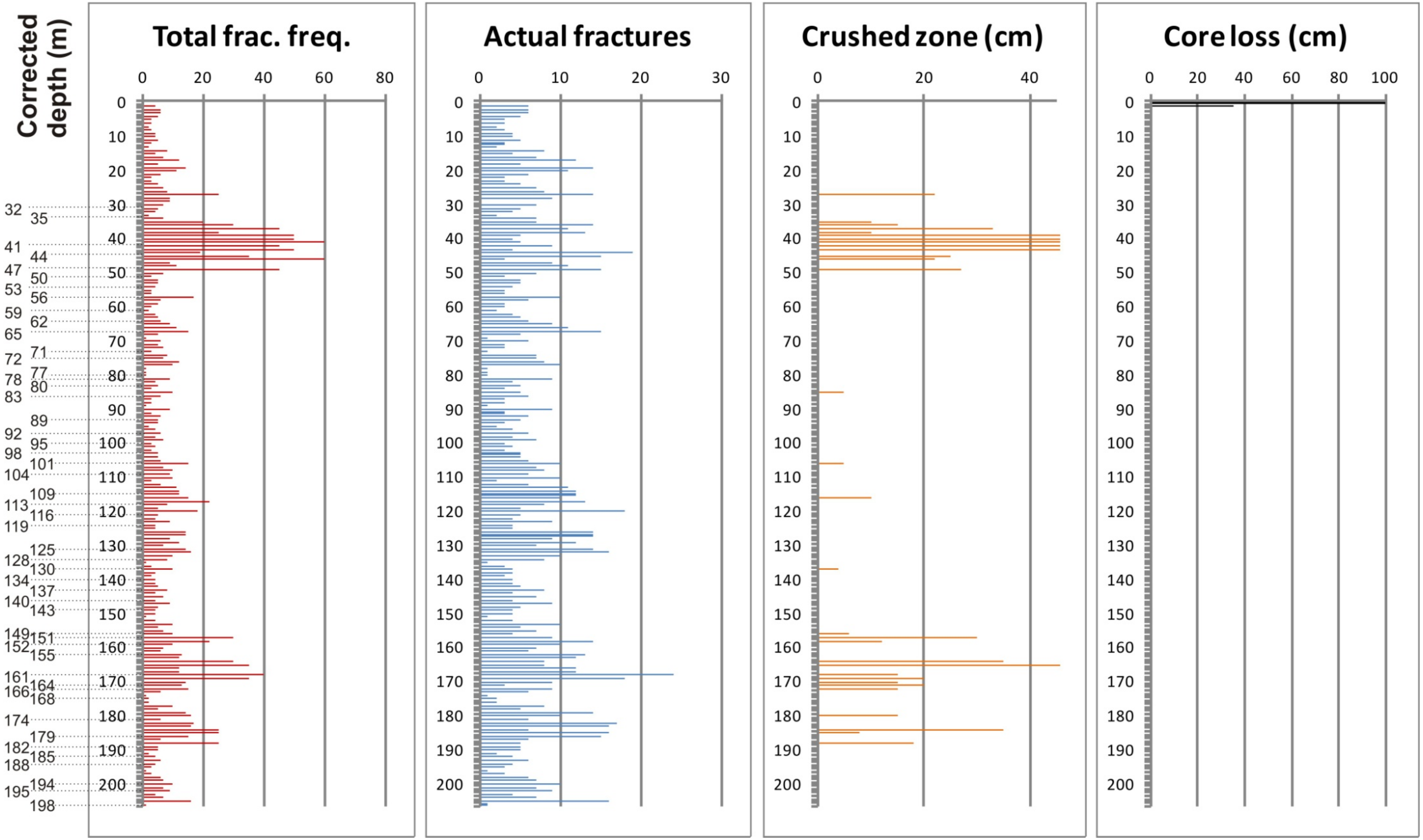

Figure 7. Graphs from core logging with total fracture frequency including fractures and crushed zones (left), actual fractures observed, crushed zones with length given in cm and core loss given in cm to the right.

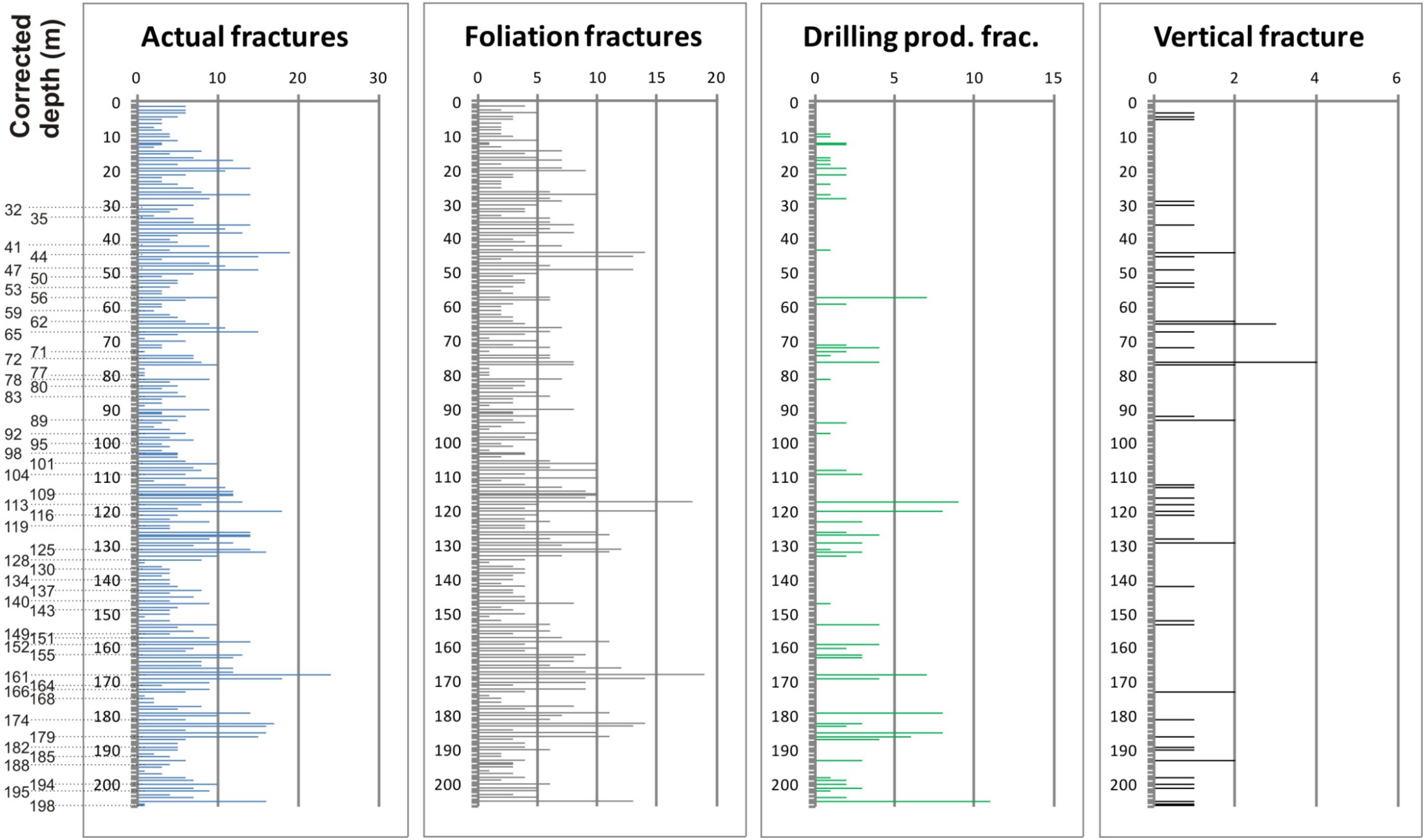

Figure 8. Graphs from core logging showing frequency of actual fractures observed (left), of those fractures are foliation fractures, drill produced fractures and vertical fractures (right) registered.

When the drilling produced fractures are subtracted from the actual fractures (Figure 8) the fracture frequency in the drill core is in general low. The average is around 5 fractures/meter, which is close to background fracturing in nature that is ~3 fractures/meter (Braathen & Gabrielsen, 2000). The zones of crushed rock indicate where possible movement may occur in the rock, however the amount and extent of crushed rock is likely influenced by the drilling process as the drilling produced fractures. In the Optical image of the borehole (NGU report 2013.020) these zones of crushed rock seem to be less crushed or extensive compared to the drill core.

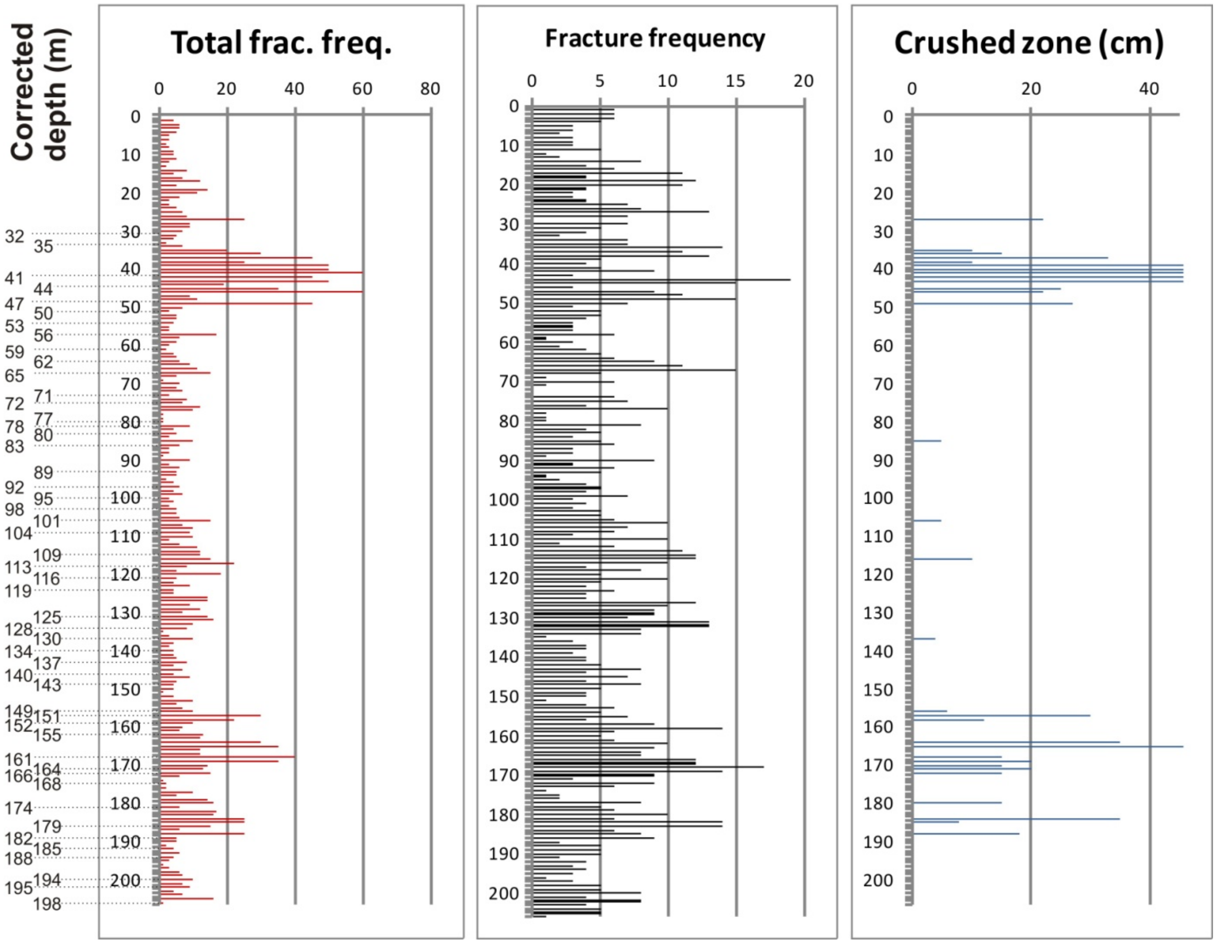

Figure 9. Graphs showing total fracture frequency to the left, which include all fractures and an estimated value of fractures that reflect the zones of crushed rock. In the middle is fracture frequency that is actual fractures minus drilling produced fractures, and to the right zones of crushed rock given in cm.

3. CORE LOGGING

Figure 10. Geological core logging from ca. 1.35 to ~6.8 m depth with pictures of the dry (left) and wet (right) core.

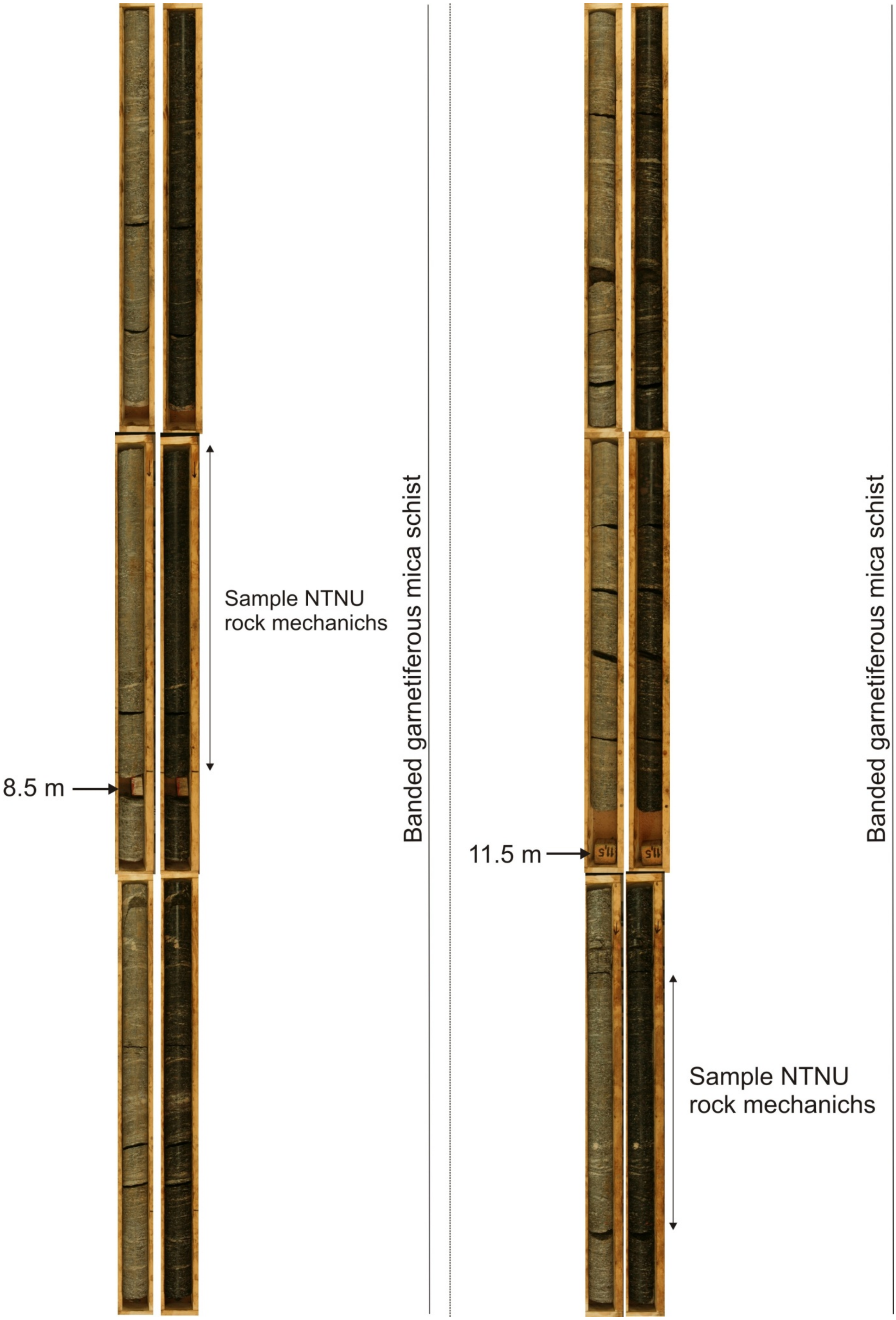

Figure 11. Geological core logging from ~6.8 to ~12.5 m depth with pictures of the dry (left) and wet (right) core.

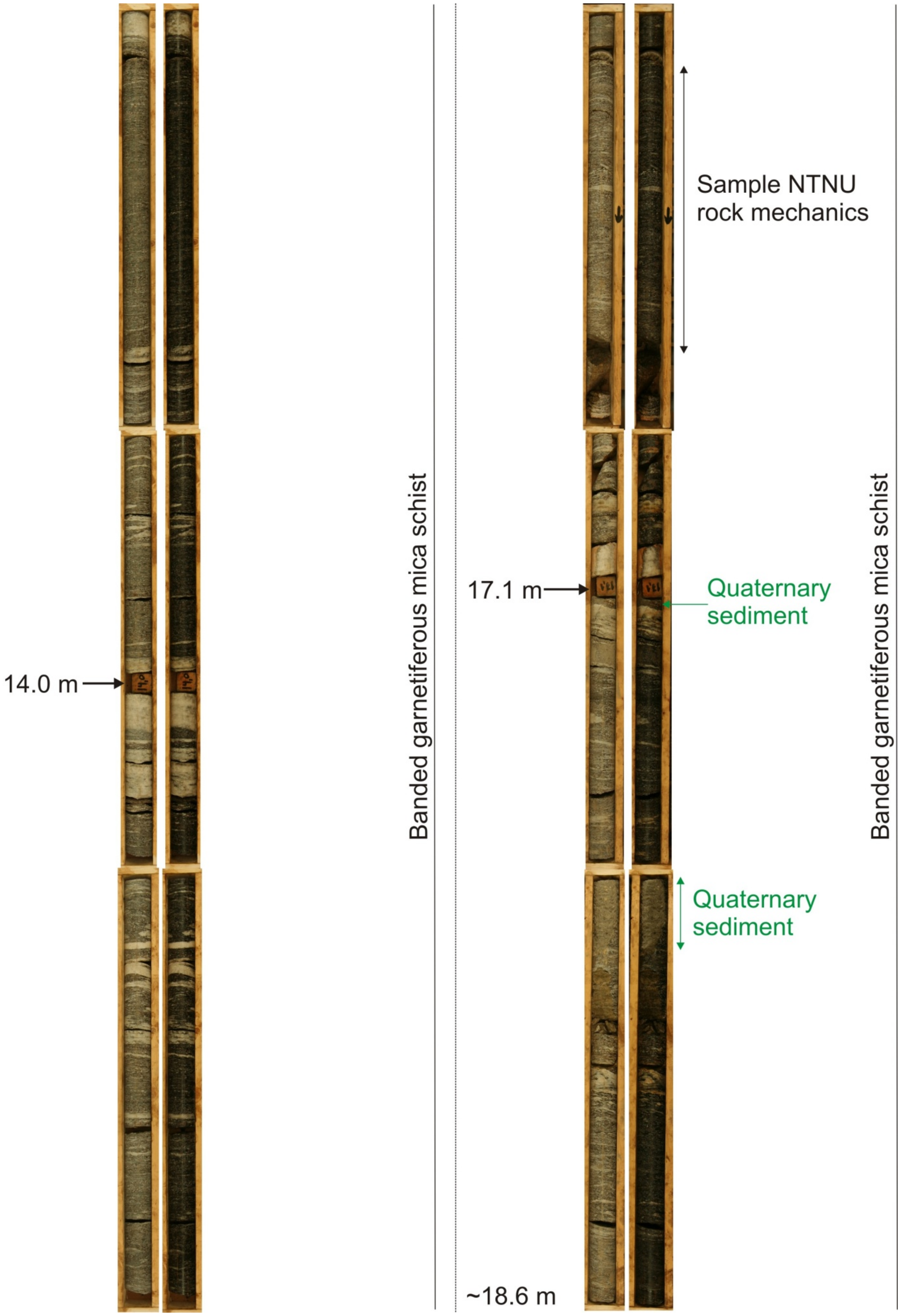

Figure 12. Geological core logging from ~12.5 to ~18.6 m depth with pictures of the dry (left) and wet (right) core.

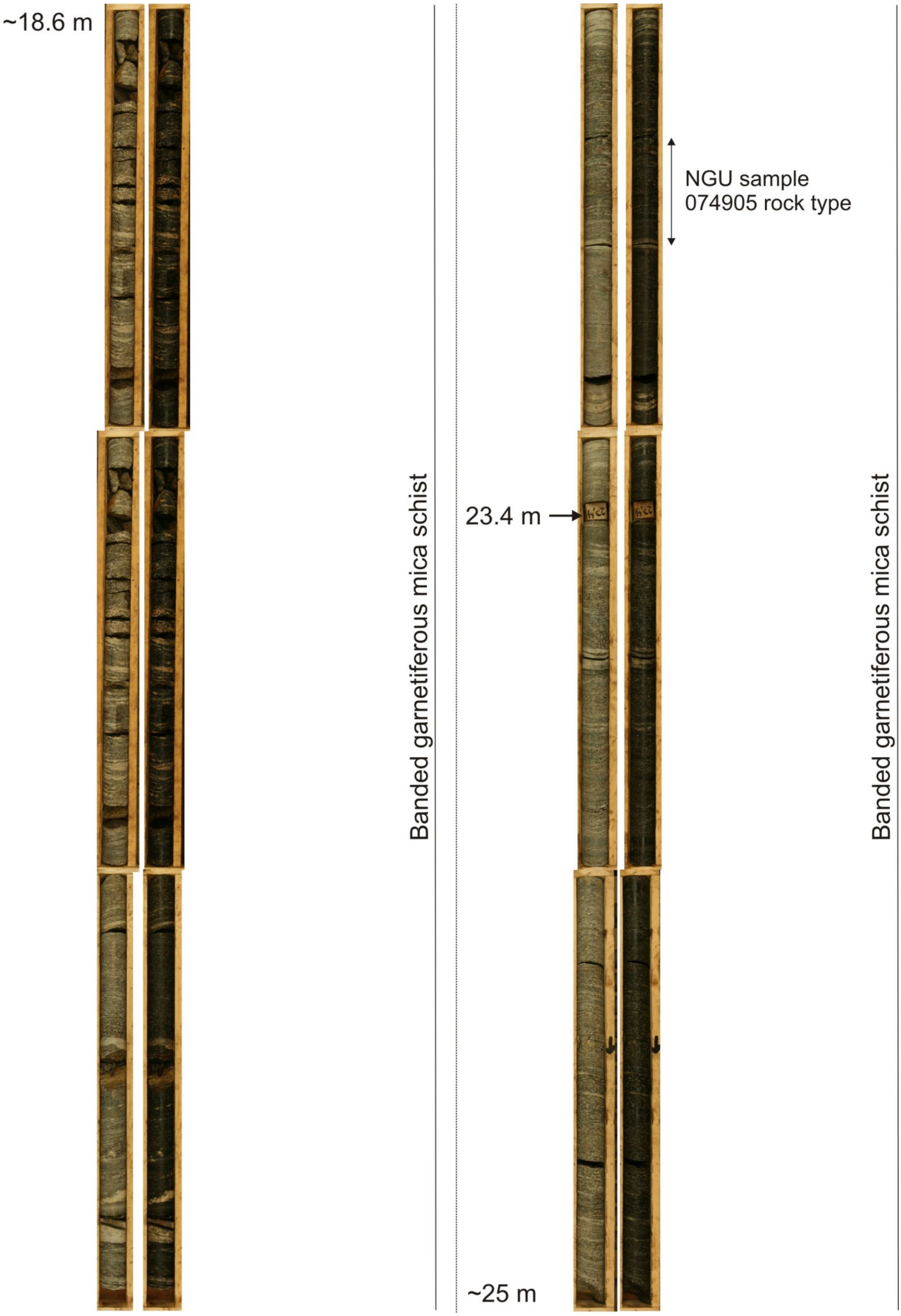

Figure 13. Geological core logging from ~18.6 to ~25 m depth with pictures of the dry (left) and wet (right) core.

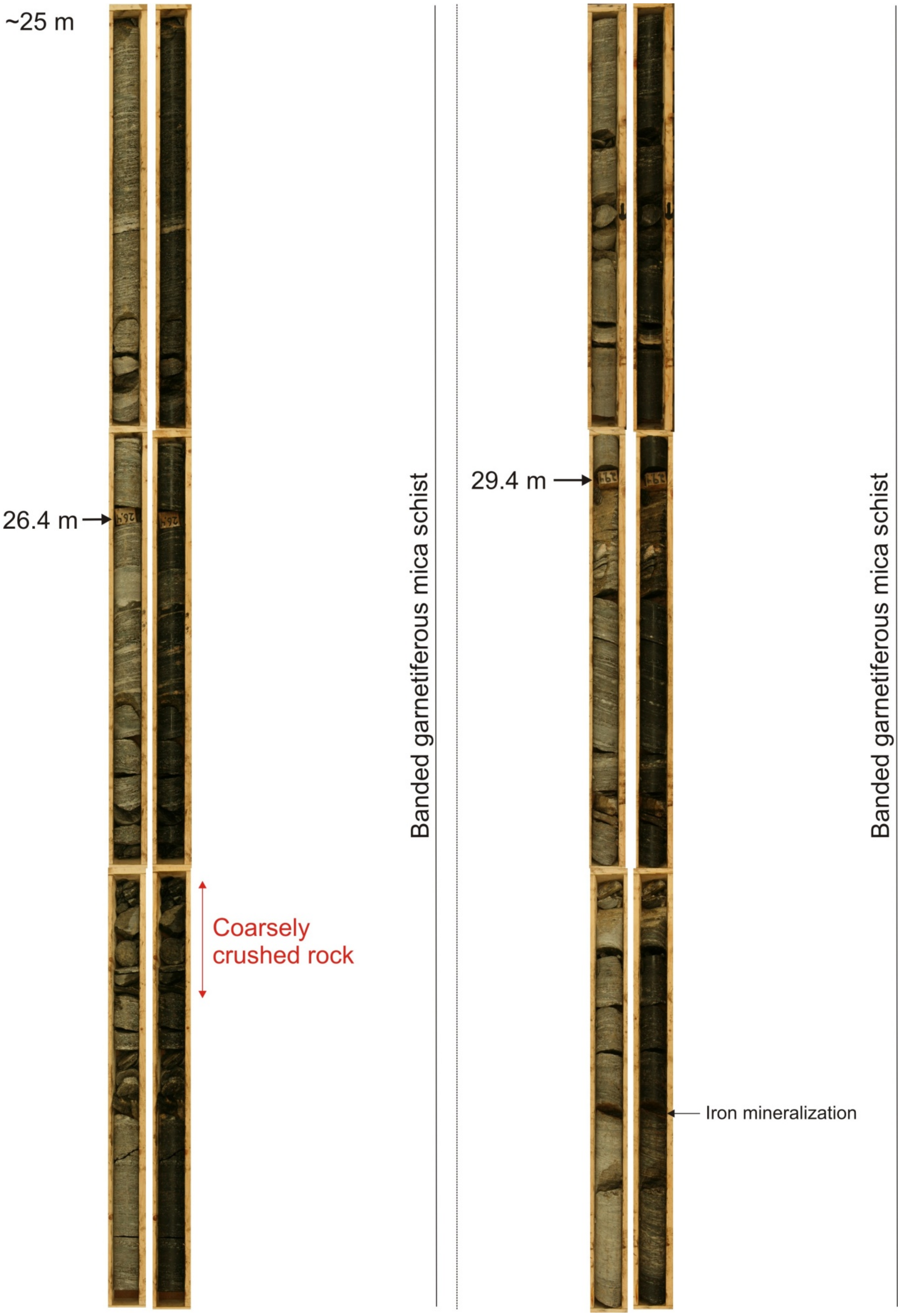

Figure 14. Geological core logging from ~25 to ~31.8 m depth with pictures of the dry (left) and wet (right) core.

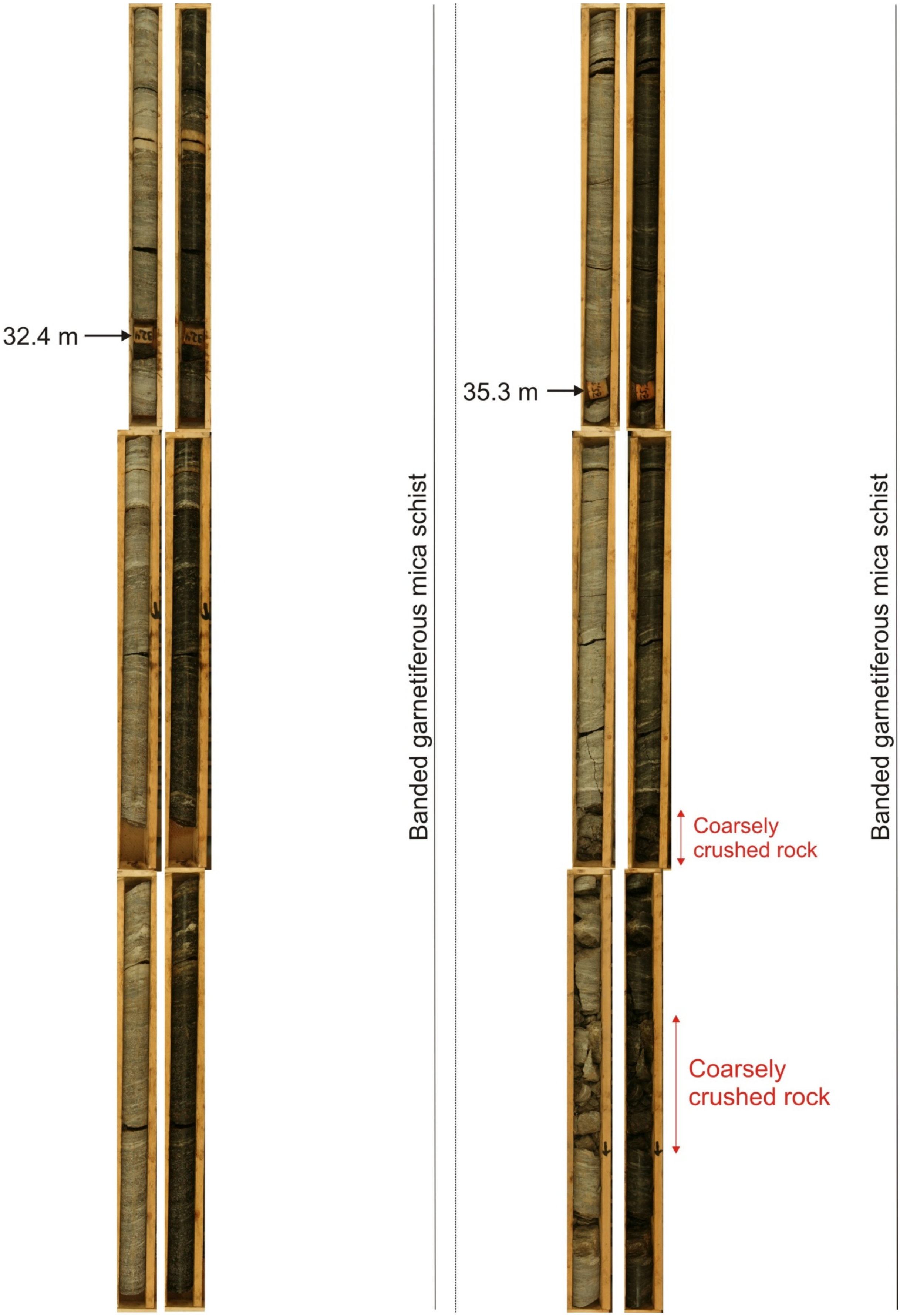

Figure 15. Geological core logging from ~31.8 to ~37 m depth with pictures of the dry (left) and wet (right) core.

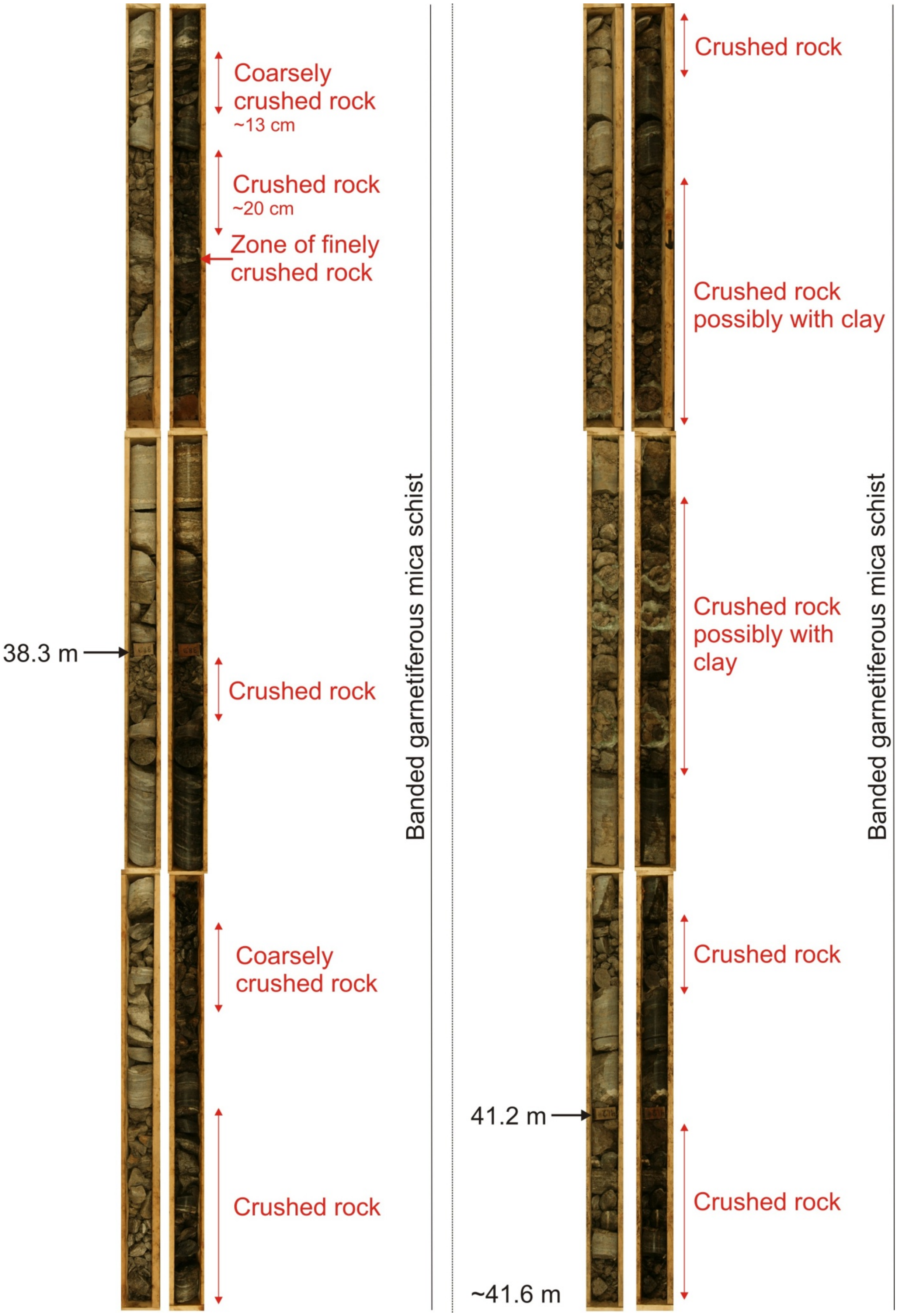

Figure 16. Geological core logging from ~37 to ~41.6 m depth with pictures of the dry (left) and wet (right) core.

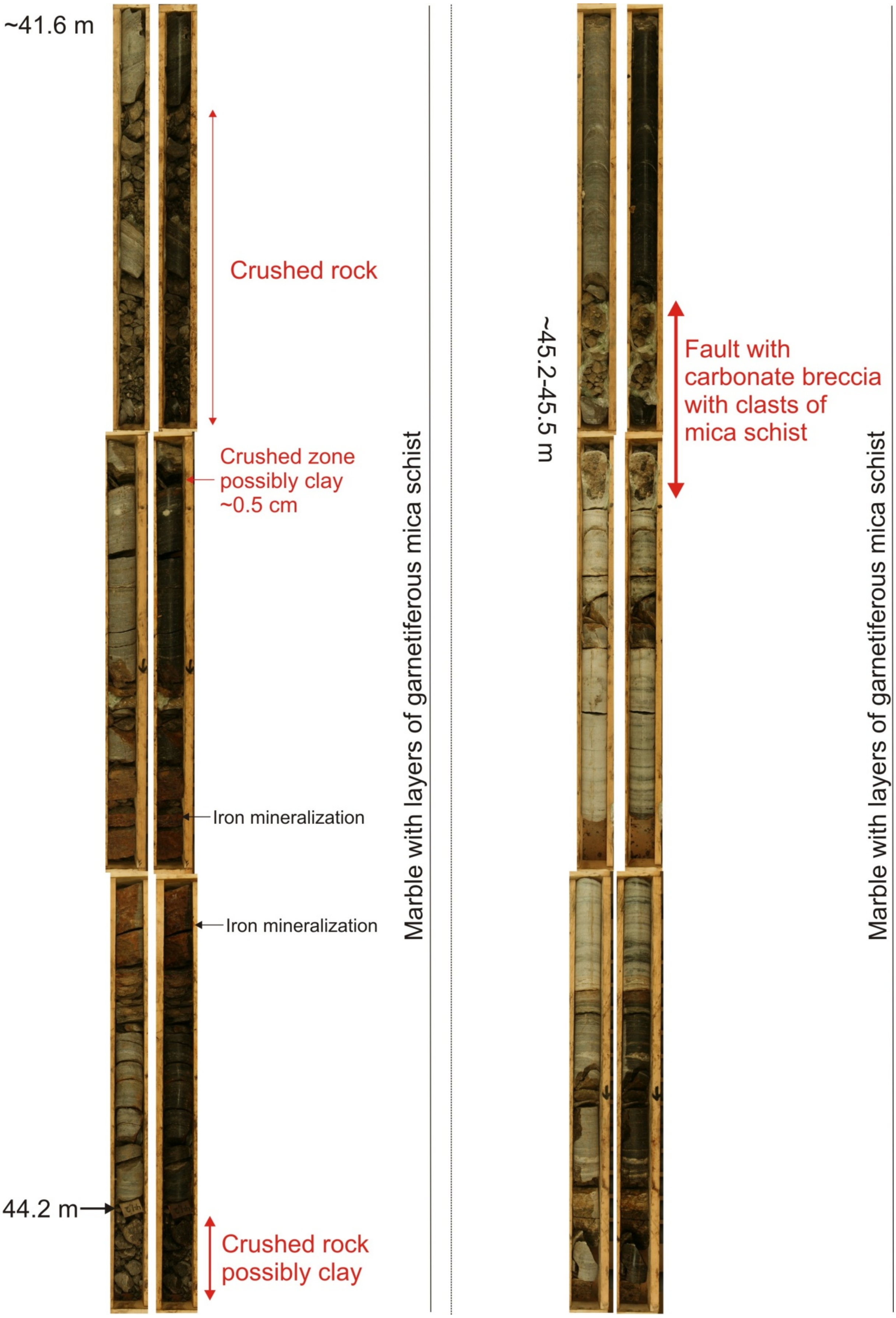

Figure 17. Geological core logging from ~41.6 to ~47.2 m depth with pictures of the dry (left) and wet (right) core.

Figure 18. Geological core logging from ~47.2 to ~53 m depth with pictures of the dry (left) and wet (right) core.

Figure 19. Geological core logging from ~53 to ~58 m depth with pictures of the dry (left) and wet (right) core.

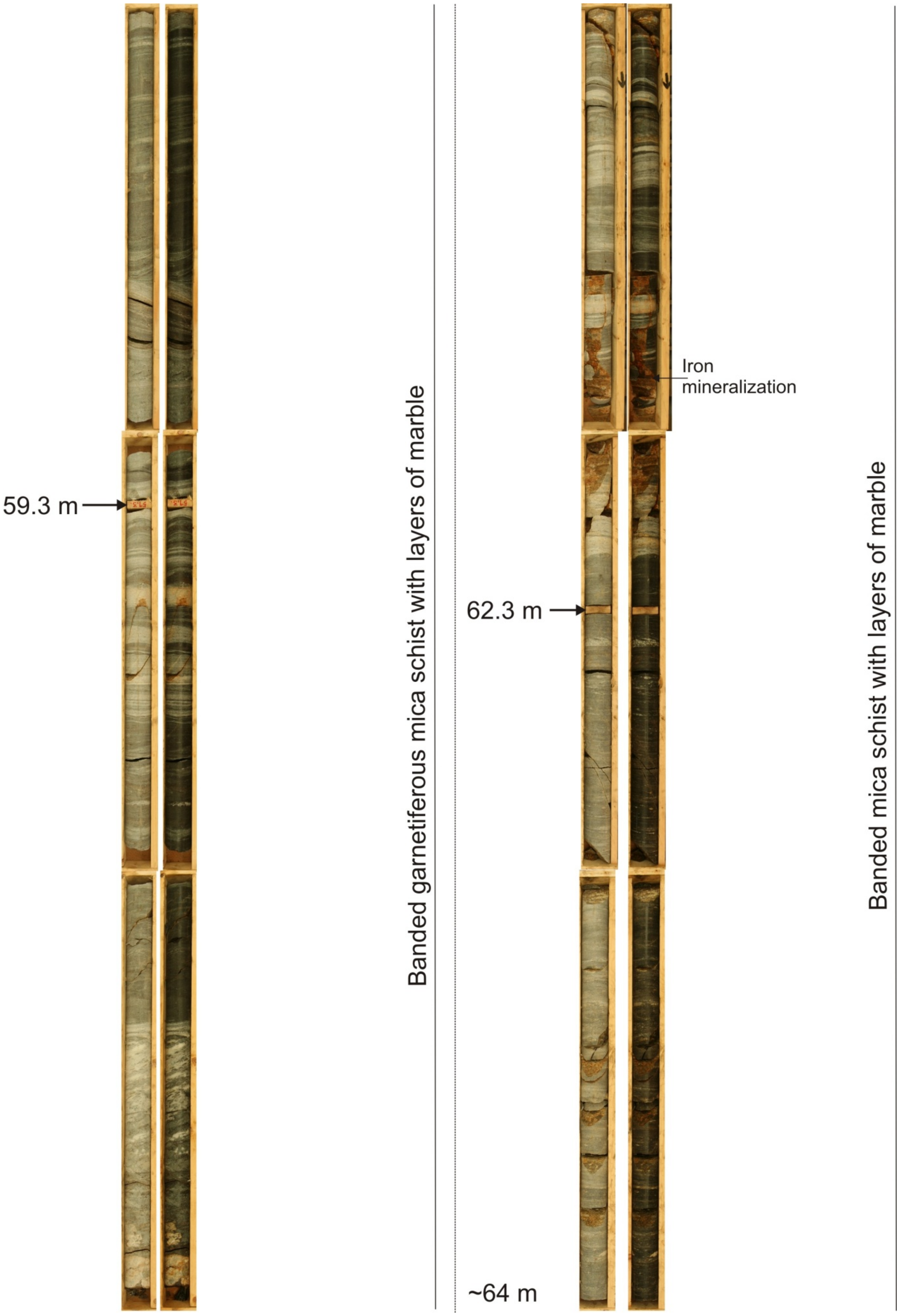

Figure 20. Geological core logging from ~58 to ~64 m depth with pictures of the dry (left) and wet (right) core.

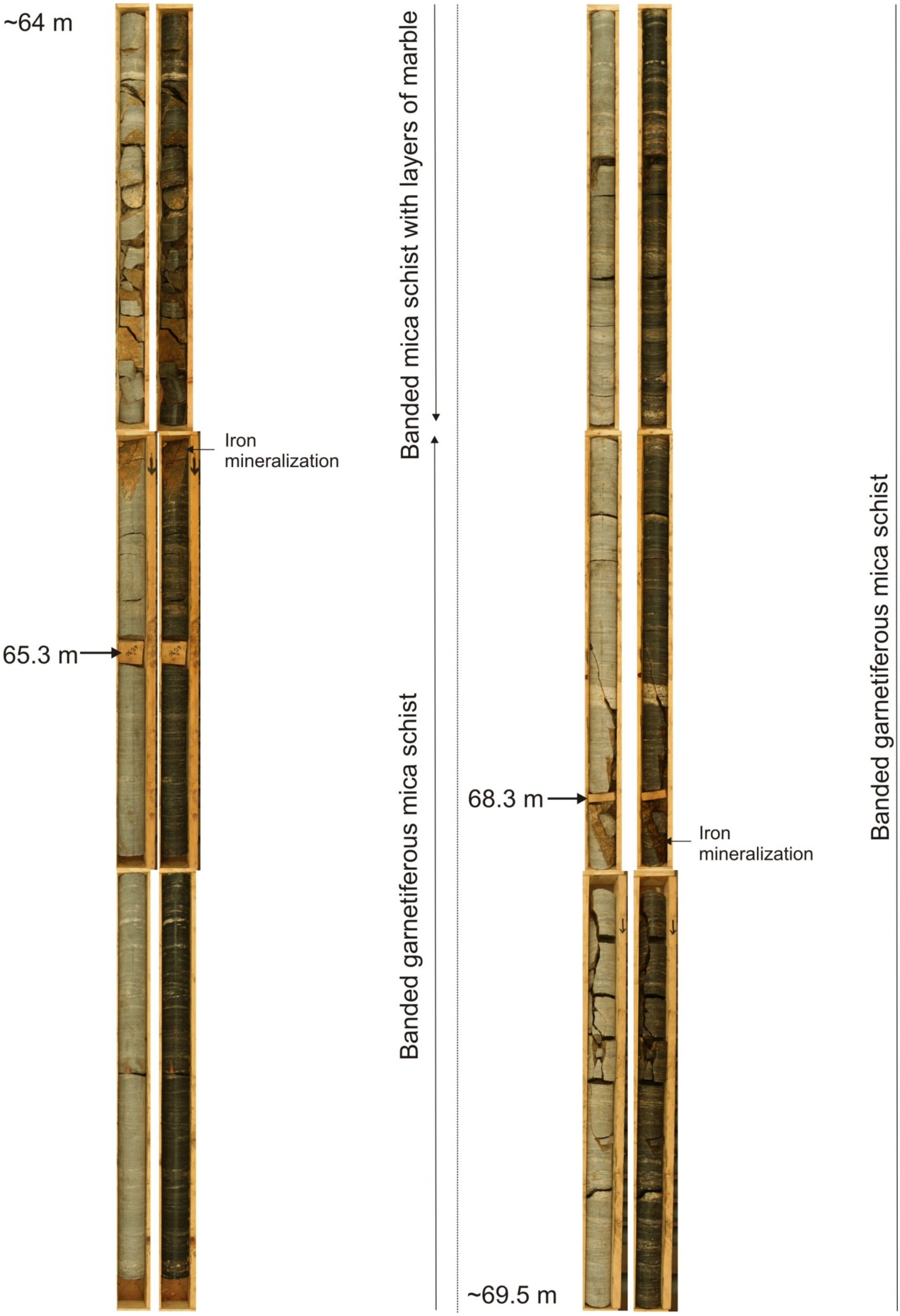

Figure 21. Geological core logging from ~64 to ~69.5 m depth with pictures of the dry (left) and wet (right) core.

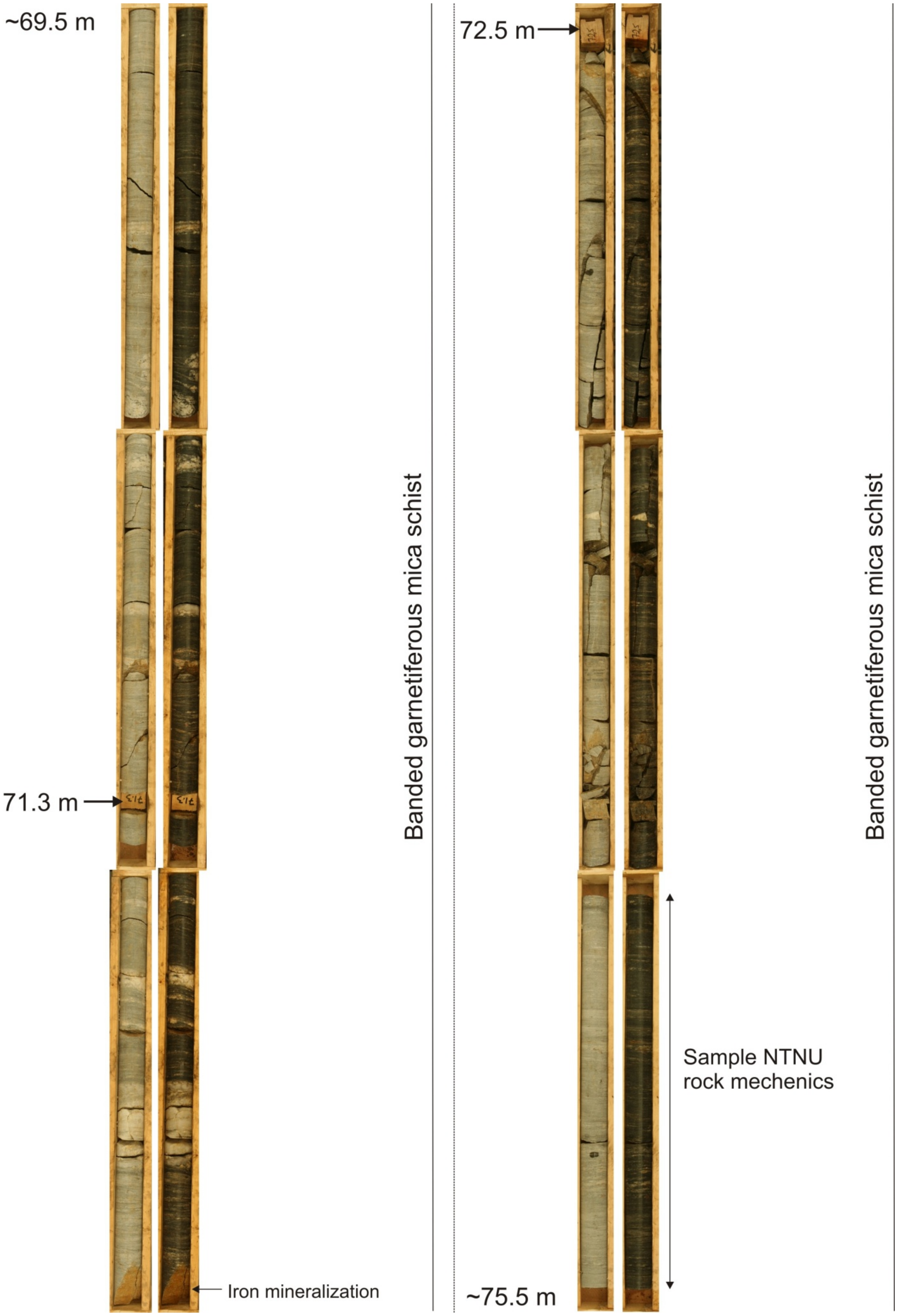

Figure 22. Geological core logging from ~69.5 to ~75.5 m depth with pictures of the dry (left) and wet (right) core.

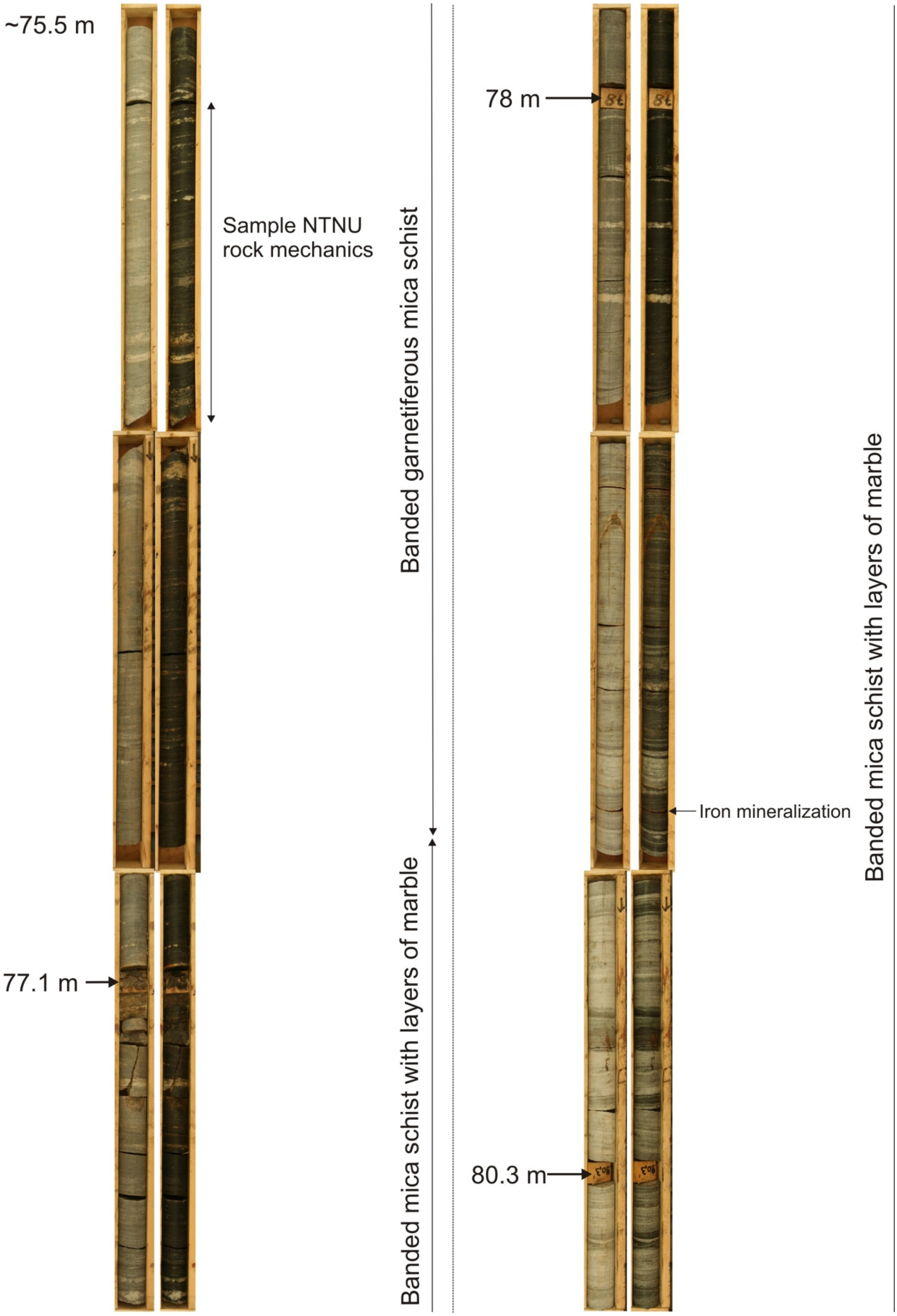

Figure 23. Geological core logging from ~75.5 to ~80.5 m depth with pictures of the dry (left) and wet (right) core.

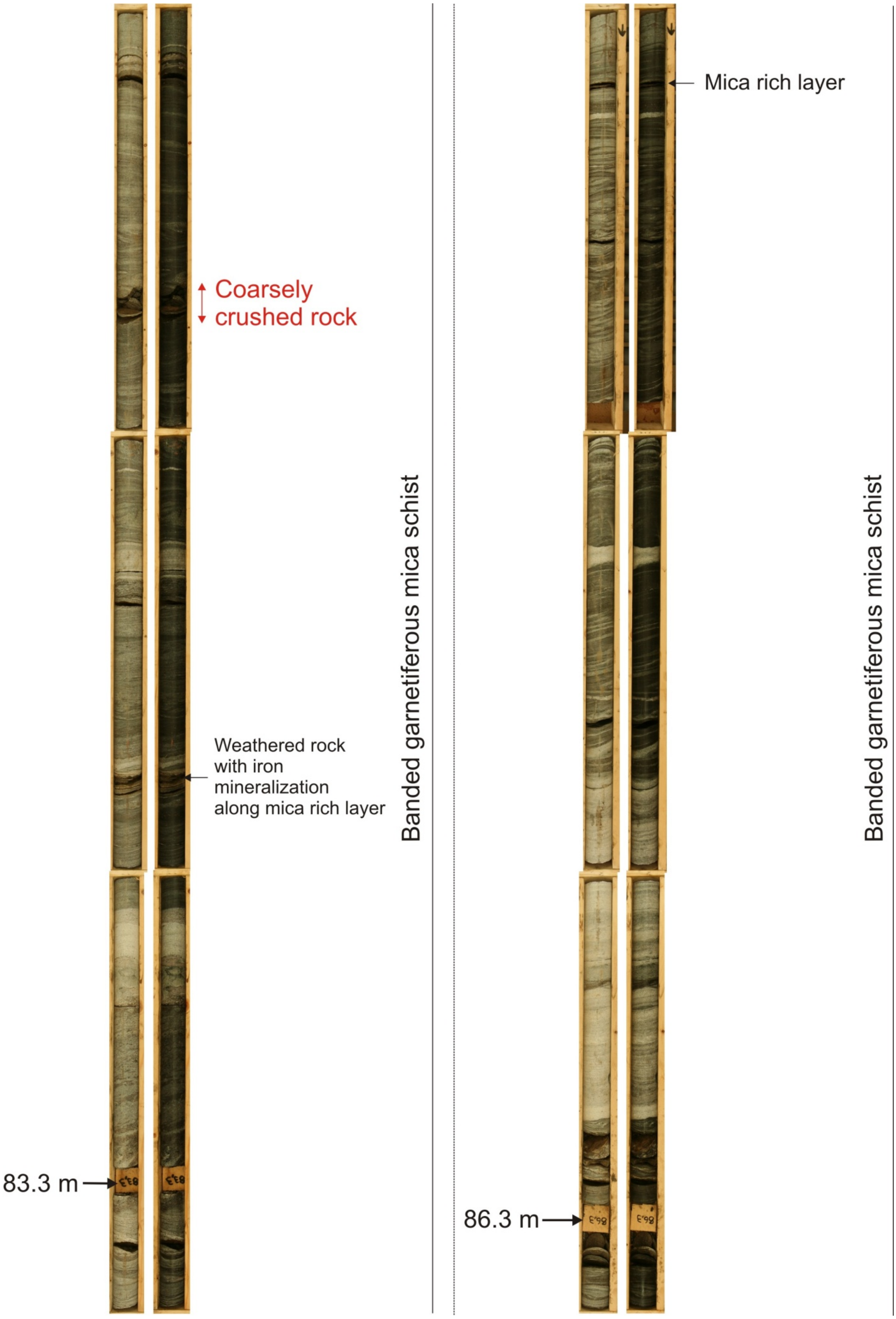

Figure 24. Geological core logging from ~80.5 to ~86.5 m depth with pictures of the dry (left) and wet (right) core.

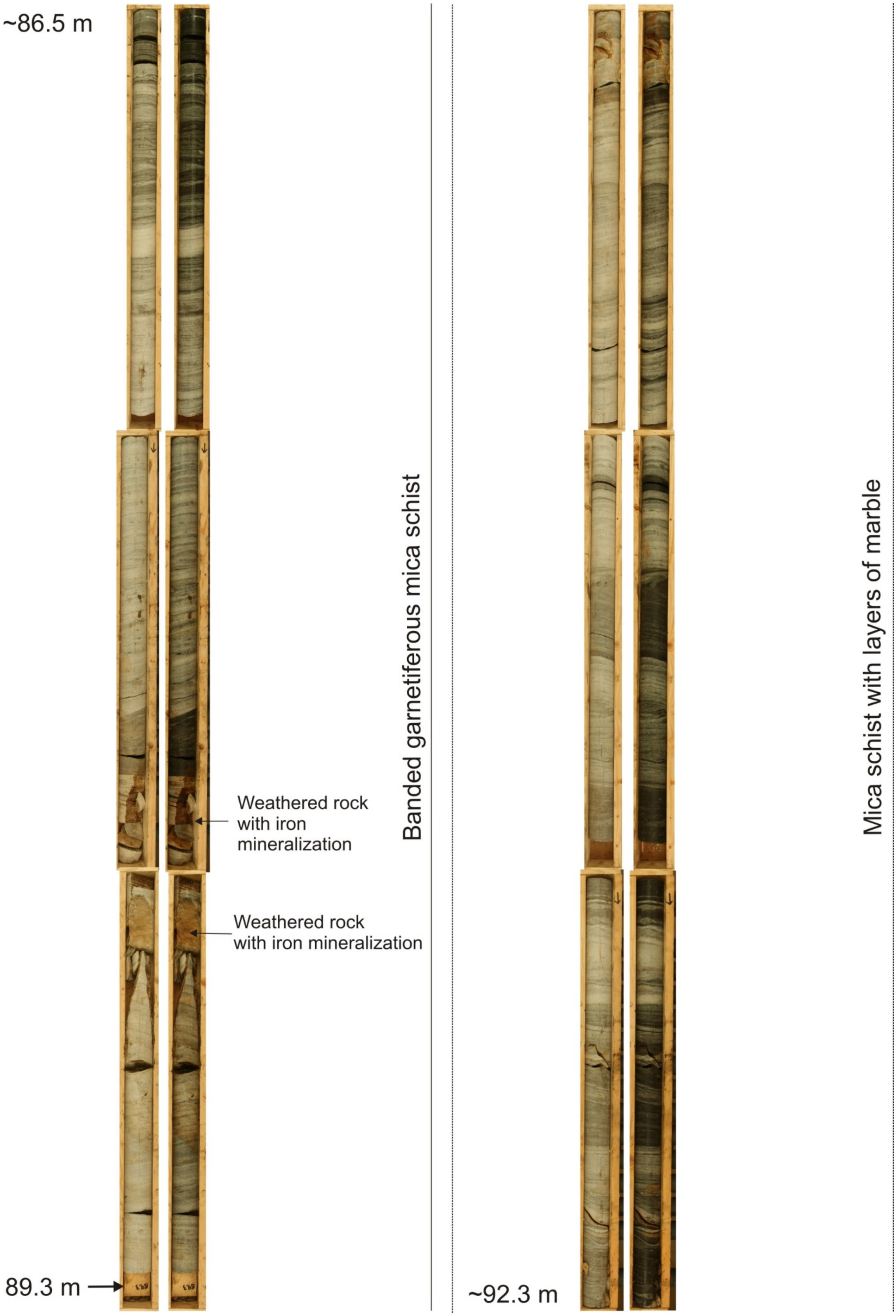

Figure 25. Geological core logging from ~86.5 to ~92.3 m depth with pictures of the dry (left) and wet (right) core.

Figure 26. Geological core logging from ~92.3 to ~98 m depth with pictures of the dry (left) and wet (right) core.

Figure 27. Geological core logging from ~98 to ~103.75 m depth with pictures of the dry (left) and wet (right) core.

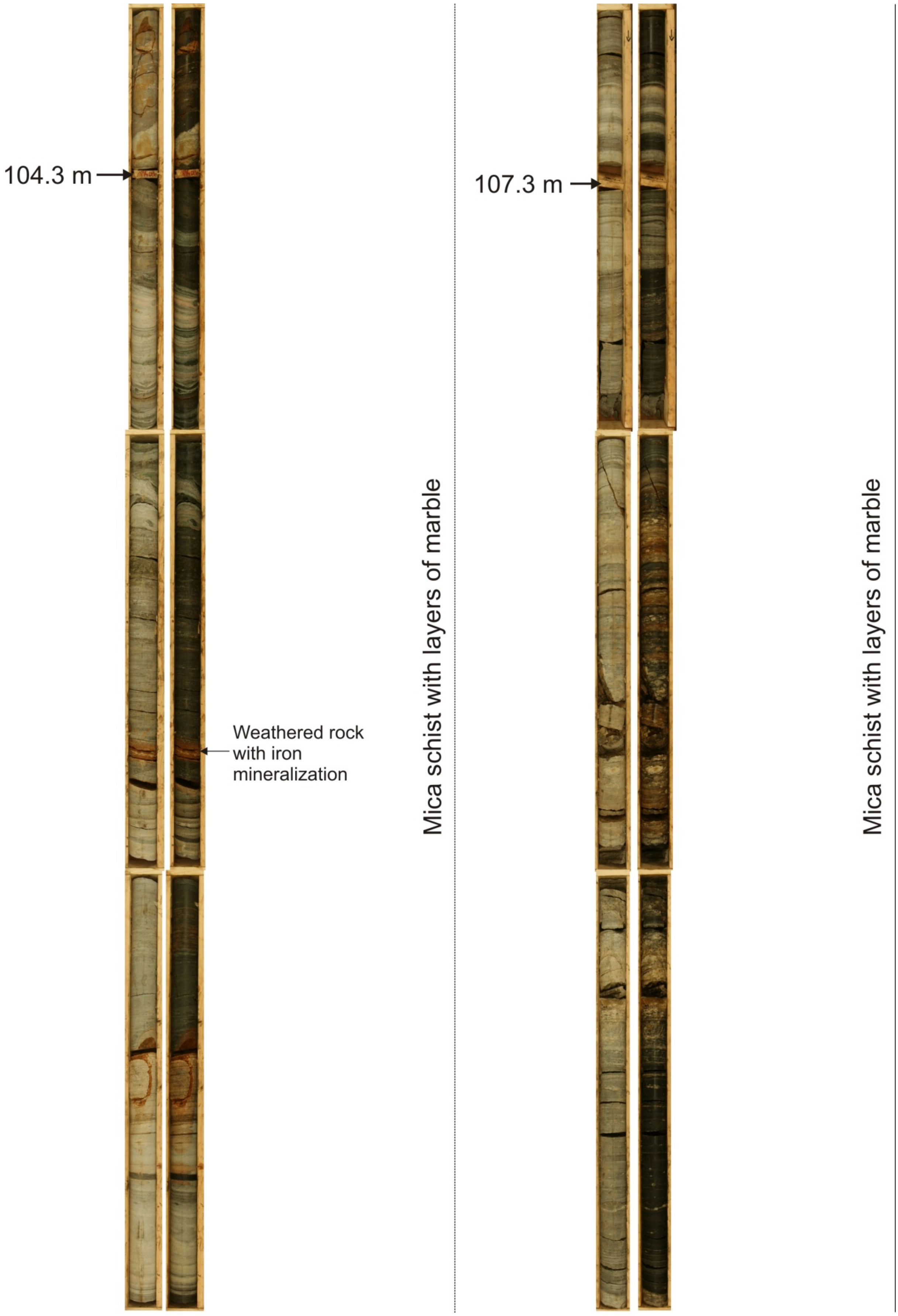

Figure 28. Geological core logging from ~103.75 to ~109.6 m depth with pictures of the dry (left) and wet (right) core.

Figure 29. Geological core logging from ~109.6 to ~115.3 m depth with pictures of the dry (left) and wet (right) core.

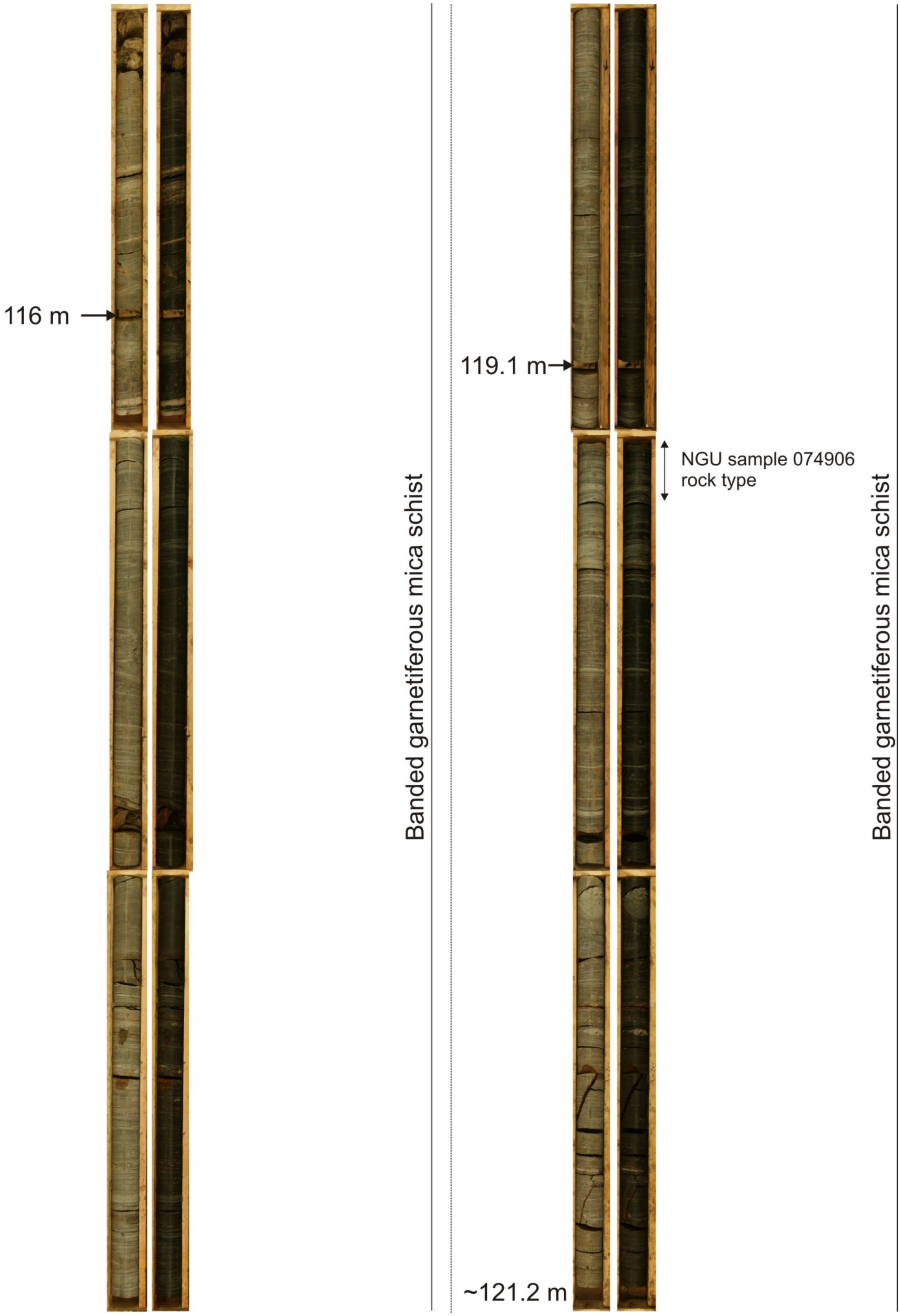

Figure 30. Geological core logging from ~115.3 to ~121.2 m depth with pictures of the dry (left) and wet (right) core.

Figure 31. Geological core logging from ~121.2 to ~126.9 m depth with pictures of the dry (left) and wet (right) core.

Figure 32. Geological core logging from ~126.9 to ~132.5 m depth with pictures of the dry (left) and wet (right) core.

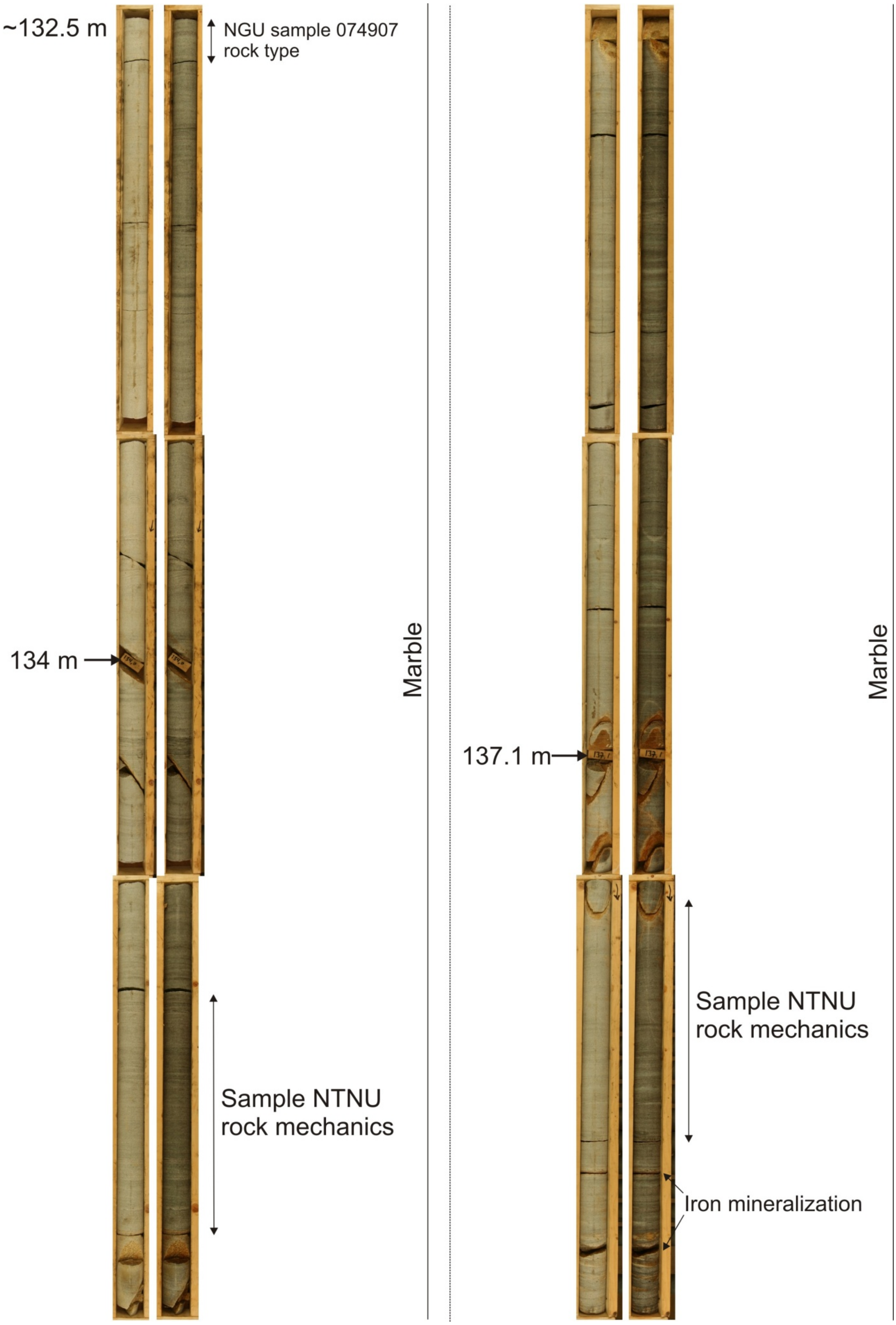

Figure 33. Geological core logging from ~132.5 to ~139 m depth with pictures of the dry (left) and wet (right) core.

Figure 34. Geological core logging from ~139 to ~144 m depth with pictures of the dry (left) and wet (right) core.

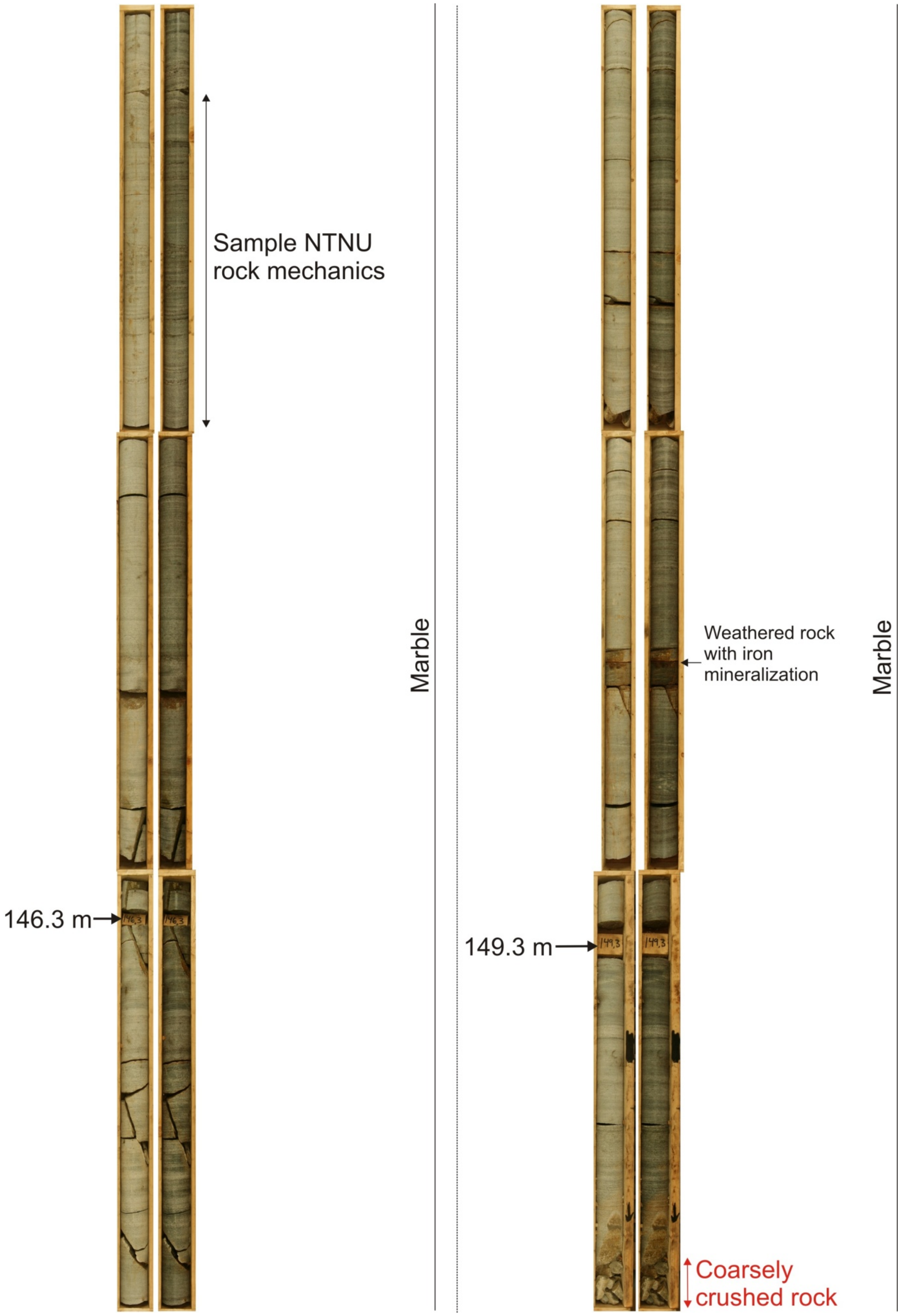

Figure 35. Geological core logging from ~144 to ~150.2 m depth with pictures of the dry (left) and wet (right) core.

Figure 36. Geological core logging from ~150.2 to ~156 m depth with pictures of the dry (left) and wet (right) core.

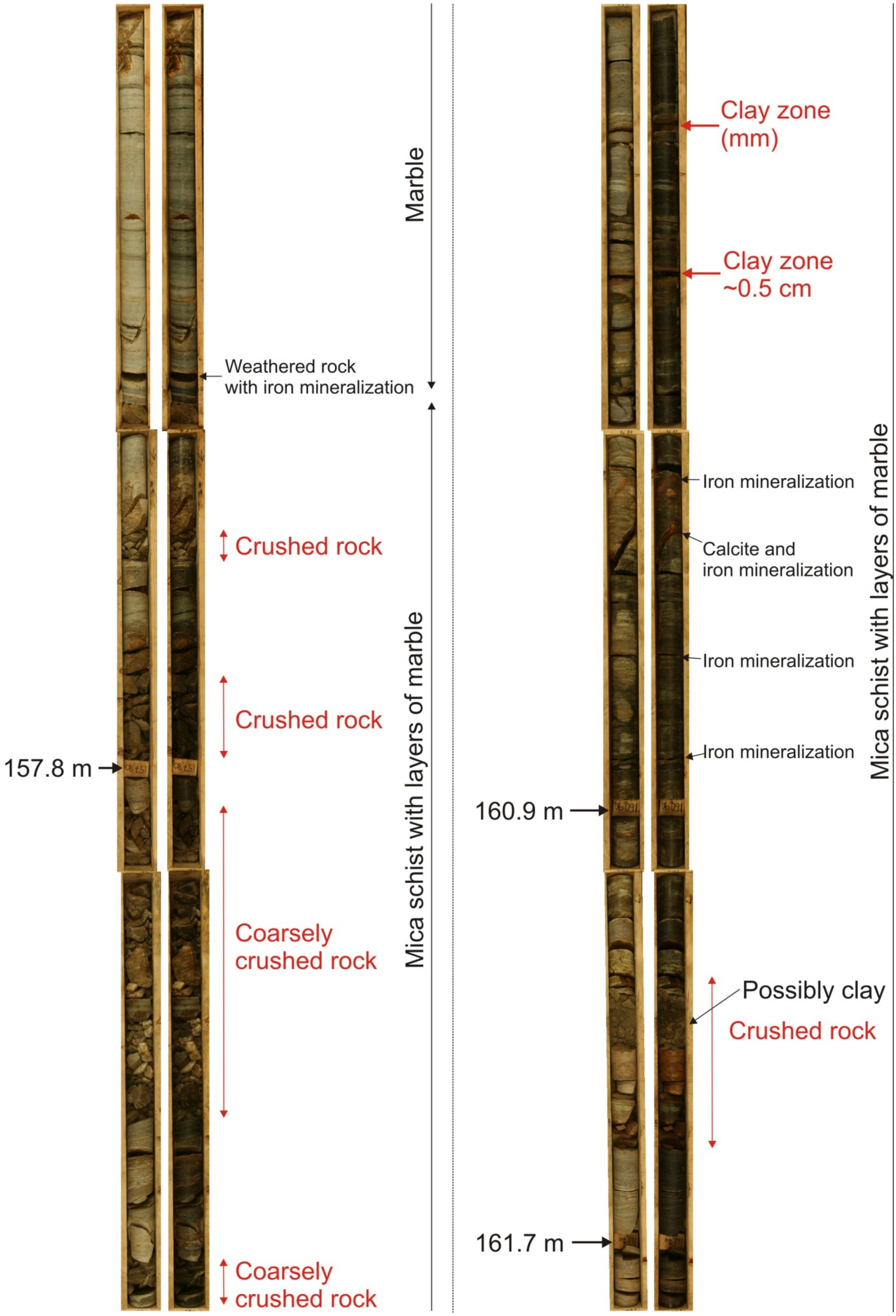

Figure 37. Geological core logging from ~156 to ~162 m depth with pictures of the dry (left) and wet (right) core.

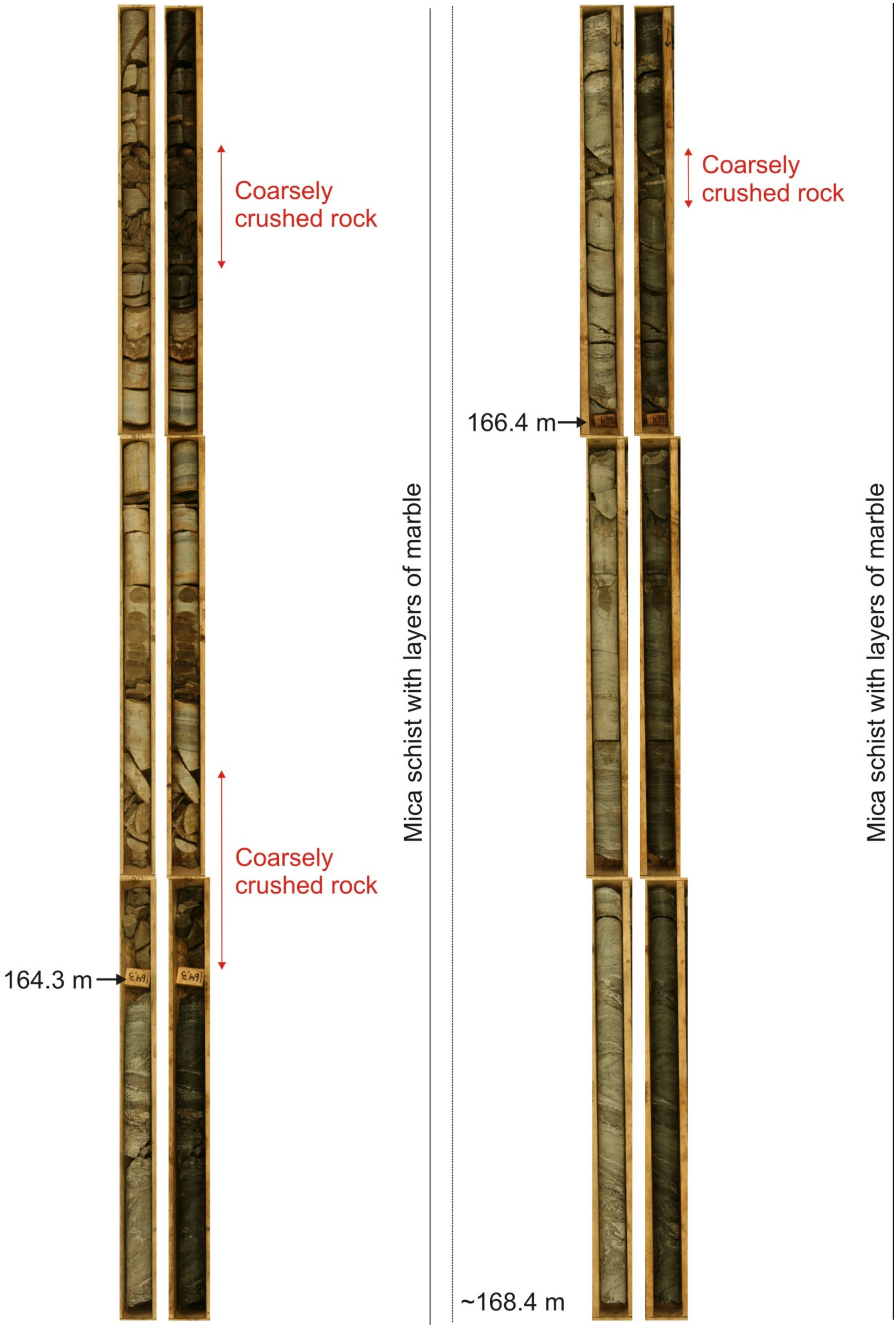

Figure 38. Geological core logging from ~162 to ~168.4 m depth with pictures of the dry (left) and wet (right) core.

Figure 39. Geological core logging from ~168.4 to ~174.4 m depth with pictures of the dry (left) and wet (right) core.

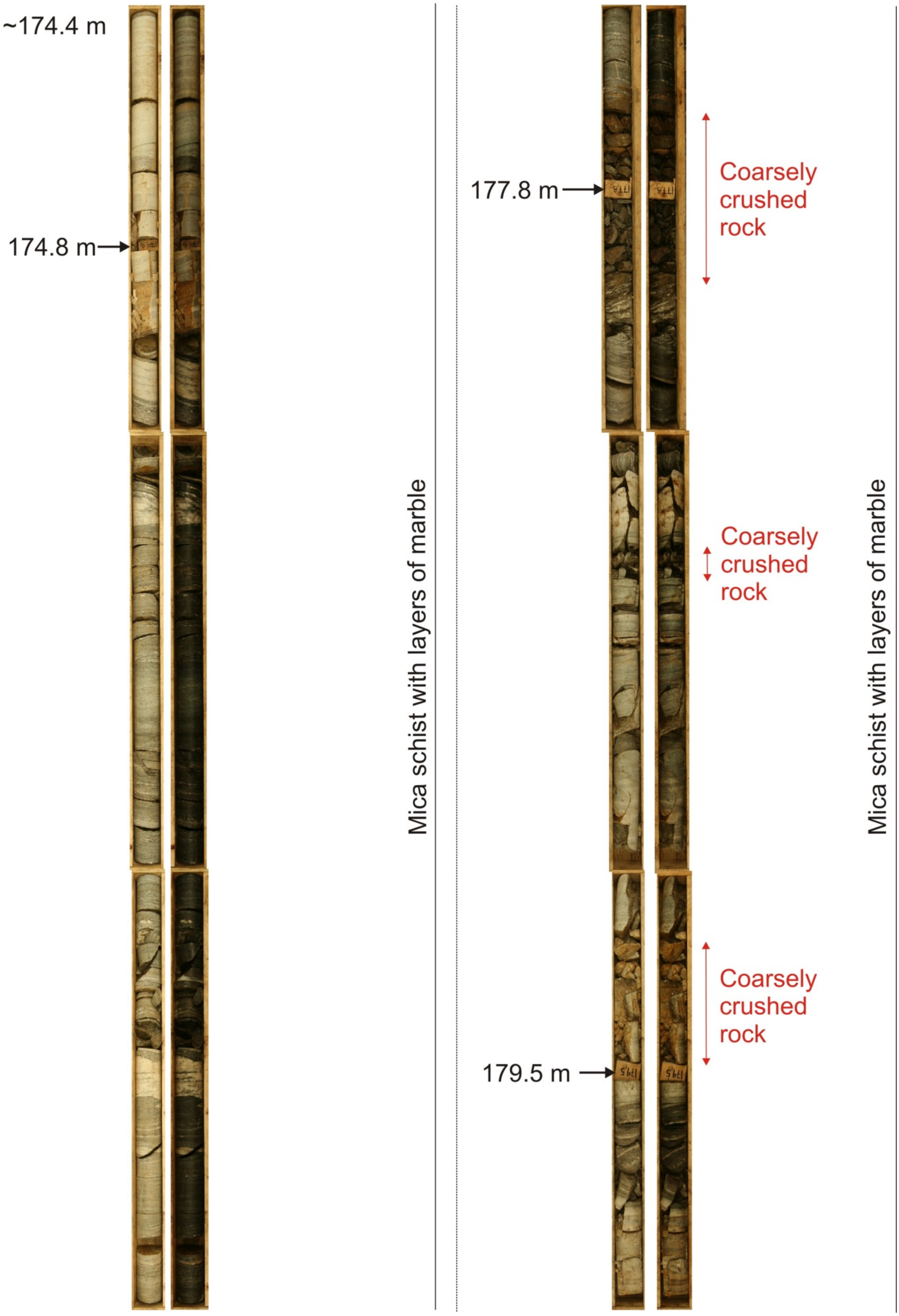

Figure 40. Geological core logging from ~174.4 to ~180 m depth with pictures of the dry (left) and wet (right) core.

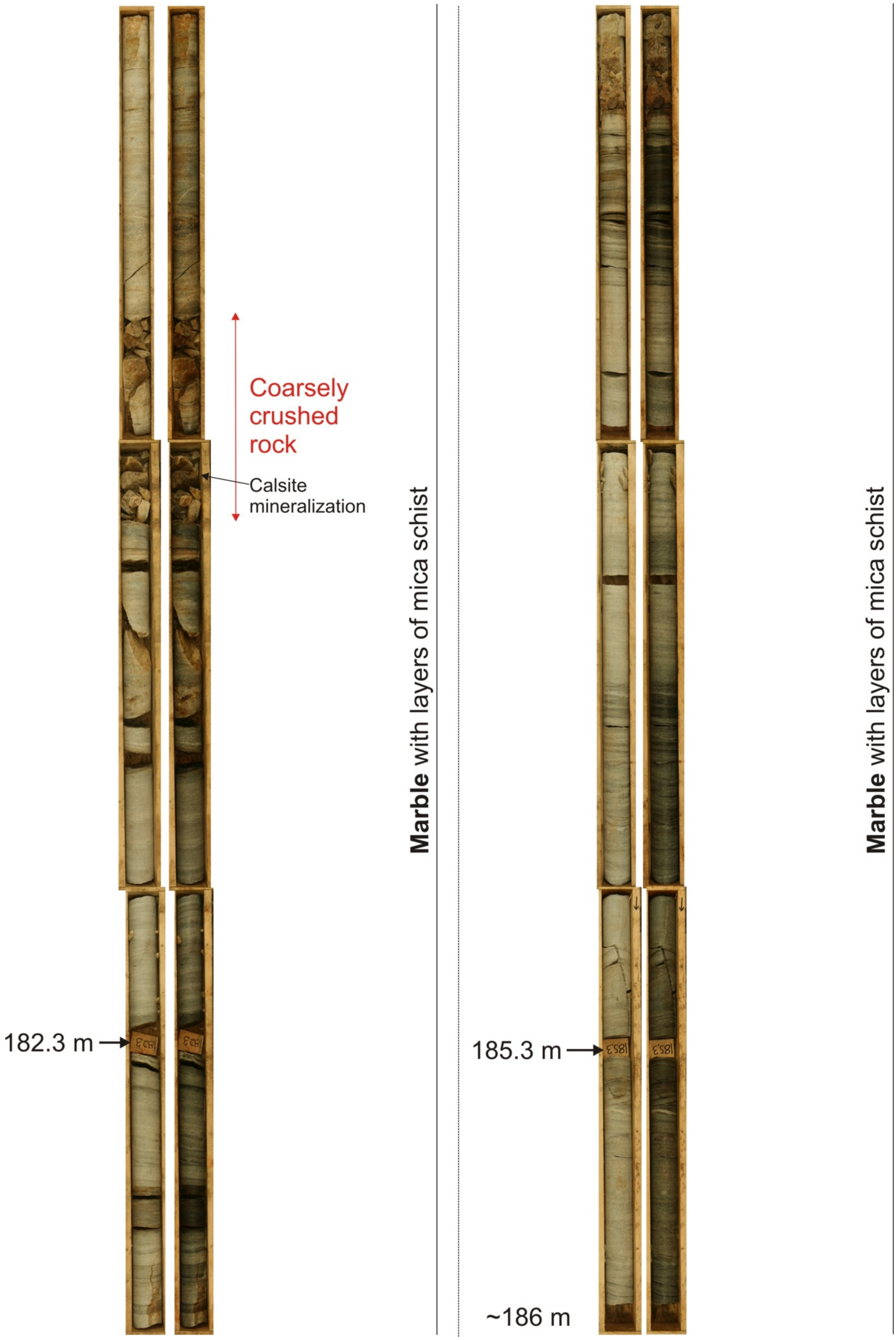

Figure 41. Geological core logging from ~180 to ~186 m depth with pictures of the dry (left) and wet (right) core.

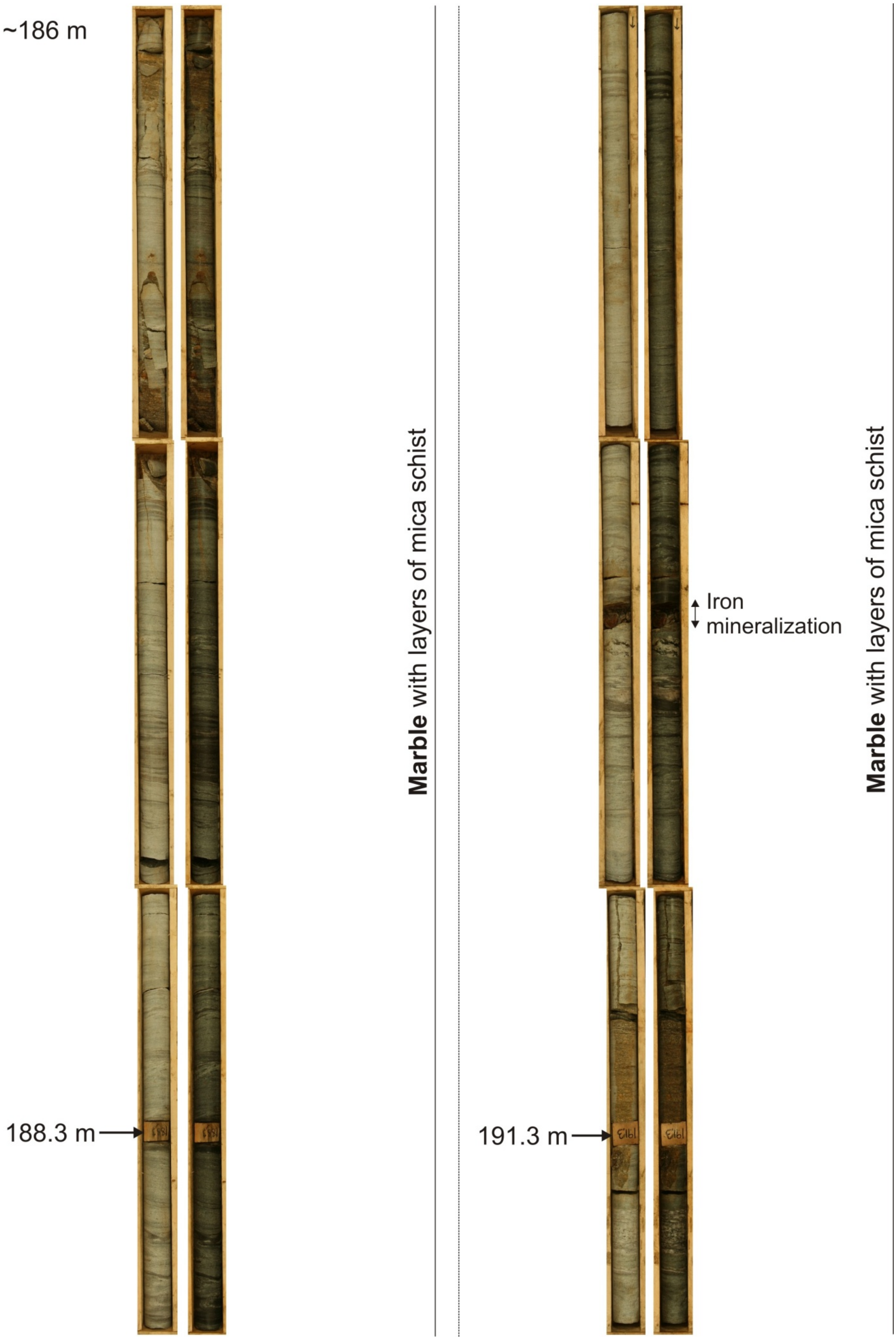

Figure 42. Geological core logging from ~186 to ~191.6 m depth with pictures of the dry (left) and wet (right) core.

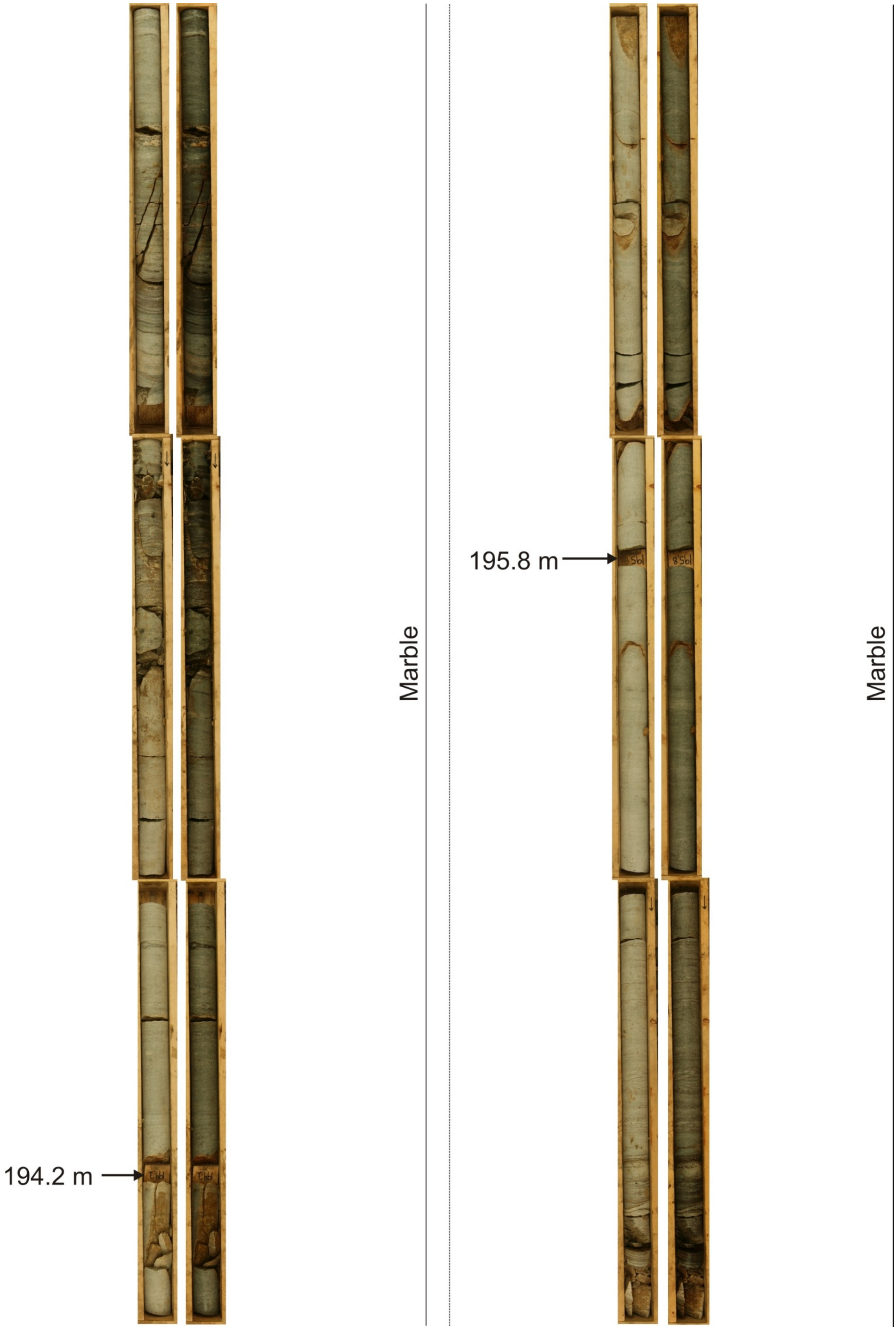

Figure 43. Geological core logging from ~191.6 to ~197 m depth with pictures of the dry (left) and wet (right) core.

Figure 44. Geological core logging from ~197 to ~198.8 m depth with pictures of the dry (left) and wet (right) core.

3.1 DOUBBLE SET OF DRILL CORES

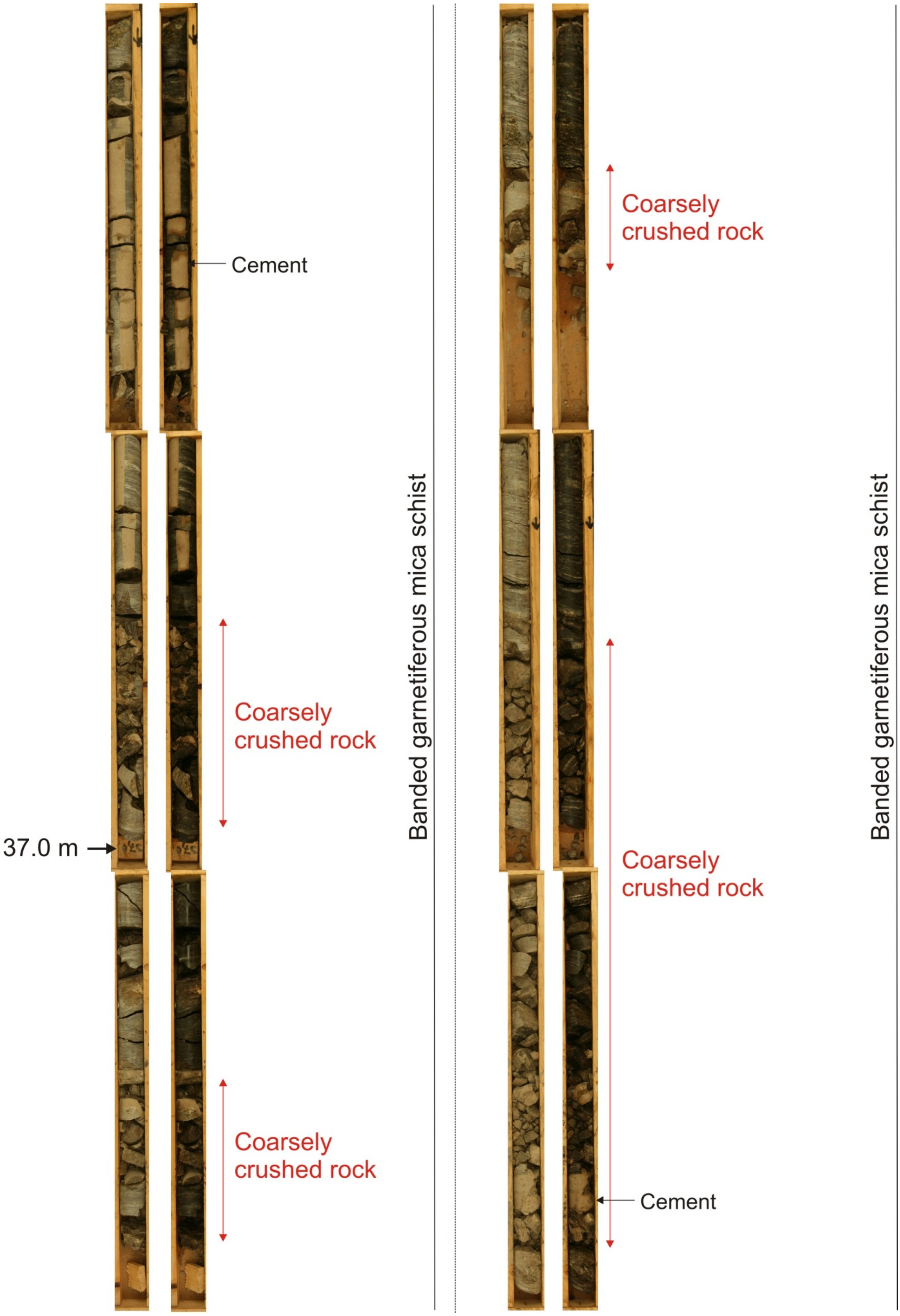

Figure 45. Geological core logging from ~35 to ~40 m depth with pictures of the dry (left) and wet (right) core.

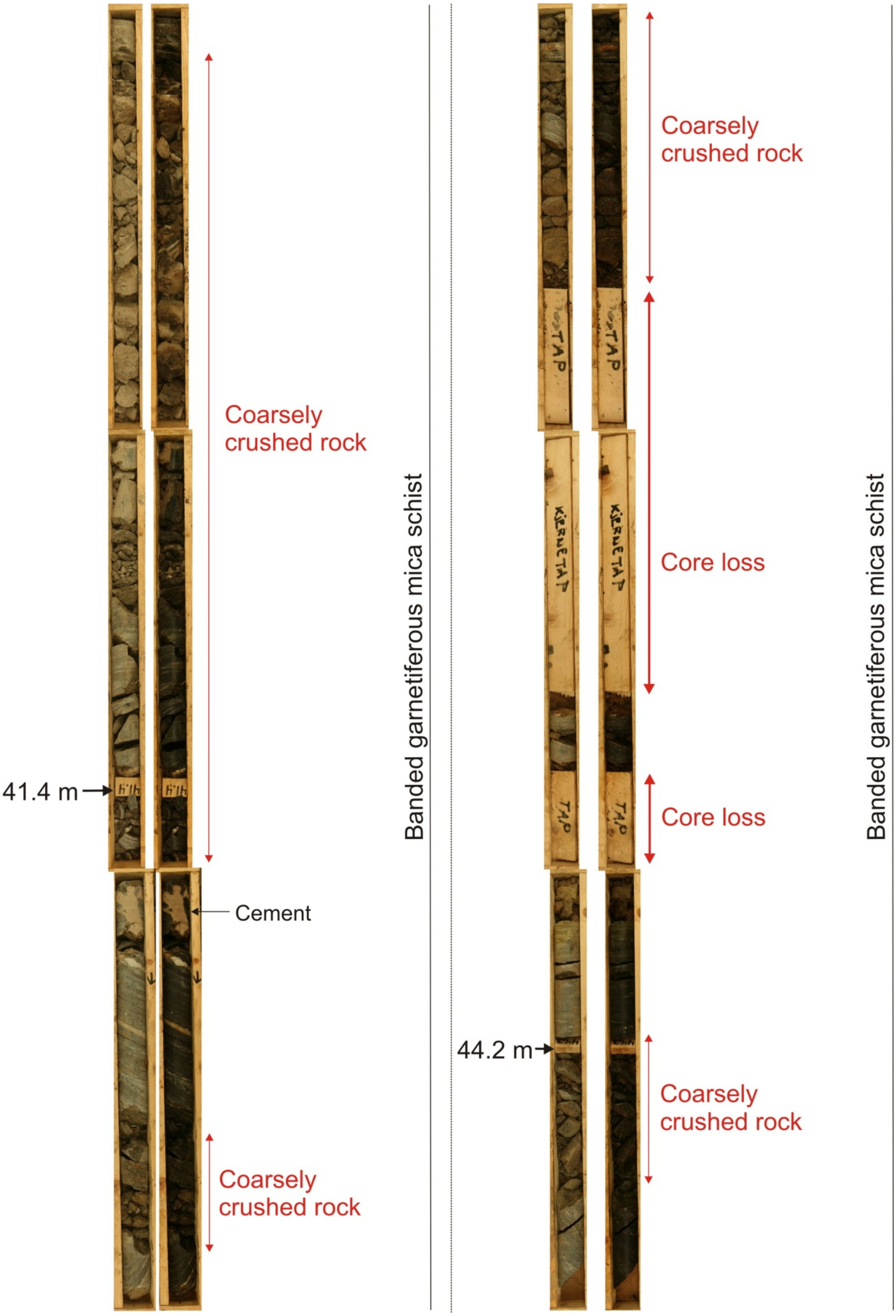

Figure 46. Geological core logging from ~40 to ~44.7 m depth with pictures of the dry (left) and wet (right) core.

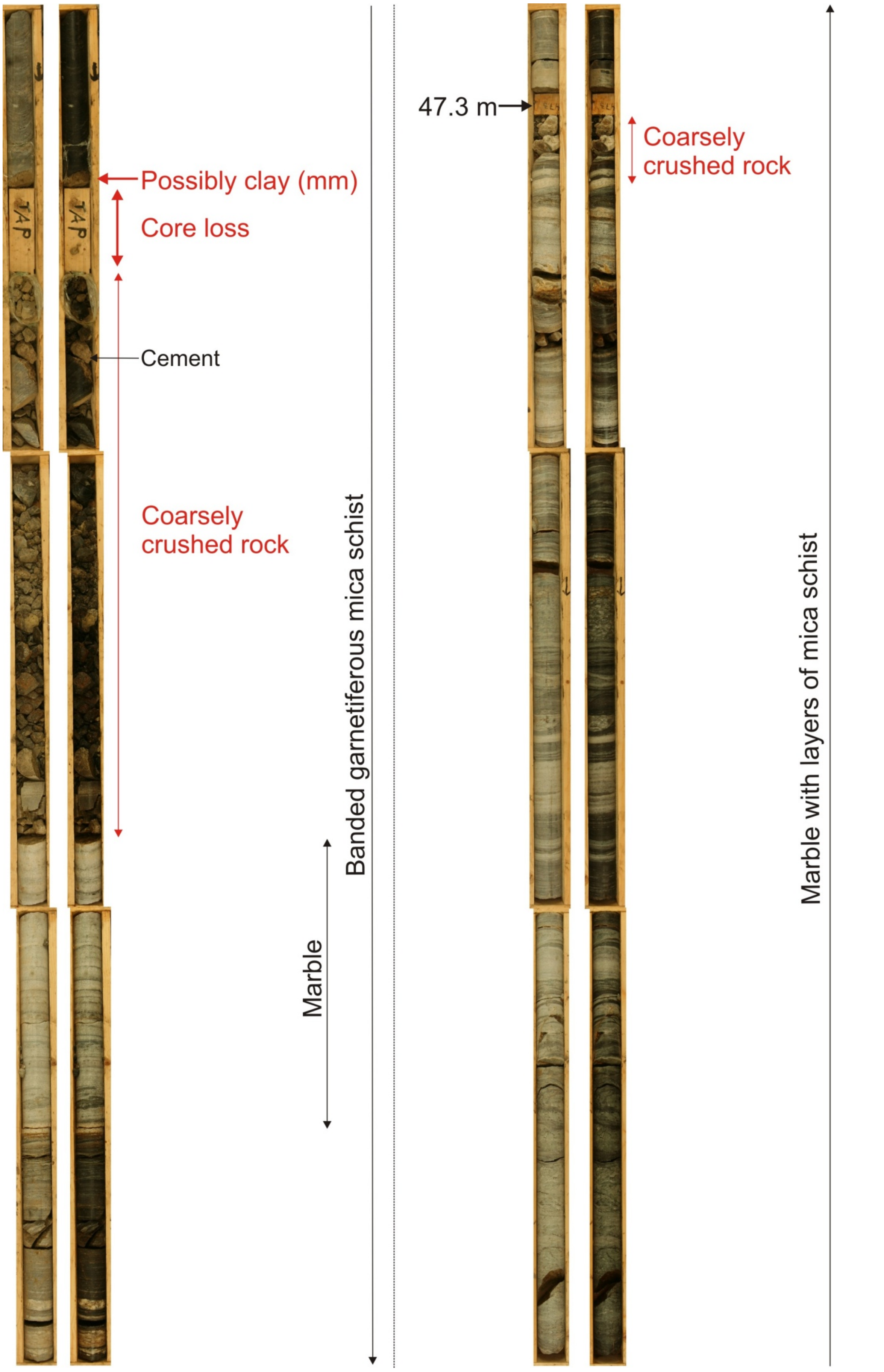

Figure 47. Geological core logging from ~44.7 to ~49.8 m depth with pictures of the dry (left) and wet (right) core.

Figure 48. Geological core logging from ~49.8 to ~55.5 m depth with pictures of the dry (left) and wet (right) core.

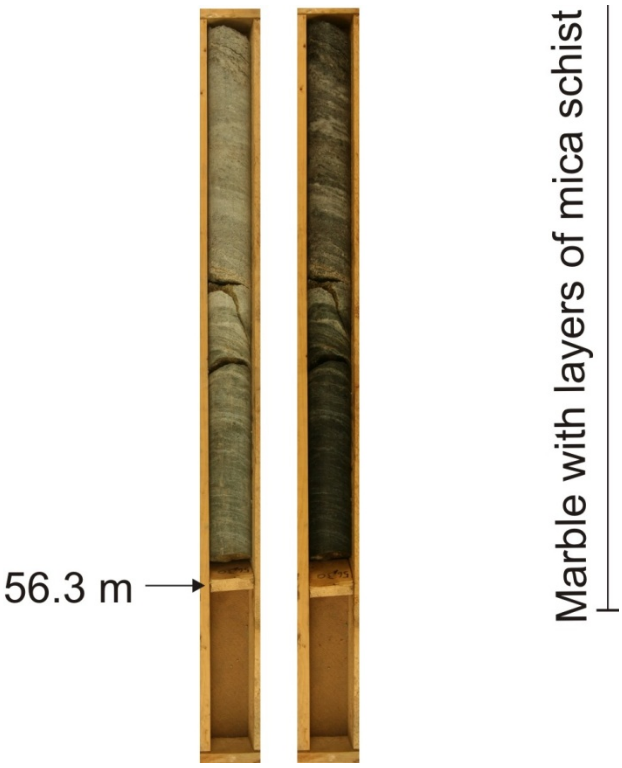

Figure 49. Geological core logging from ~55.5 to ~56.3 m depth with pictures of the dry (left) and wet (right) core.

4. CONCLUSIONS

The bedrock in the drill core consists generally of banded garnetiferous mica schist, banded mica schist with layers of marble and marble with layers of mica schist (Figure 49). 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 core. The orientation of the foliation and fractures are documented in NGU report 20013.20 by Elvebakk.

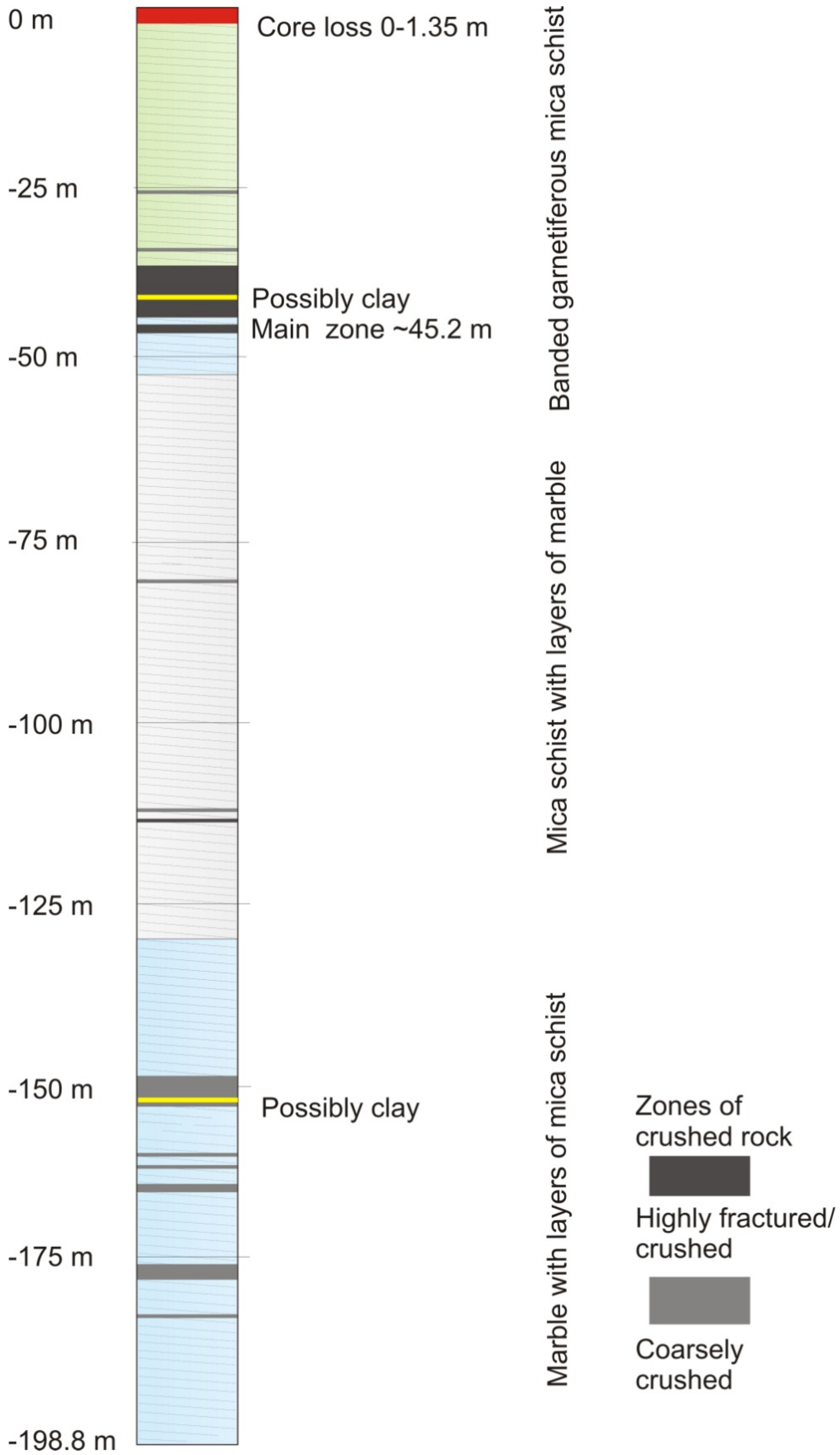

Figure 50. Overview of core log with main bedrock sections and zones of crushed rock indicated.

The main zone in the drill core is between ~37 and ~46 metre, where ~37 to ~42 metre consist of intensely crushed rock with possible clay (Figure 1). At ~45.2-45.5 meter an old fault with carbonate breccia and fault breccia on the sliding plane is observed. This zone is regarded as the primary zone of displacement (Figure 2 and Figure 3).

The other zones of crushed rock that occur in the drill core consist of coarsely crushed rock. Such zones of coarsely crushed rock are frequent from ~148 metre to ~181 metre. The only exception is the zone at ~148.5 to ~152 metre, where the rock is crushed with possible clay occurrence (Figure 49).

Figure 6, Figure 7 and Figure 8 show the fracture frequency recorded in the drill core, the total log that includes all types of fractures and an estimated value that reflect the zones of crushed rock, in addition to other logs. When the "true" fracture frequency is evaluated, the drilling produced fractures are subtracted from the "actual" fractures that does not include zones of crushed rock, the fracture frequency is in general low; ~5 fractures/meter. This is comparable to natural background fracturing, which is ~3 fractures/meter (Braathen & Gabrielsen, 2000). The zones of crushed rock indicate possible zones of displacement, and affect the fracture frequency. As the amount of fractures are influenced by the drilling process so is the zones of crushed rock; that the amount and extent of the zones of crushed rock are greater than what occurs in the borehole log (Elvebakk, 2013).

The procedure for depth documentation during drilling is inconsistent, but the drilling company has gone through the drill cores at a later stage in order to sort out the discrepancy. However, there are still a series of divergence in recorded depths, illustrated in Table 2, where the gray shading is where the depth recording is not consistent. The error is not necessarily where the gray shading is indicated, but somewhere between the recorded depths; bold numbers. As seen from Table 2, there is no logic in the error of recorded depths. There is possible core loss, which is not documented in the core.

The bedrock in the double borehole is similar to the main borehole, and the zones that occur do not differentiate much from those in the main borehole, with exception of extensive core loss.

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