# Appendix E: Comparison of Adjacent CPT Traces Before, During and After the CES

The data presented in this Appendix support the assumption that the estimated resistance of soil to liquefaction was essentially the same prior to the 2010-2011 Canterbury Earthquake Sequence (**CES**) as it has been estimated post-CES. This assumption is discussed in detail in Section 6.5.

There are 25 locations in Christchurch where Cone Penetration Tests (**CPT**s) were performed after the CES which are within 10m of CPTs that were performed before the CES. This set of adjacent pairs of pre-CES and post-CES CPT profiles enables one to examine if the CPT results were altered significantly by the CES. The locations of these 25 CPT sets are shown as blue and green circles on Figure E1.1. Additionally, CPTs were undertaken at 8 locations in the eastern suburbs of Christchurch following the September 2010 earthquake, and additional CPTs were pushed again at these 8 locations at various times (from 3 to 6 times) following later main earthquake events. The locations of these 8 CPT pairs are shown as purple circles in Figure E1.1.

Comparison of adjacent CPT tip resistance ($q_c$) and soil behaviour type index value ($I_c$) traces at each location are shown in the attached plots in:

- **Annex E1** for the twenty five locations where pre and post-CES CPTs were undertaken within 10m of each other; and
- **Annex E2** for the locations where CPT were pushed at various times following the main earthquake events.

Inspection of each CPT pair and CPT set shows that while there are minor variations between the CPT traces at each location there is no inherent bias towards either an increase or a decrease in $q_c$ with time. The minor variations in $q_c$ between the pre- and post-CES values between adjacent CPTs is typically due to spatial variability in ground conditions over short distances. This variability in ground conditions is reflected in the corresponding $I_c$ traces.

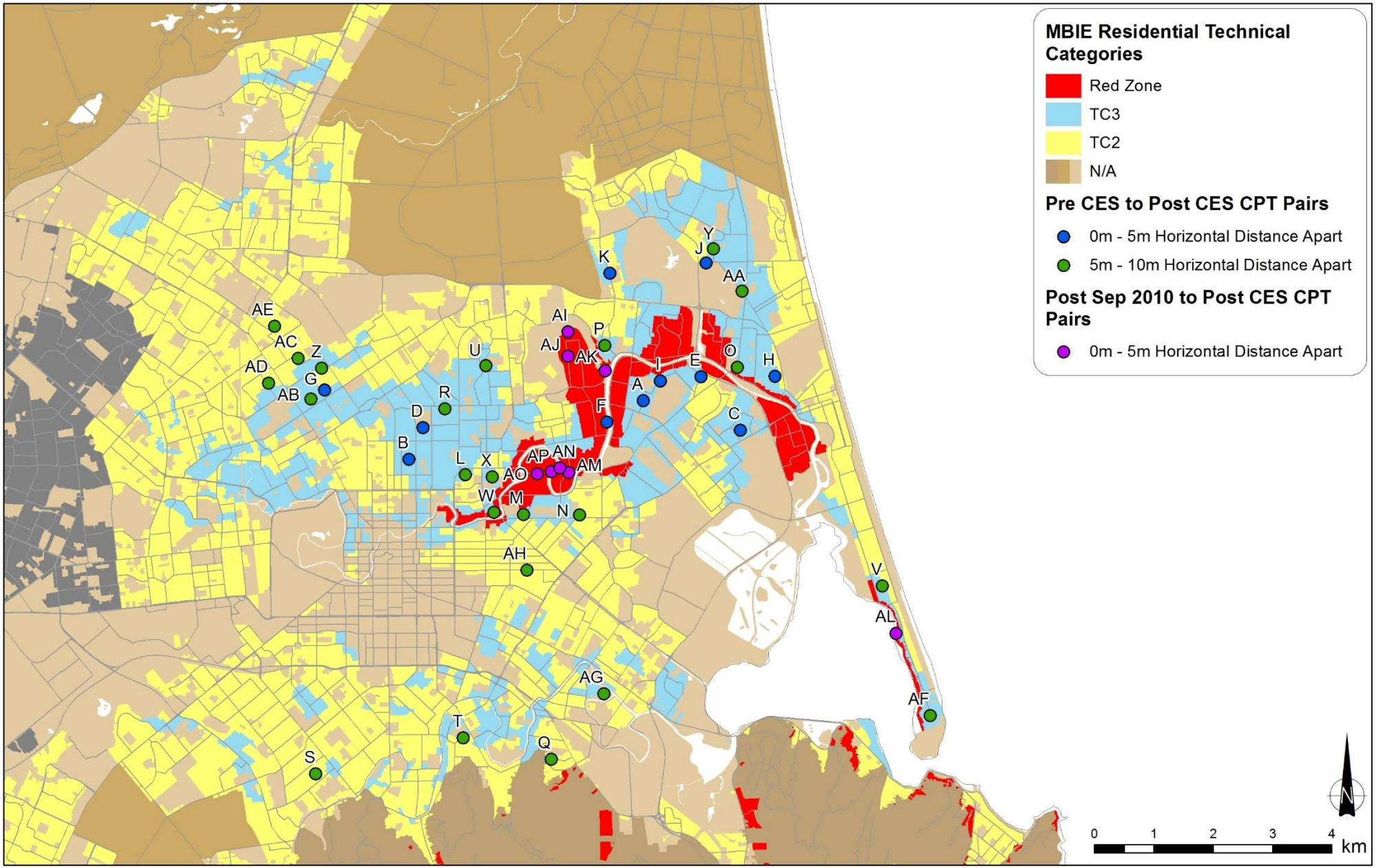



*Figure E1.1: Locations where repeat CPTs have been undertaken*

Based on these CPTs it is not possible to conclude that there has been a change in $q_c$ as a result of the CES. To examine further whether the CES has changed soil properties, pre and post-CES $q_c$ values for all the CPT pairs and CPT sets (where the corresponding $I_c$ value is less than 2.6) have been plotted as cumulative frequency graphs for 0 to 5m and 5 to 10m as shown in Figures E1.2 and E1.3, respectively.

Figure E1.2 shows the cumulative frequency graphs for 0 to 5m and 5 to 10m horizontal distance corresponding to pre and post-CES CPT $q_c$ values for the 25 locations in Christchurch described above (i.e. CPT pairs A to AH in Annex E1). There is little difference between the cumulative distributions for the pre and post-CES values and insufficient difference to substantiate a change in soil properties.

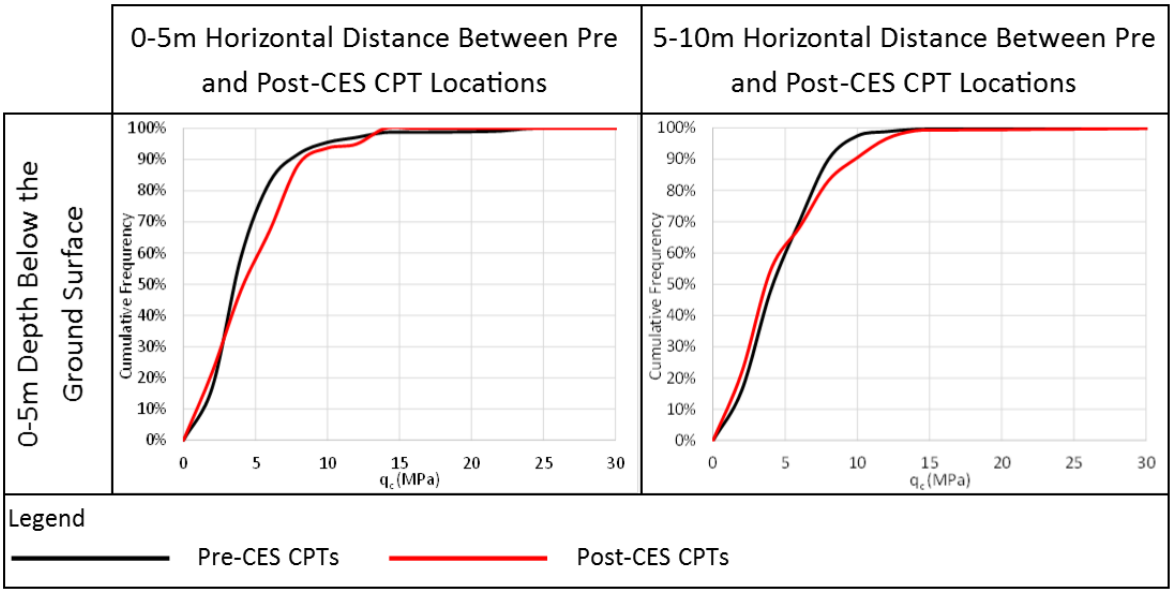



*Figure E1.2: Pre and post CES cumulative frequency graphs of $q_c$ for varying depths from CPT locations in Figure E1.1 filtered for soil layers with $I_c < 2.6$.*

Figure E1.3 shows the cumulative frequency graphs for 0 to 5m and 5 to 10m depth below ground surface corresponding to post-September 2010, post-February 2011, post-June 2011, and post-December 2011 CPT $q_c$ values for the 8 locations in Christchurch described above (i.e. CPT sets AI to AP in Annex E2).

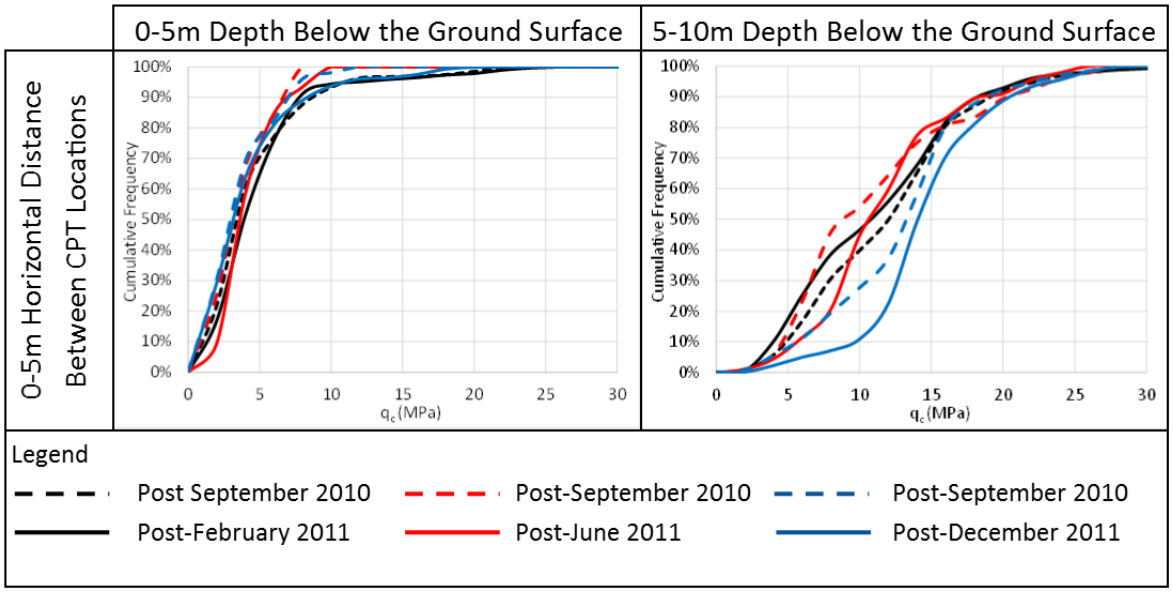



*Figure E1.3: Post-September 2010, post-February 2011, post-June 2011 and post-CES cumulative frequency graphs of qc for varying depths from CPT locations in Figure E1.1 filtered for soil layers with Ic < 2.6.*

Inspection of the CPT sets in Annex E2 shows that several of the post-December 2011 CPT $q_c$ traces have higher values compared to the other CPT $q_c$ traces. Further inspection of the corresponding $I_c$ traces indicates that these CPTs were undertaken in soils with different soil behaviour type indices. This highlights the potential for spatial variability of ground conditions over relatively short distances in the Christchurch area. To reduce the error associated with comparing $q_c$ values from significantly different soil types, the post-September 2010 and post-December 2011 $q_c$ data were filtered manually to exclude portions of the CPT $q_c$ traces where the post-September 2010 and post-December 2011 CPT $I_c$ values were sufficiently different. Table E1.1 lists the depth ranges for the 8 sets of CPT traces where the $q_c$ values were excluded.

**Table E1.1: Length of CPT $q_c$ trace excluded from Figure E1.3**

| CPT Set | Length of CPT $q_c$ trace excluded |
|---|---|
| AI | 0 – 7.2m |
| AJ | 2.3 – 5.2m |
| AK | Nil |
| AL | 4.0 – 6.0m |
| AM | 2.4 – 5.0m |
| AN | 3.1 – 6.0m |
| AO | 3.5 – 4.7m |
| AP | 3.4 – 4.8m |

The resulting cumulative distribution plots show little difference for depths of 0 to 5m below ground surface. This is the depth range of soil deposits that tend to have the largest effect on potentially damaging ground deformations. Greater variability in the cumulative distributions is apparent for the 5 to 10m depth, reflecting a more rapid change in subsurface conditions for the deeper deposits at the locations of the 8 sets of CPT traces.

Note that there are three different cumulative frequency curves for the post-September 2010 data in Figure E1.3, because the CPTs that were used with each corresponding post-February,

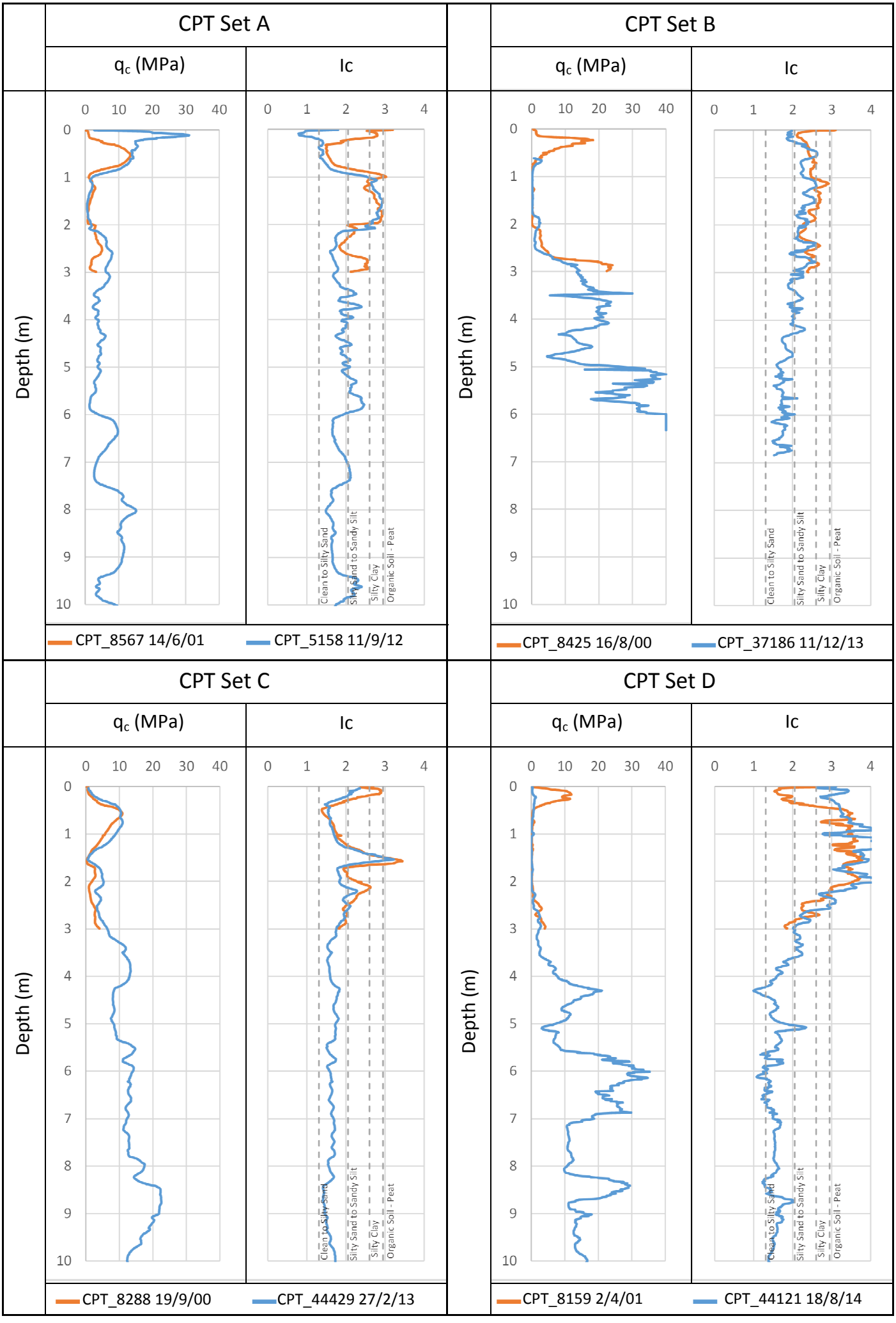
post-June or post-December 2011 CPT's were different for each event. Therefore, three slightly different post-September 2010 cumulative frequency curves were generated for comparison with the post-February, post-June, and post-December 2011 cumulative frequency curves.

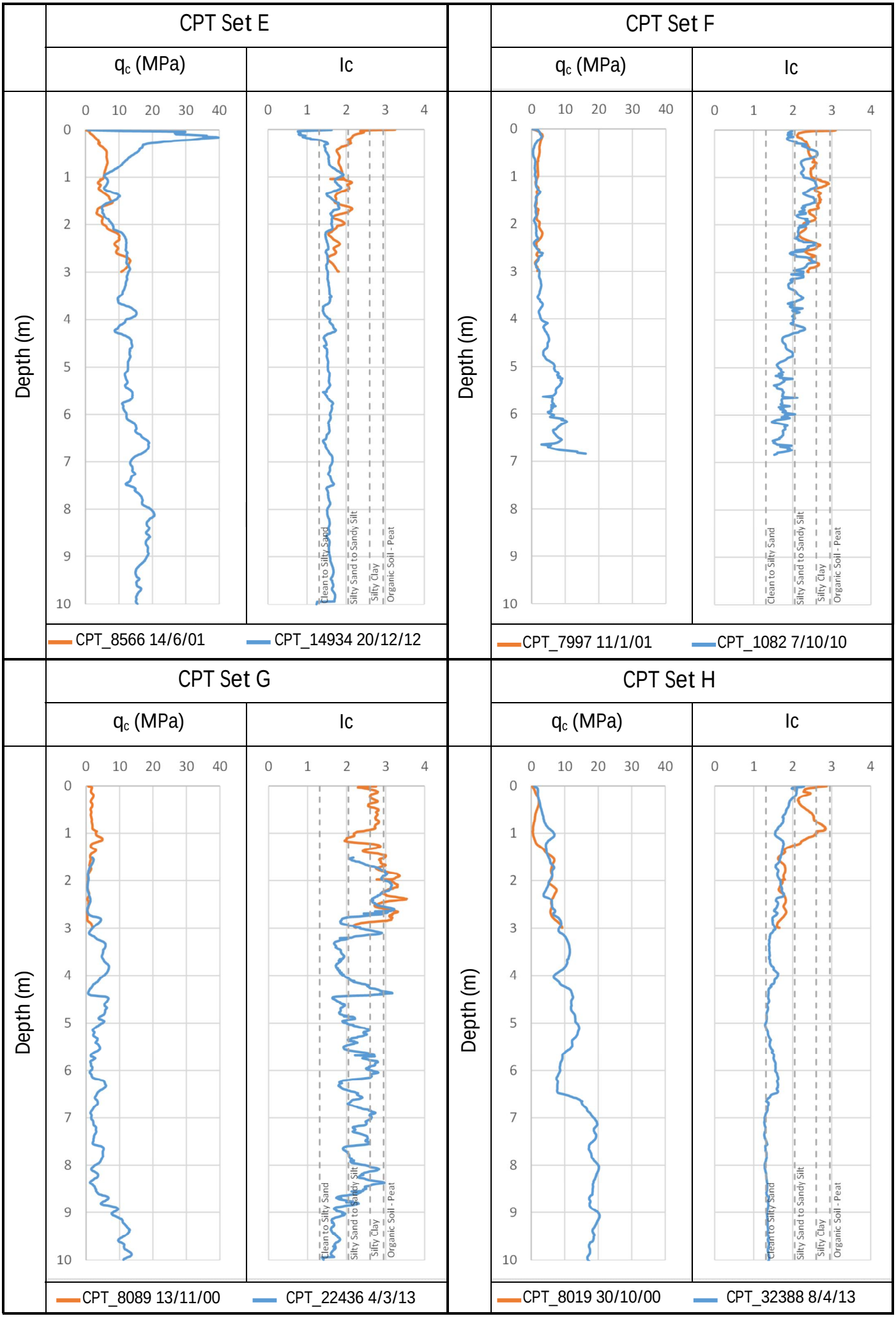
There is little difference between the cumulative distributions for the post-September 2010, post-February 2011, post-June 2011 and post-December 2011 values, and insufficient difference to substantiate a change in soil properties.

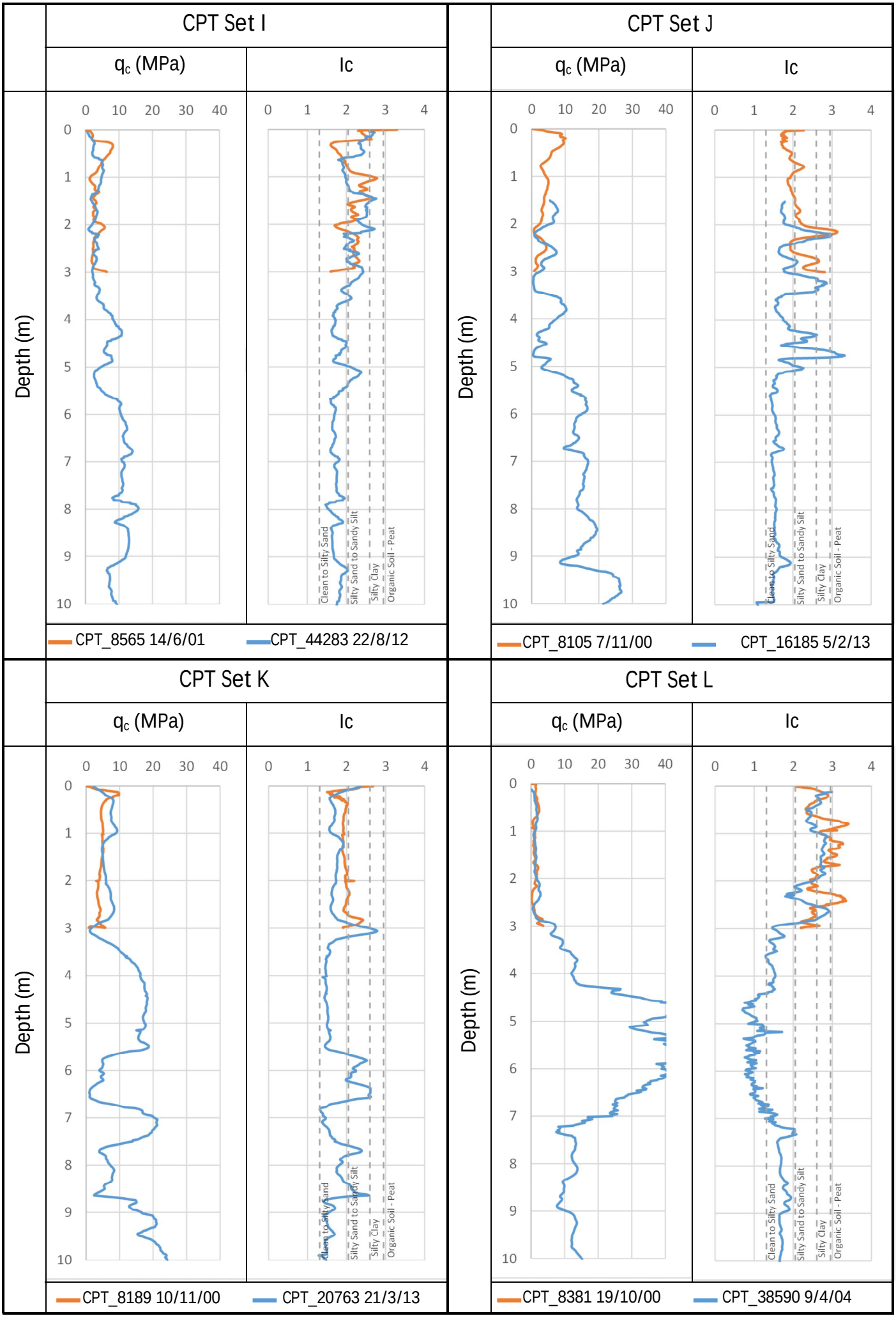
Collectively, these figures demonstrate that there is a lack of systemic bias in the pre-CES values being higher or lower than the post-CES values. This supports the assumption that the CES has not changed the resistance of soil to liquefaction in the Christchurch area.

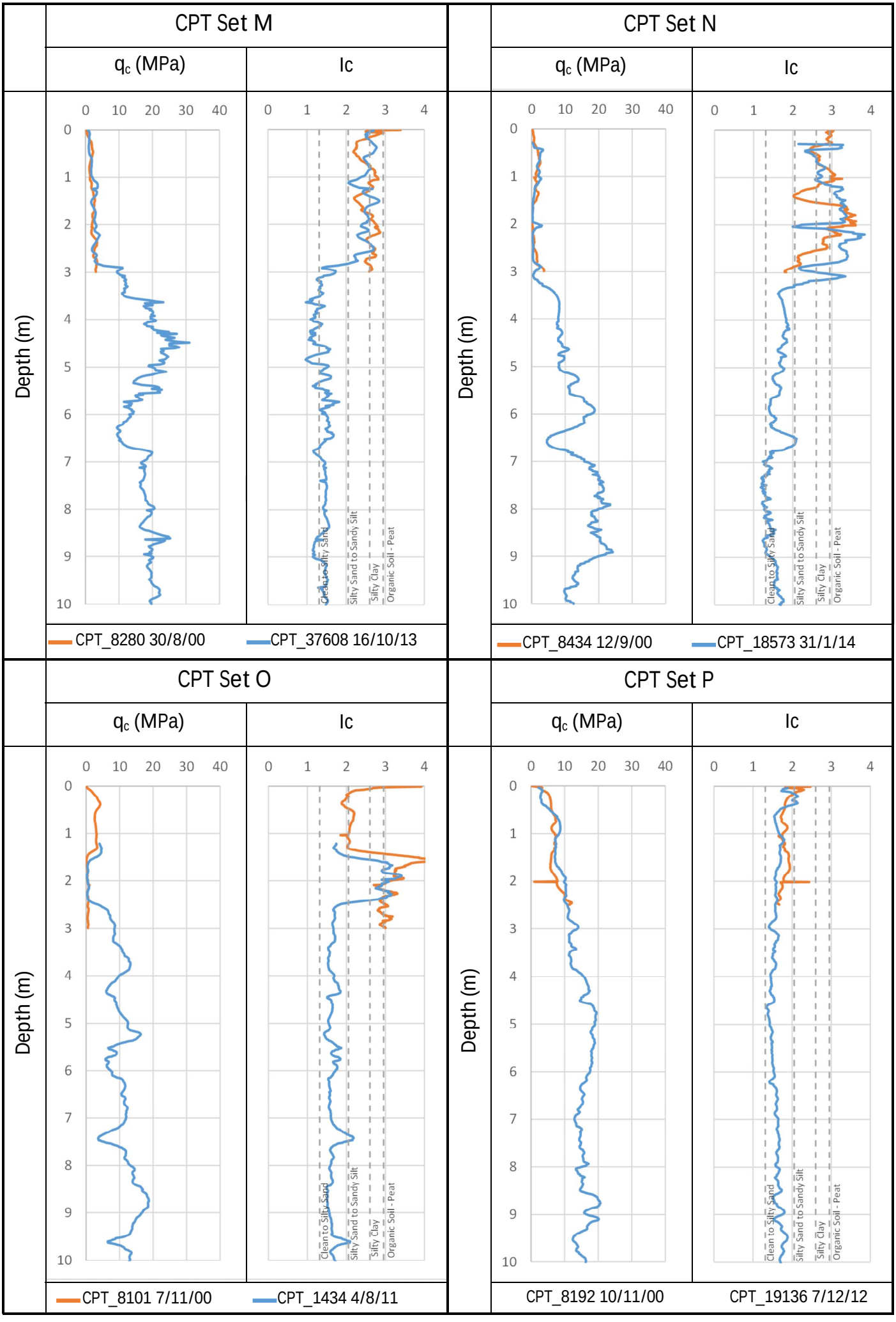
## Annex E1 – Comparison of CPT Pairs Before and After the CES

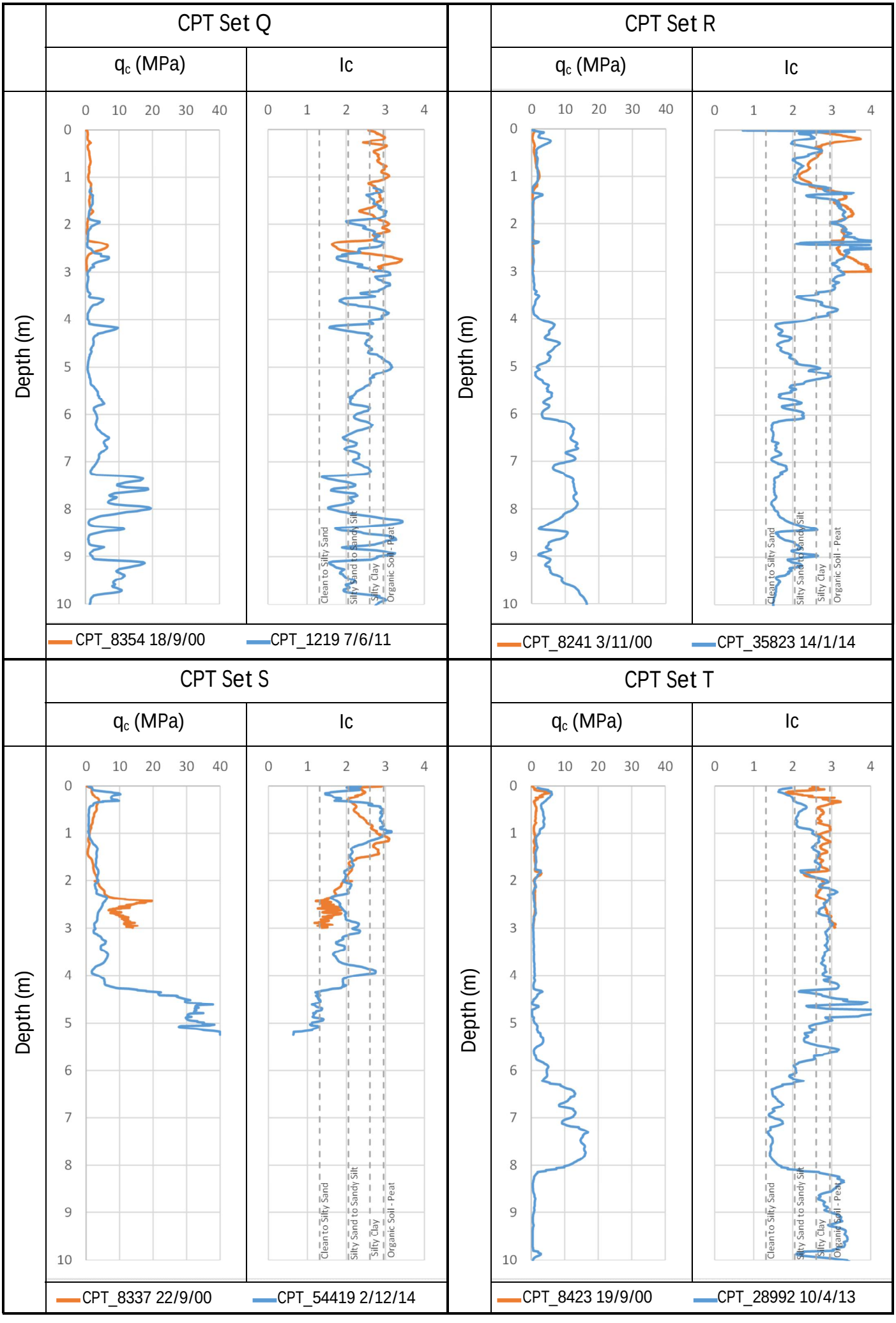
The following CPT pairs (A to AH) have been categorised according to the time the data was collected relative to the preceding earthquake. The CPT data is displayed according to the legend provided below.

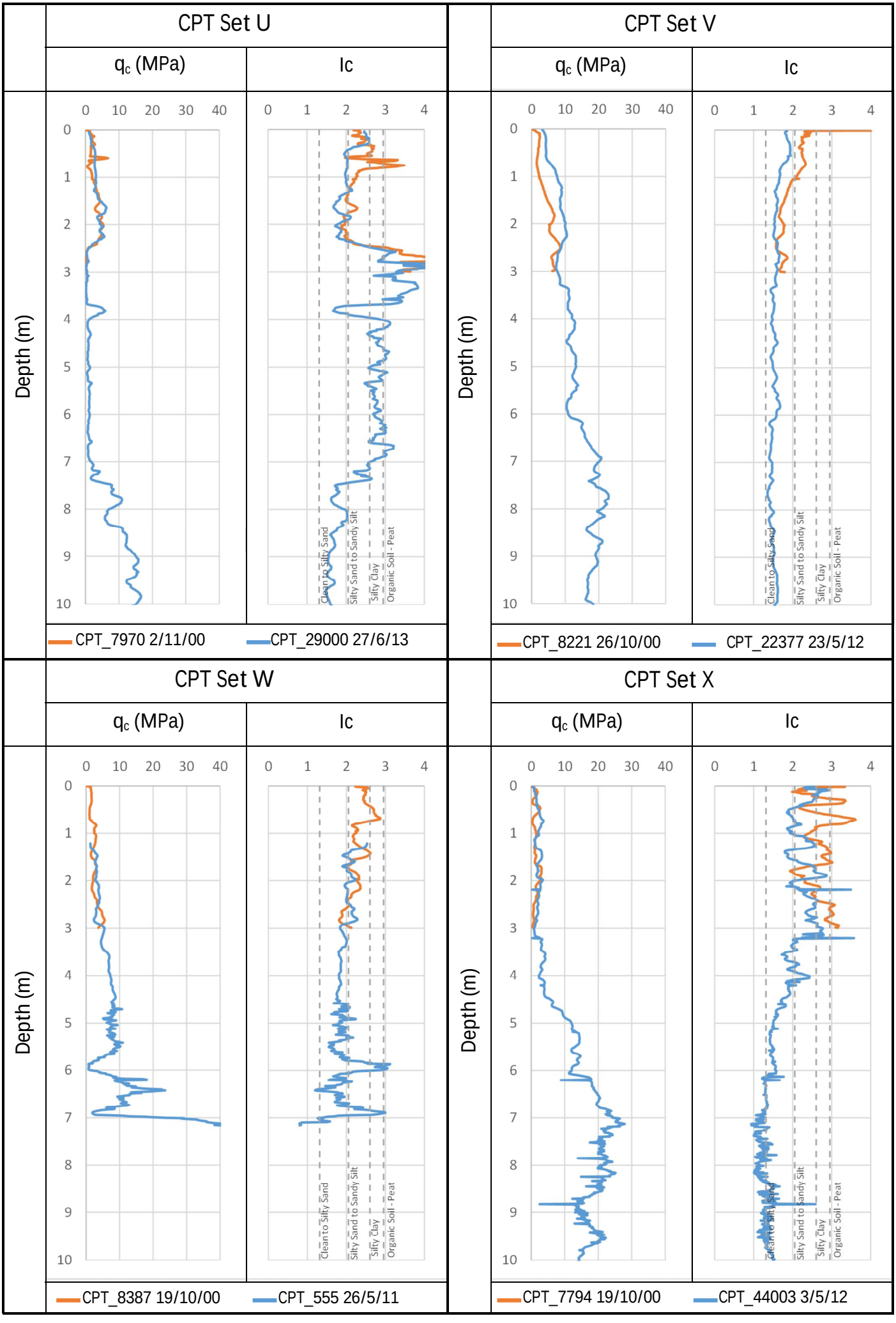

CPT Set A
qc (MPa)
Ic
Depth (m)
0 10 20 30 40
0 1 2 3 4
Clean to Silty Sand
Silty Sand to Sandy Silt
Silty Clay
Organic Soil - Peat
CPT_8567 14/6/01
CPT_5158 11/9/12
CPT Set B
qc (MPa)
Ic
Depth (m)
CPT_8425 16/8/00
CPT_37186 11/12/13
CPT Set C
qc (MPa)
Ic
Depth (m)
CPT_8288 19/9/00
CPT_44429 27/2/13
CPT Set D
qc (MPa)
Ic
Depth (m)
CPT_8159 2/4/01
CPT_44121 18/8/14

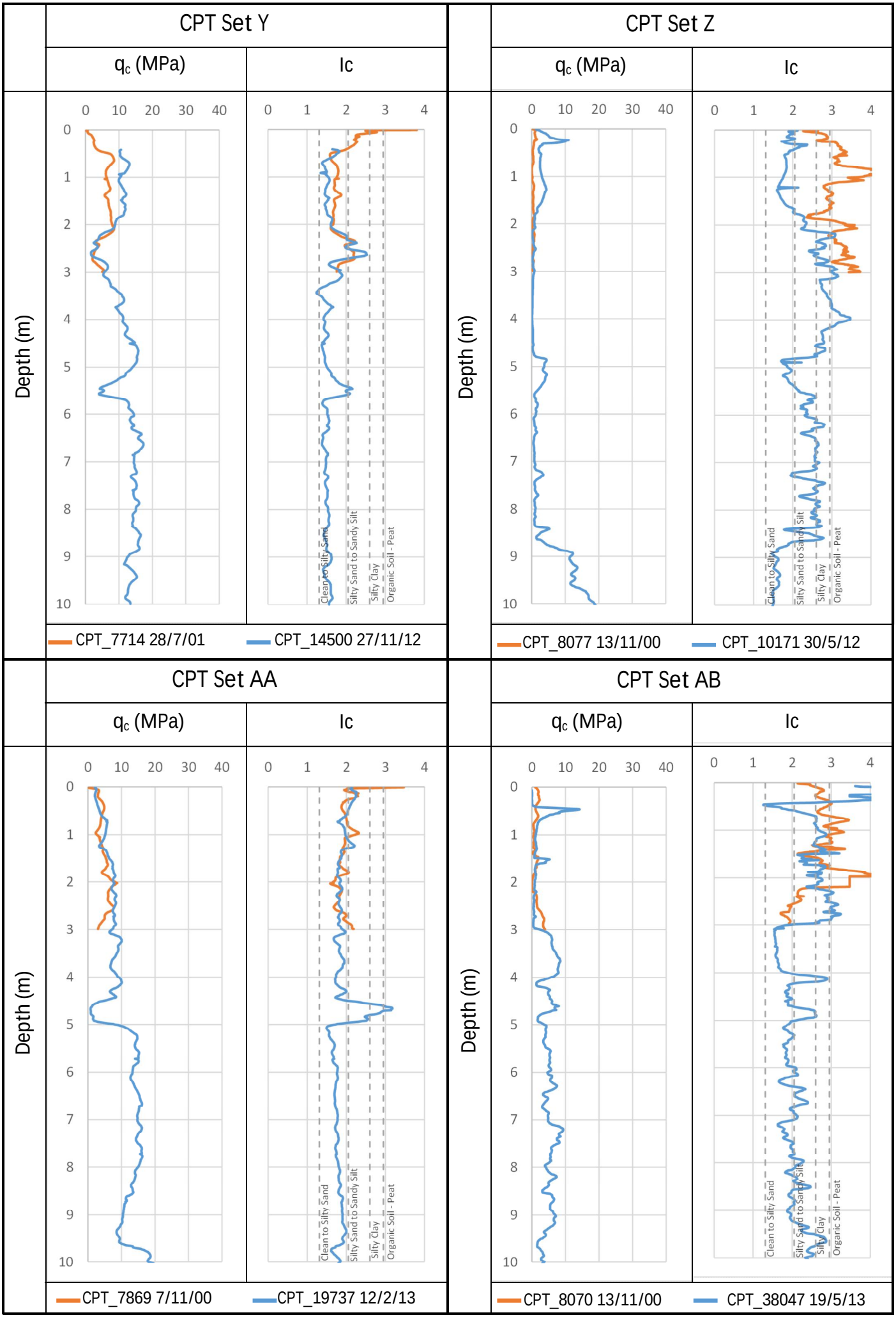

CPT Set E
qc (MPa)
Ic
Depth (m)
0 10 20 30 40
0 1 2 3 4
Clean to Silty Sand
Silty Sand to Sandy Silt
Silty Clay
Organic Soil - Peat
CPT_8566 14/6/01
CPT_14934 20/12/12
CPT Set F
qc (MPa)
Ic
Depth (m)
CPT_7997 11/1/01
CPT_1082 7/10/10
CPT Set G
qc (MPa)
Ic
Depth (m)
CPT_8089 13/11/00
CPT_22436 4/3/13
CPT Set H
qc (MPa)
Ic
Depth (m)
CPT_8019 30/10/00
CPT_32388 8/4/13


CPT Set I
qc (MPa)
Ic
Depth (m)
0 10 20 30 40
0 1 2 3 4
0 1 2 3 4 5 6 7 8 9 10
Clean to Silty Sand
Silty Sand to Sandy Silt
Silty Clay
Organic Soil - Peat
CPT_8565 14/6/01
CPT_44283 22/8/12
CPT Set J
qc (MPa)
Ic
Depth (m)
CPT_8105 7/11/00
CPT_16185 5/2/13
CPT Set K
qc (MPa)
Ic
Depth (m)
CPT_8189 10/11/00
CPT_20763 21/3/13
CPT Set L
qc (MPa)
Ic
Depth (m)
CPT_8381 19/10/00
CPT_38590 9/4/04

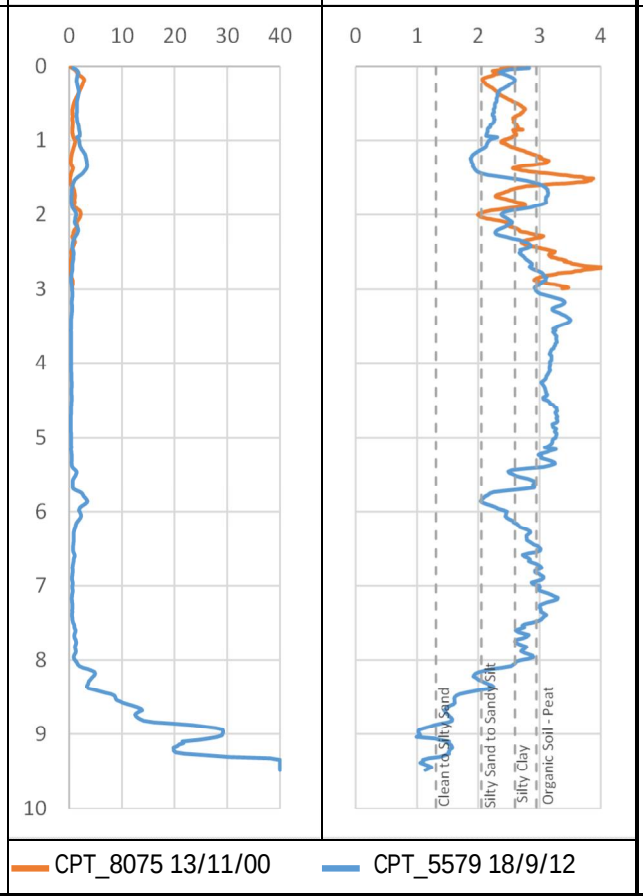

CPT Set M
qc (MPa)
Ic
Depth (m)
0 10 20 30 40
0 1 2 3 4
Clean to Silty Sand
Silty Sand to Sandy Silt
Silty Clay
Organic Soil - Peat
CPT_8280 30/8/00
CPT_37608 16/10/13
CPT Set N
qc (MPa)
Ic
Depth (m)
CPT_8434 12/9/00
CPT_18573 31/1/14
CPT Set O
qc (MPa)
Ic
Depth (m)
CPT_8101 7/11/00
CPT_1434 4/8/11
CPT Set P
qc (MPa)
Ic
Depth (m)
CPT_8192 10/11/00
CPT_19136 7/12/12


CPT Set Q
qc (MPa)
Ic
Depth (m)
0 10 20 30 40
0 1 2 3 4
0 1 2 3 4 5 6 7 8 9 10
Clean to Silty Sand
Silty Sand to Sandy Silt
Silty Clay
Organic Soil - Peat
CPT_8354 18/9/00
CPT_1219 7/6/11
CPT Set R
qc (MPa)
Ic
Depth (m)
CPT_8241 3/11/00
CPT_35823 14/1/14
CPT Set S
qc (MPa)
Ic
Depth (m)
CPT_8337 22/9/00
CPT_54419 2/12/14
CPT Set T
qc (MPa)
Ic
Depth (m)
CPT_8423 19/9/00
CPT_28992 10/4/13

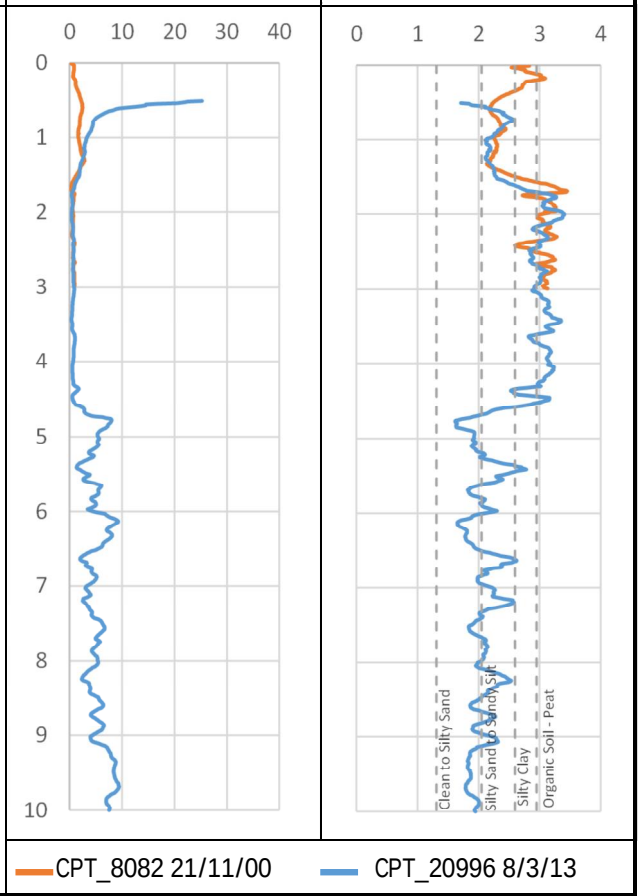

CPT Set U
qc (MPa)
Ic
Depth (m)
0 10 20 30 40
0 1 2 3 4
0 1 2 3 4 5 6 7 8 9 10
Clean to Silty Sand
Silty Sand to Sandy Silt
Silty Clay
Organic Soil - Peat
CPT_7970 2/11/00
CPT_29000 27/6/13
CPT Set V
qc (MPa)
Ic
Depth (m)
CPT_8221 26/10/00
CPT_22377 23/5/12
CPT Set W
qc (MPa)
Ic
Depth (m)
CPT_8387 19/10/00
CPT_555 26/5/11
CPT Set X
qc (MPa)
Ic
Depth (m)
CPT_7794 19/10/00
CPT_44003 3/5/12


CPT Set Y
qc (MPa)
Ic
Depth (m)
0 10 20 30 40
0 1 2 3 4
0 1 2 3 4 5 6 7 8 9 10
Clean to Silty Sand
Silty Sand to Sandy Silt
Silty Clay
Organic Soil - Peat
CPT_7714 28/7/01
CPT_14500 27/11/12
CPT Set Z
qc (MPa)
Ic
Depth (m)
CPT_8077 13/11/00
CPT_10171 30/5/12
CPT Set AA
qc (MPa)
Ic
Depth (m)
CPT_7869 7/11/00
CPT_19737 12/2/13
CPT Set AB
qc (MPa)
Ic
Depth (m)
CPT_8070 13/11/00
CPT_38047 19/5/13

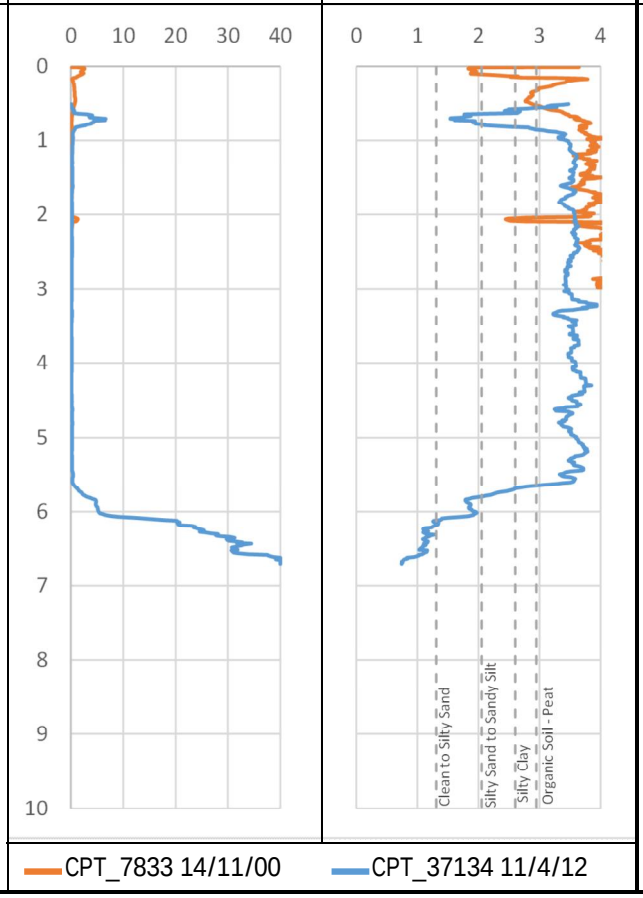
## CPT Set AC



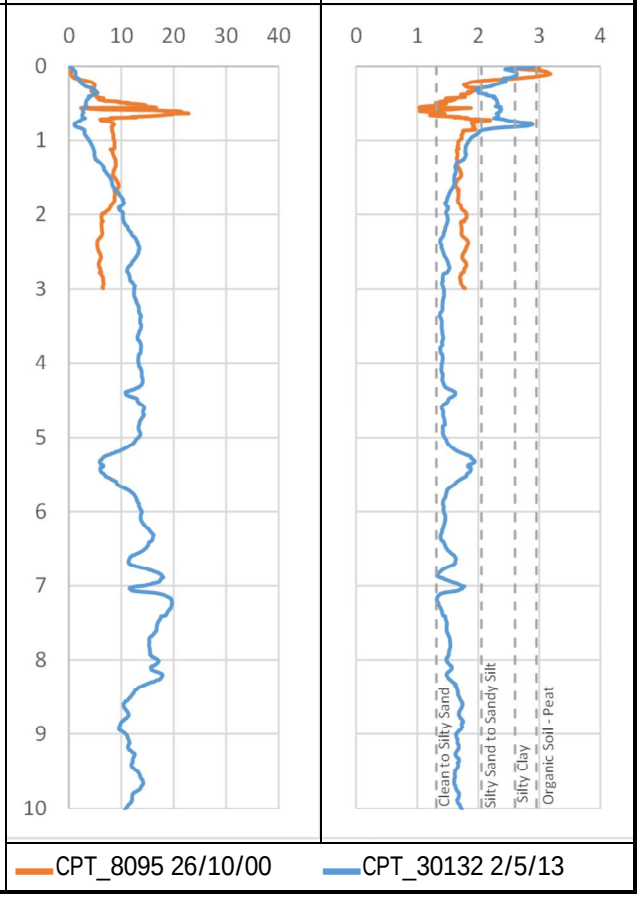

## CPT Set AD

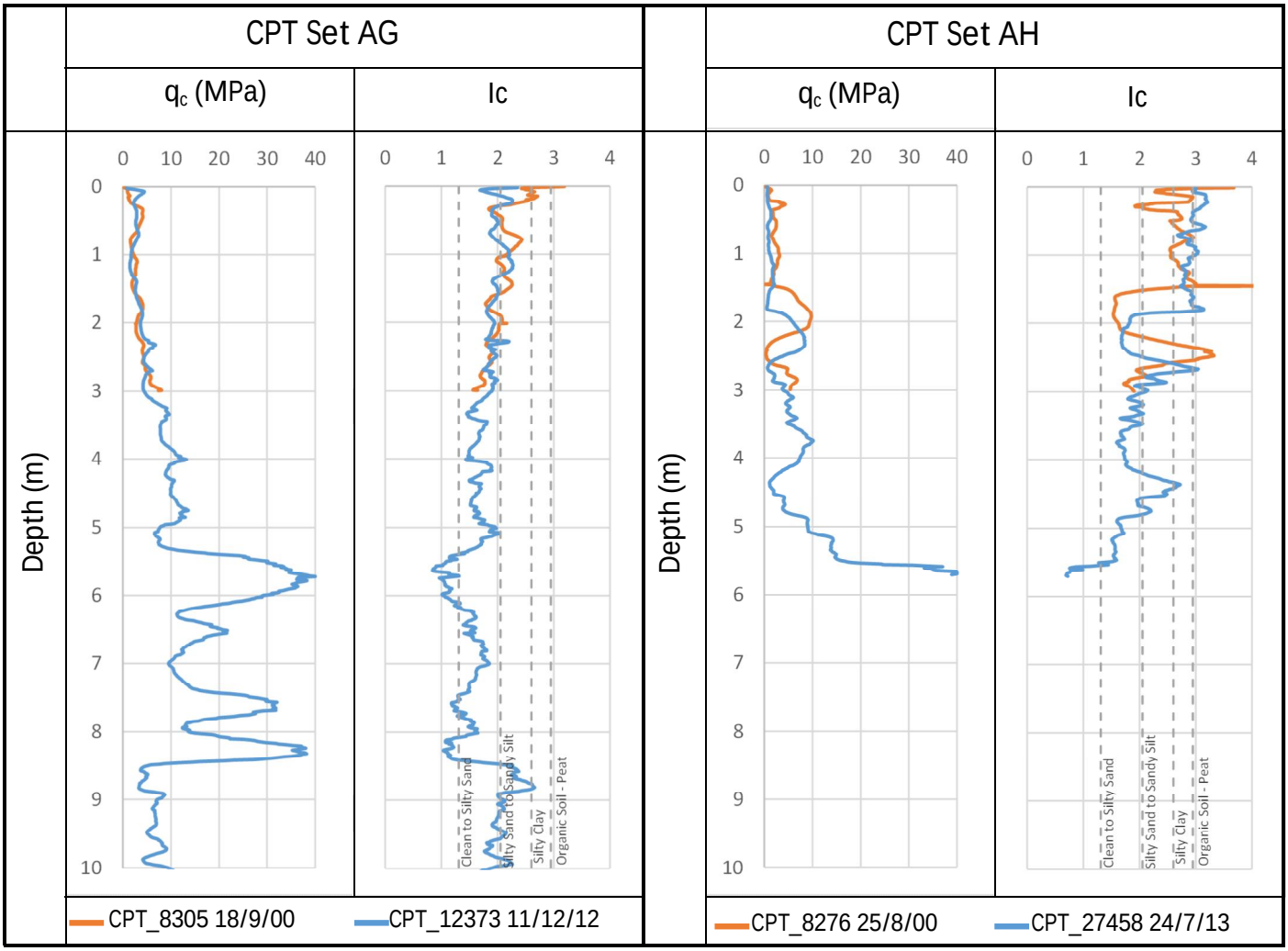



## CPT Set AE



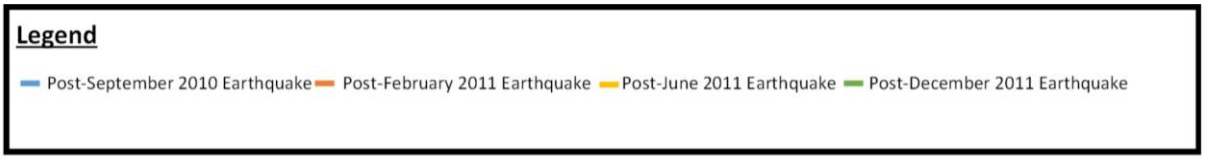

## CPT Set AF



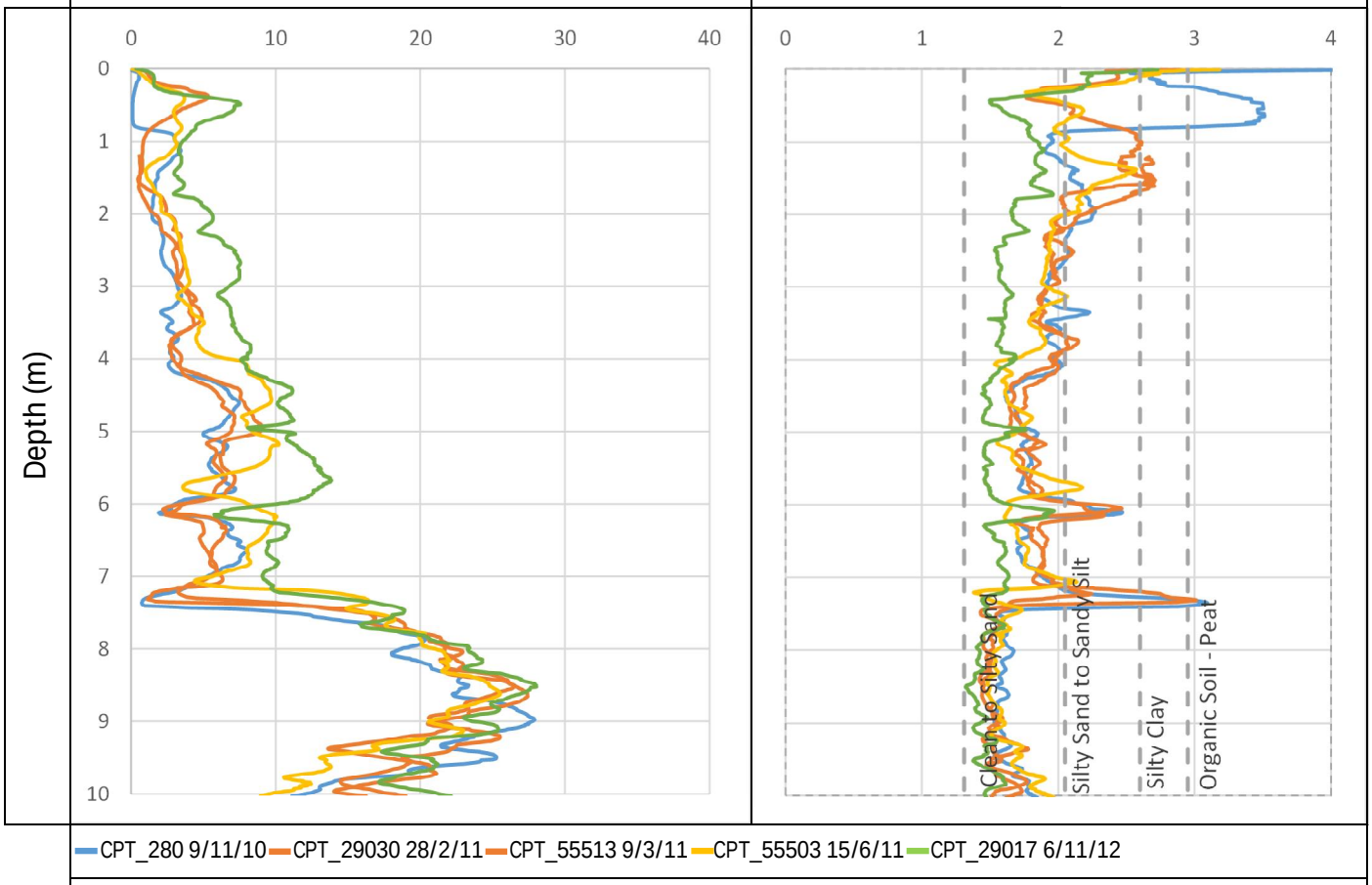

CPT Set AG
CPT Set AH
qc (MPa)
Ic
Depth (m)
0 10 20 30 40
0 1 2 3 4
Clean to Silty Sand
Silty Sand to Sandy Silt
Silty Clay
Organic Soil - Peat
CPT_8305 18/9/00
CPT_12373 11/12/12
CPT_8276 25/8/00
CPT_27458 24/7/13

# Annex E2 – Comparison of CPT Sets Before, During and After the CES

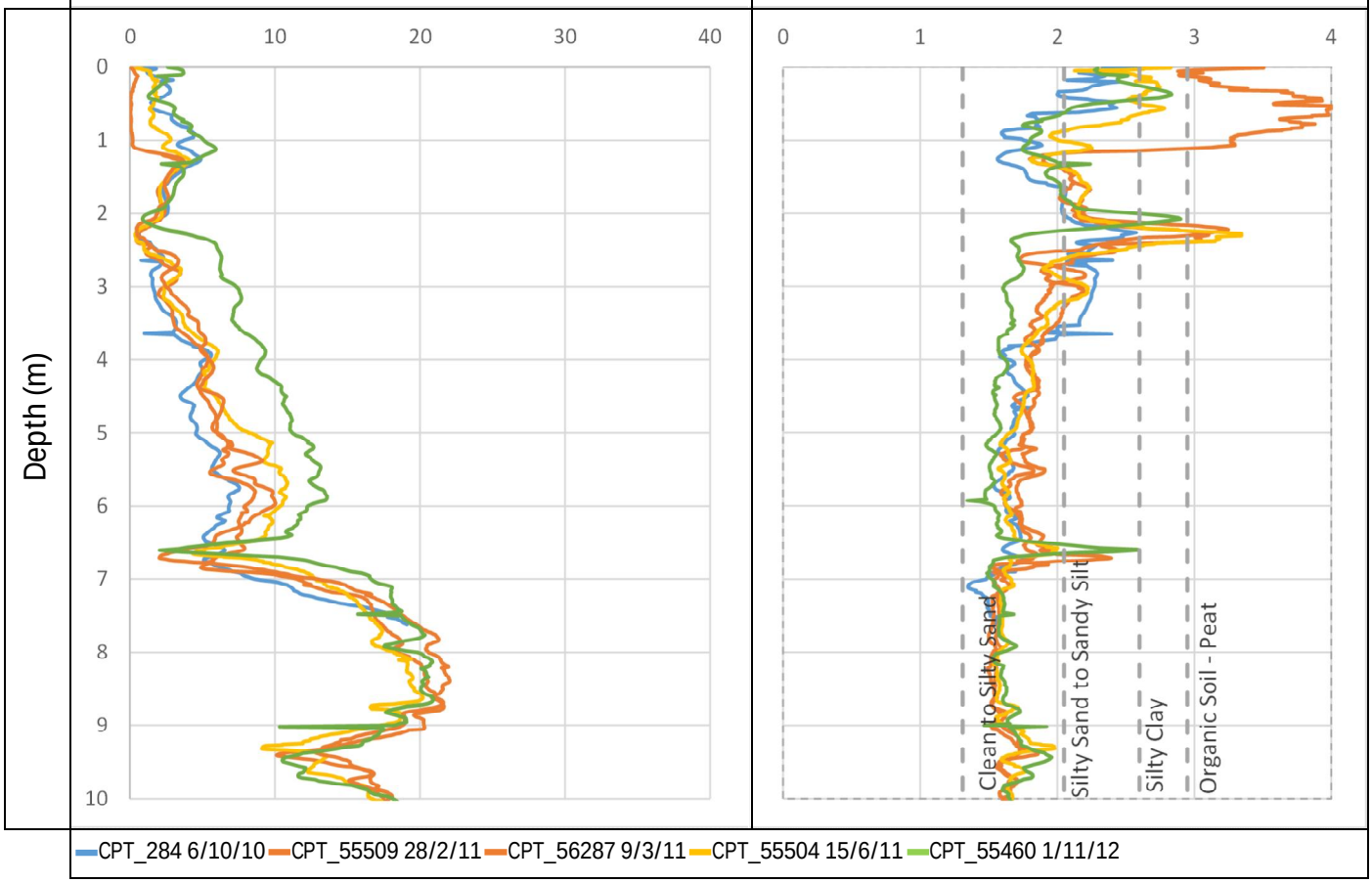
The following CPT sets (AI to AN) have been categorised according to the time the data was collected relative to the preceding earthquake. The CPT data is displayed according to the legend provided below.



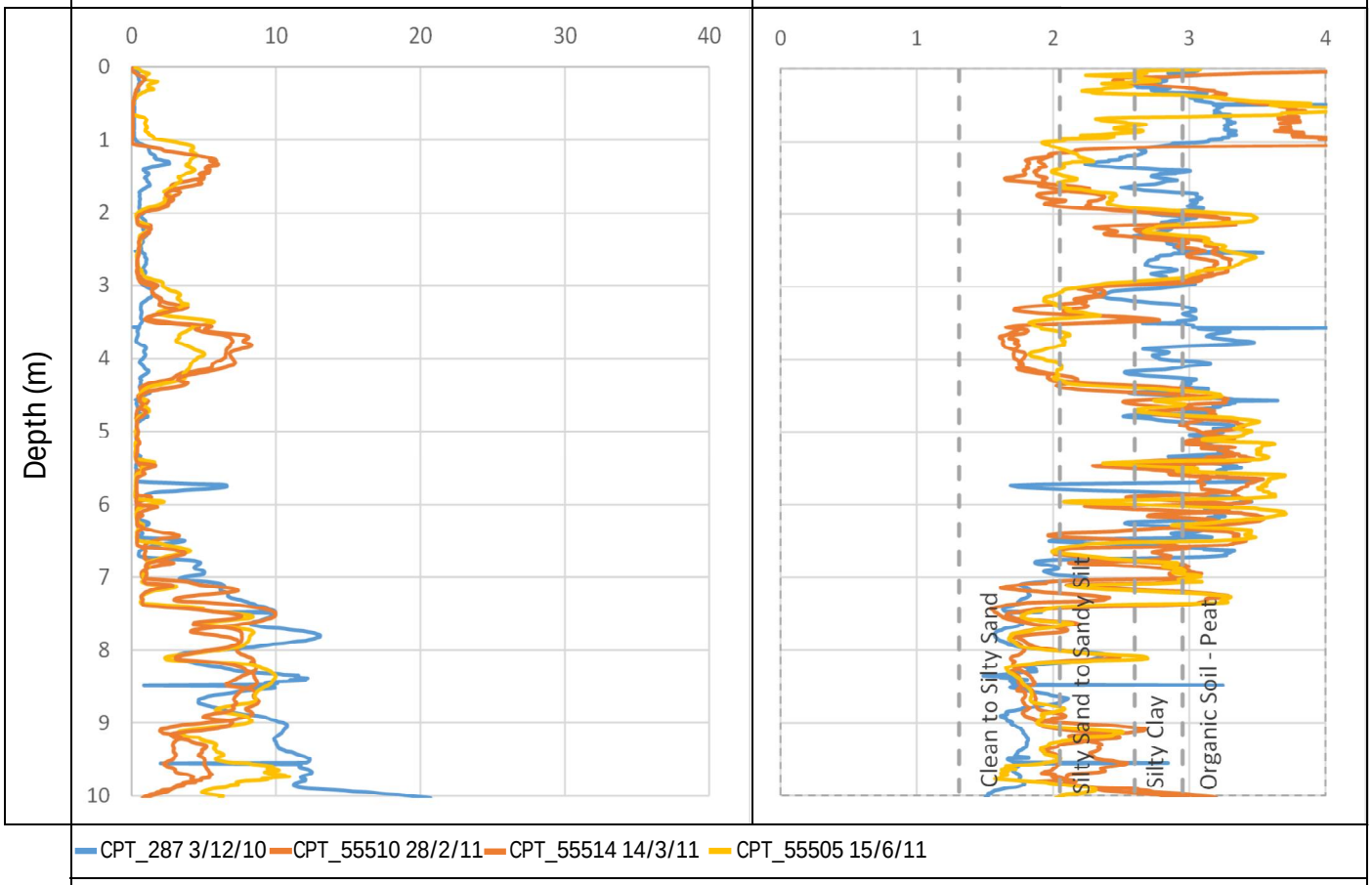
## CPT Set AI



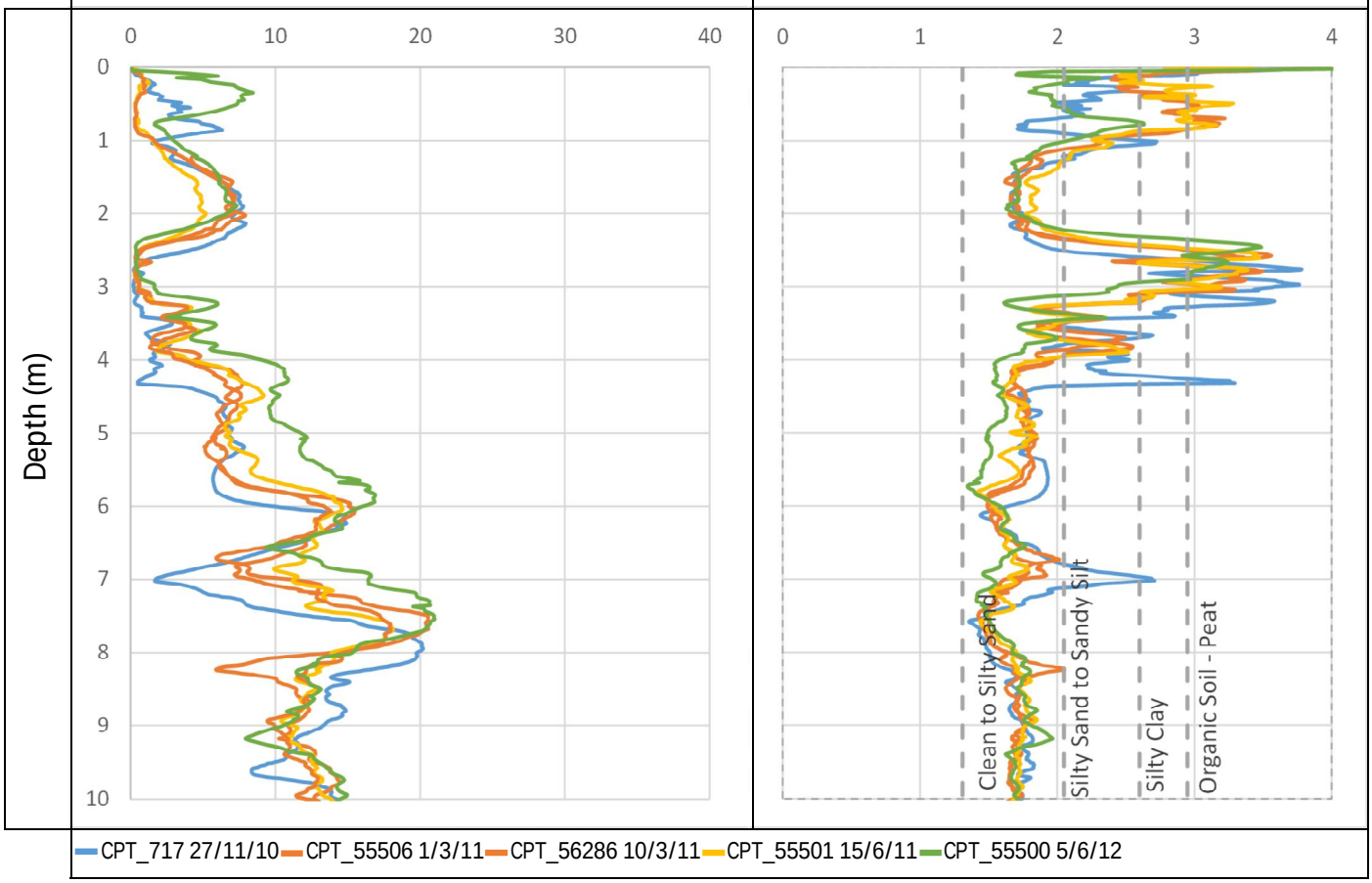

## CPT Set AJ



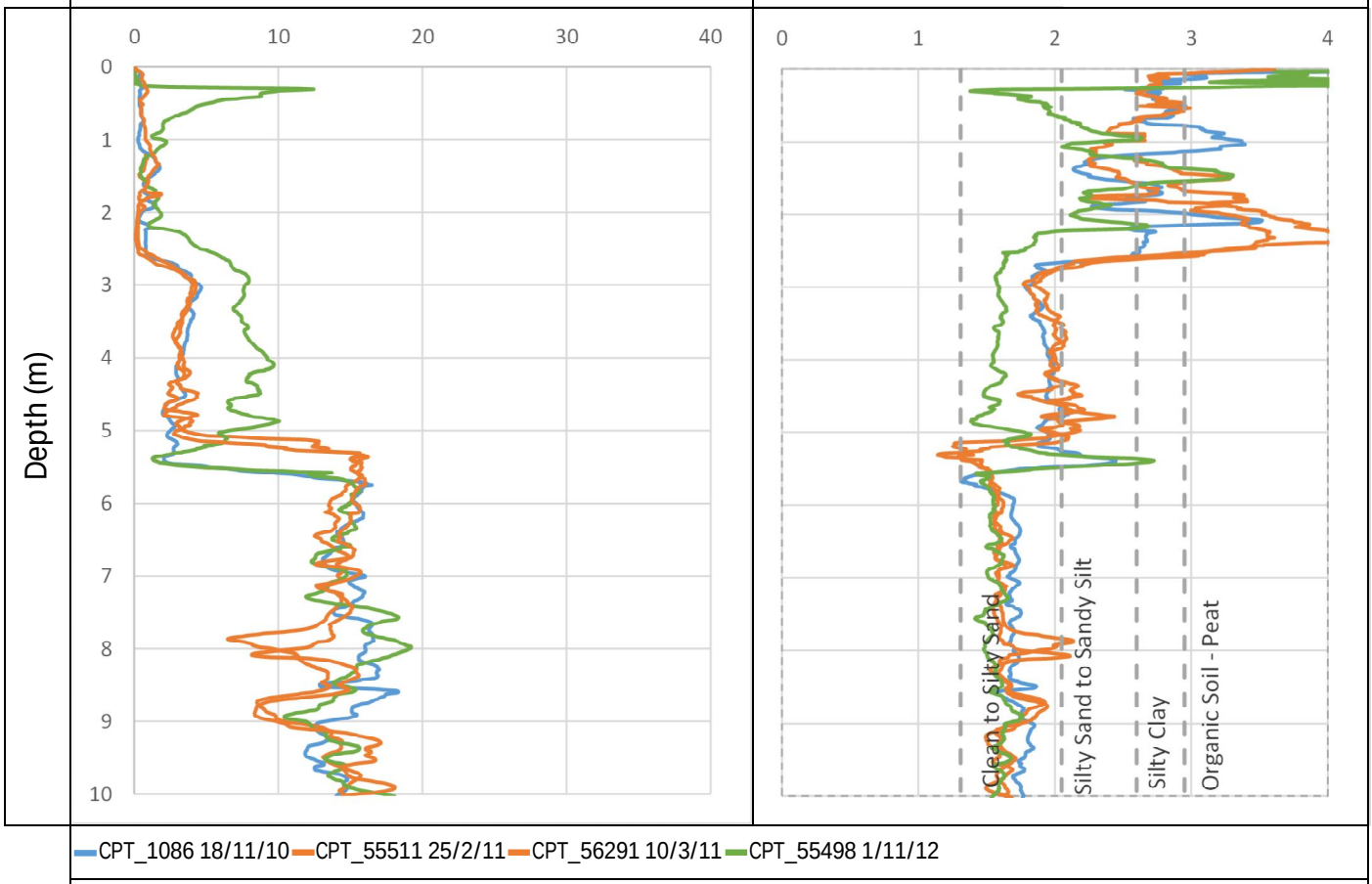
## CPT Set AK



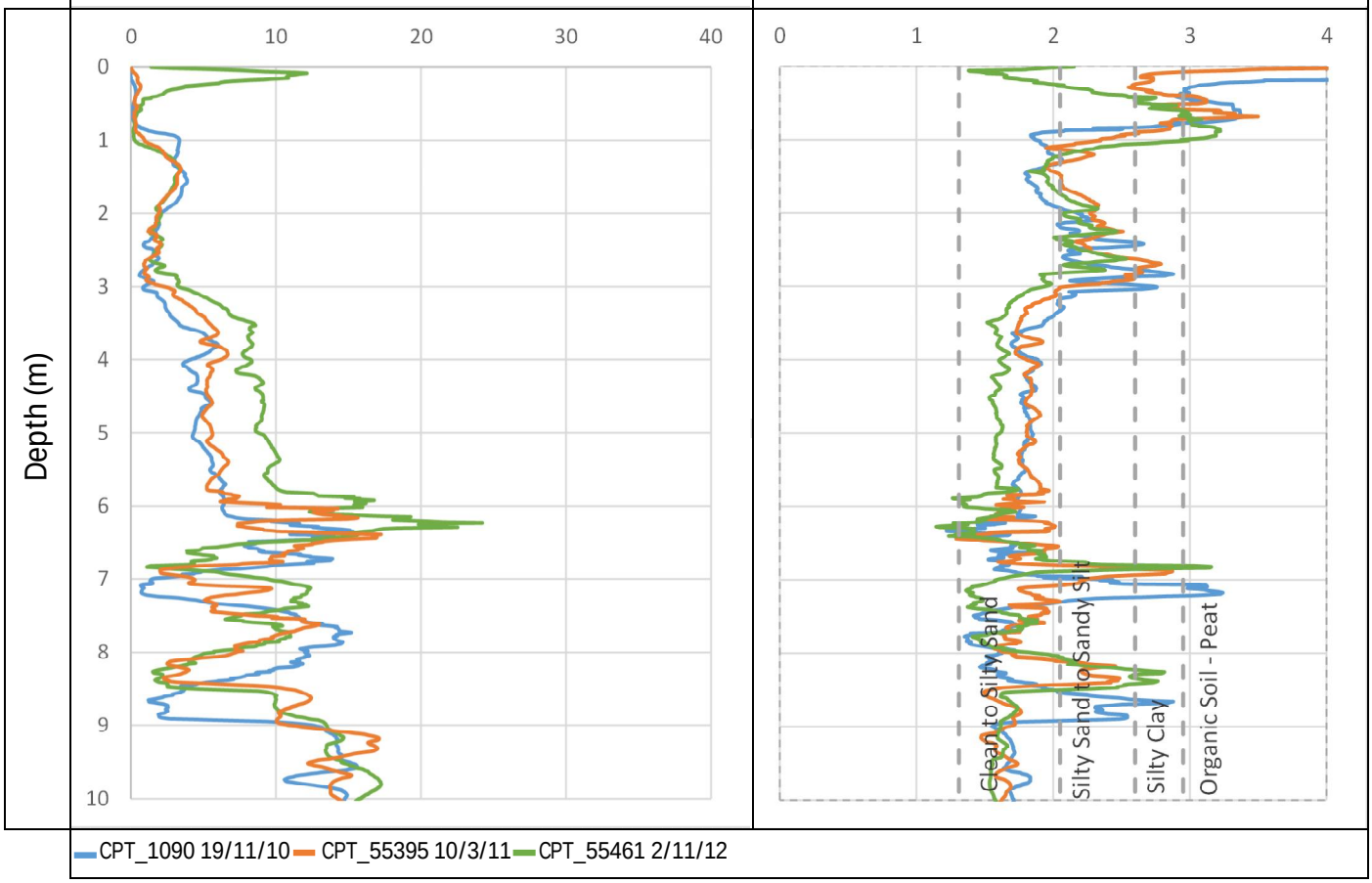

## CPT Set AL



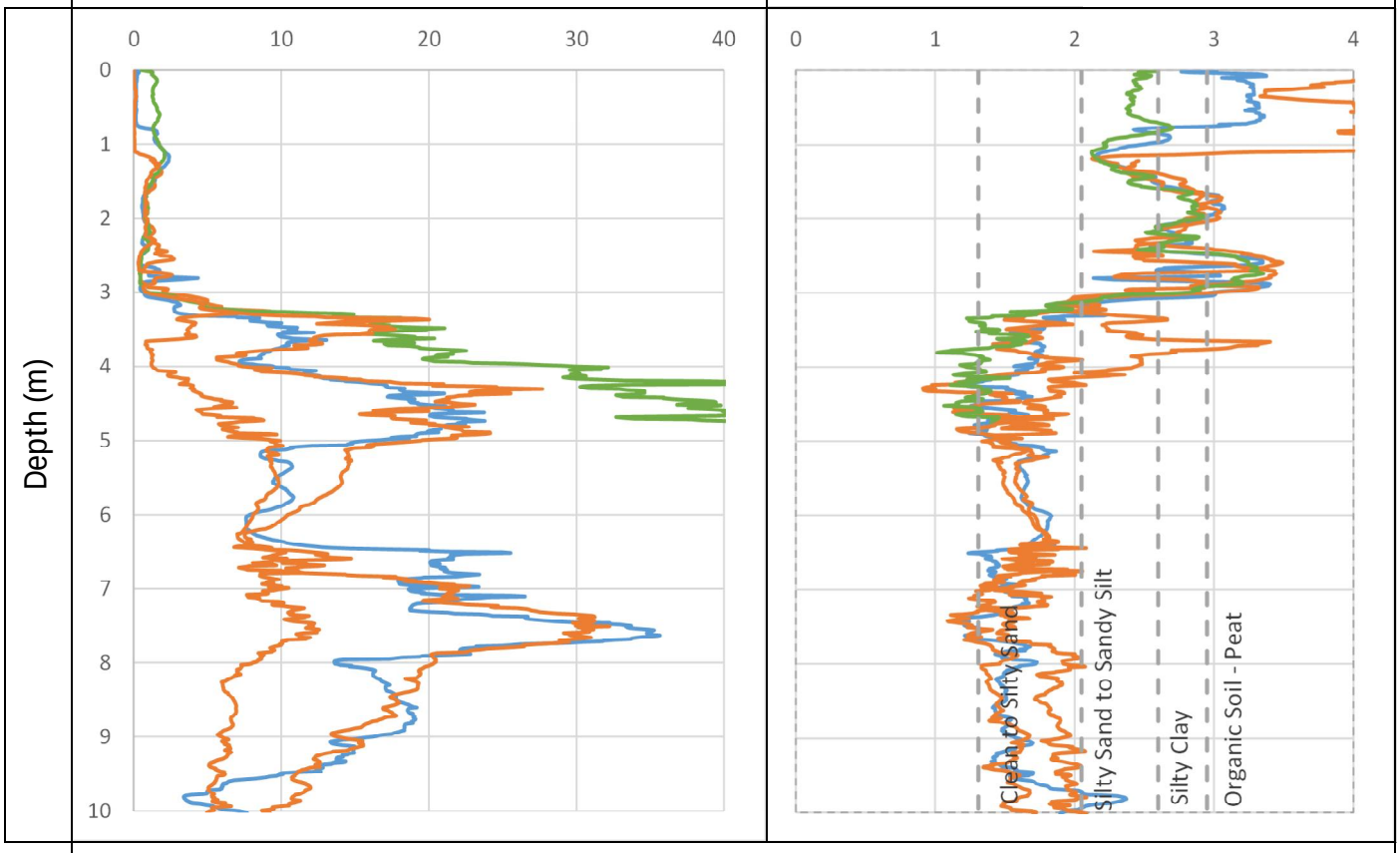
## CPT Set AM




## CPT Set AN



## CPT Set AO




## CPT Set AP