2.4 Hydrogeological Investigations

2.4.1 Aim

- To obtain basic, high quality data on the transmissivity, hydraulic conductivity and hydraulic heads in the sedimentary rocks and the weathered granite.

2.4.2 Work performed

Hydraulic tests: Pulse, slug, and pumping tests, the latter with water sampling, were carried out in a predefined sequence (Figure 27) in each interval tested to confirm reproducibility of the hydraulic parameters obtained. The test intervals were selected in rock facies representative of each sedimentary formation previously defined [6]. The testing shows the correlation between the characteristics of geology such as grain size, structure, lithology, cohesion and weathering in sedimentary rocks and those of hydrogeology such as hydraulic conductivity and head. The test intervals and packer locations were decided based on the results of drilling fluid monitoring, core description, BTV and geophysical/fluid logs; packer locations were optimised in order to seal the test intervals completely.

Hydraulic tests using double packers were performed in eight intervals (Table 4):

- Main part and basal conglomerate of the Akeyo Formation in MSB-2 and 4,
- Main part of the Toki Lignite-bearing Formation in MSB-2,
- Weathered zone in the Toki Granite in MSB-2 and 3, and
- NNW fault in MSB-3.

Single packer hydraulic tests with water sampling were conducted (Table 4):

- Above the unconformity, immediately after drilling to either the middle of the basal conglomerate of the Toki Lignite-bearing Formation or the uranium mineralised zone in MSB-2 and 4, to acquire hydraulic and hydrochemical data only from the sedimentary rocks and distinct from the granite.
- In the Toki Granite, little or no weathered zone is developed in the granite intersected by MSB-1 and 4; hydraulic tests were performed in the fresh granite to acquire hydraulic and hydrochemical data.

Calliper logging was performed after every 30 m of drilling. When significant enlargement of borehole had occurred in the Akeyo Formation in MSB-2, 3 and 4, drilling was temporarily stopped and hydraulic testing was immediately performed.

Pulse and slug injection tests were conducted in three intervals of low hydraulic head (Toki Granite in MSB-1, basal conglomerate of the Akeyo Formation and the Toki Lignite-bearing Formation in MSB-4).

Fluid logging: Spinner, electromagnetic and heat-pulse flowmeter logging in steady, and pumping or injection states were performed to identify water-conducting features. Conventional temperature logging was also performed to determine main inflow/outflow points. Because the significant inflow/outflow point present at about 20 m depth in MSB-2 could possibly affect the deeper measurements, fluid logging in MSB-2 was performed with pumping from below the 20 m depth to exclude any adverse effect.

Table 4 Summary of hydraulic testing and groundwater sampling in MSB boreholes

Borehole	Test No.	Test intervals: Drilling Depth (mabh) Top	Drilling Depth (mabh) Bottom	Vertical Depth (mbgl) Top	Vertical Depth (mbgl) Bottom	Geological Descriptions	Objectives*	Packer Configuration	Test Sequence**	Remarks
MSB-1	1	196.2	201.0	-	-	Fresh Toki Granite	T,S,H	Single	INF-PSR-PI1-SI1-SIS1-SI2-SIS2-PI2-DEF	Injection state
MSB-2	1	19.0	67.5	-	-	Main part, Akeyo Formation	T,S,H	Double	INF-PSR-PI-SW1-SWS1-SW2-RW1-RW2-RWS-PW-DEF	
	2	69.0	77.5	-	-	Basal conglomerate, Akeyo Formation	T,S,H	Double	INF-PSR-PW1-PW2-SW1-SWS1-SW2-RW1-RW2-RWS-PW3-DEF	
	3	79.0	130.5	-	-	Main part, Toki Lignite-bearing Formation	T,S,H,W	Double	INF-PSR-PW1-SW1-SWS1-PW2-SW2-RW1-RW2-WS-RWS-PW3-DEF	
	4	132.0	154.0	-	-	Basal conglomerate, Toki Lignite-bearing Formation	T,S,H,W	Single	INF-PSR-PW1-SW1-SWS1-RW-WS-RWS-PW2-DEF	
	5	171.5	175.5	-	-	Weathered zone, Toki Granite	T,S,H,W	Double	INF-PSR-PW1-SW1-SWS1-RW-WS-RWS-PW2-DEF	
MSB-3	1	87.0	93.0	82.2	87.9	NNW fault	T,S,H	Double	INF-PSR-PW1-SW-SWS-PW2-DEF	
	2	178.5	181.5	169.0	171.9	Weathered zone, Toki Granite	T,S,H	Double	INF-PSR-PW1-SW/SWS-PW2-DEF	
MSB-4	1	15.5	62.0	-	-	Main part, Akeyo Formation	T,S,H	Double	INF-PSR-SW1-SI-SIS-SW2-INF-PI-DEF	injection state
	2	63.5	76.5	-	-	Basal conglomerate, Akeyo Formation	T,S,H	Double	INF-PSR-PI1-SI-SIS-PI2-DEF	injection state
	3	78.0	91.0	-	-	Main part, Toki Lignite-bearing Formation	T,S,H	Single	INF-PSR-PW1-SW1-SWS1-SW-SW2-SWS2-PW2-DEF	
	4	95.5	99.0	-	-	Fresh Toki Granite	T,S,H,W	Single	INF-PSR-PW1-SW1-SWS1-SW2-RW1-RWS1-RW2-RWS2-RW-WS-RWS-PW2-DEF	

* T: transmissivity
S: storativity
H: hydraulic head
W: water sampling

** INF: packer inflation
PSR: static pressure recovery
PW: pulse withdrawal
PI: pulse injection
SW: slug withdrawal
SWS: pressure recovery after slug withdrawal
SI: slug injection
SIS: pressure recovery after slug injection
RW: constant rate withdrawal
RWS: pressure recovery after constant rate withdrawal
WS: groundwater sampling during RW phase
DEF: packer deflation

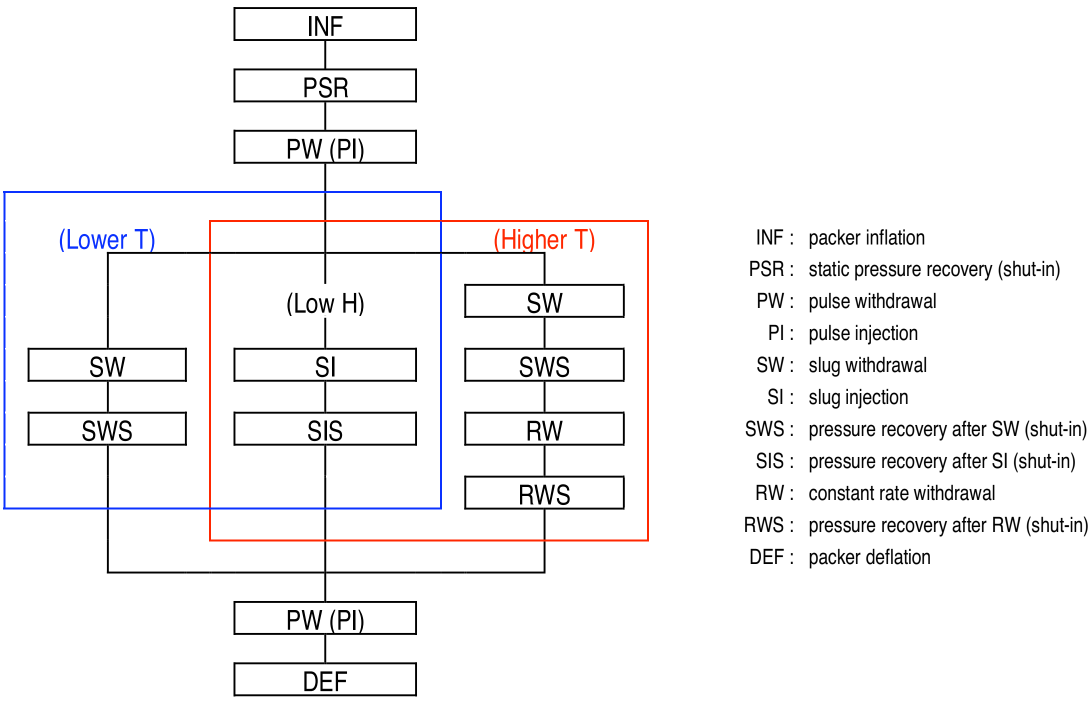

Figure 27 Test sequence options for hydraulic tests

2.4.3 Results

Hydraulic test:

- Best estimates of hydraulic conductivities and hydraulic heads are shown in Figures 28, 29, 30 and 31, Table 5 and Appendix II.
- The hydraulic conductivities of the sedimentary rocks and the granite in all boreholes, ranging from 10^{-6} to 10^{-8} ms^{-1}, are almost the same as those in DH-2 [7], but generally higher than in the Shobasama-site, the Tono Mine area and the Regional Hydrogeological Study area [6, 7] (Figure 32).
- Hydraulic conductivity of the NNW fault intersected by MSB-3 was determined to be 9.25 x 10^{-9} ms^{-1}, which is lower than conductivity in the other test intervals. The NNW fault is therefore assumed to be a potentially hydraulic barrier to groundwater flow in the sedimentary rocks.
- Hydraulic heads in the main part of the Akeyo Formation are 40 to 50 metres higher than in the deeper parts in MSB-2 and 4.
- Hydraulic head distributions in MSB-2 and DH-2 [7] have the same tendency (Figure 33).
- Hydraulic head distributions below the basal conglomerate of the Akeyo Formation in MSB-2 and below the main part of the Akeyo Formation in MSB-4 are almost hydrostatic.
- Although the hydraulic conductivity values at the bottom of the sedimentary rocks are about two orders of magnitude higher than the values for the top of the granite in MSB-2 (See Table 5), the hydraulic heads in the sedimentary rocks are only about 1 to 2 metres lower than in the granite immediately below.

Fluid logging:

- Most anomalies identified were at lithological boundaries and in conglomerates in each borehole (Figures 28, 29, 30 and 31). Water-conducting features were defined at depths where distinct fluid logging anomalies were identified, that is, in proximity to fractures observed in both BTV images and core descriptions or in unconsolidated coarse clastic layers.

2.4.4 Evaluations

- Basic, high quality data was acquired on the transmissivity, hydraulic conductivity and hydraulic heads in the planned test intervals in the sedimentary rocks and the weathered granite.
- A general understanding of the hydraulic head distributions in the MIU Construction Site has been established from the MSB investigations.
- Hydraulic parameters determined from the hydraulic testing, together with the long-term monitoring data will provide a basis for the construction of hydrogeological models.

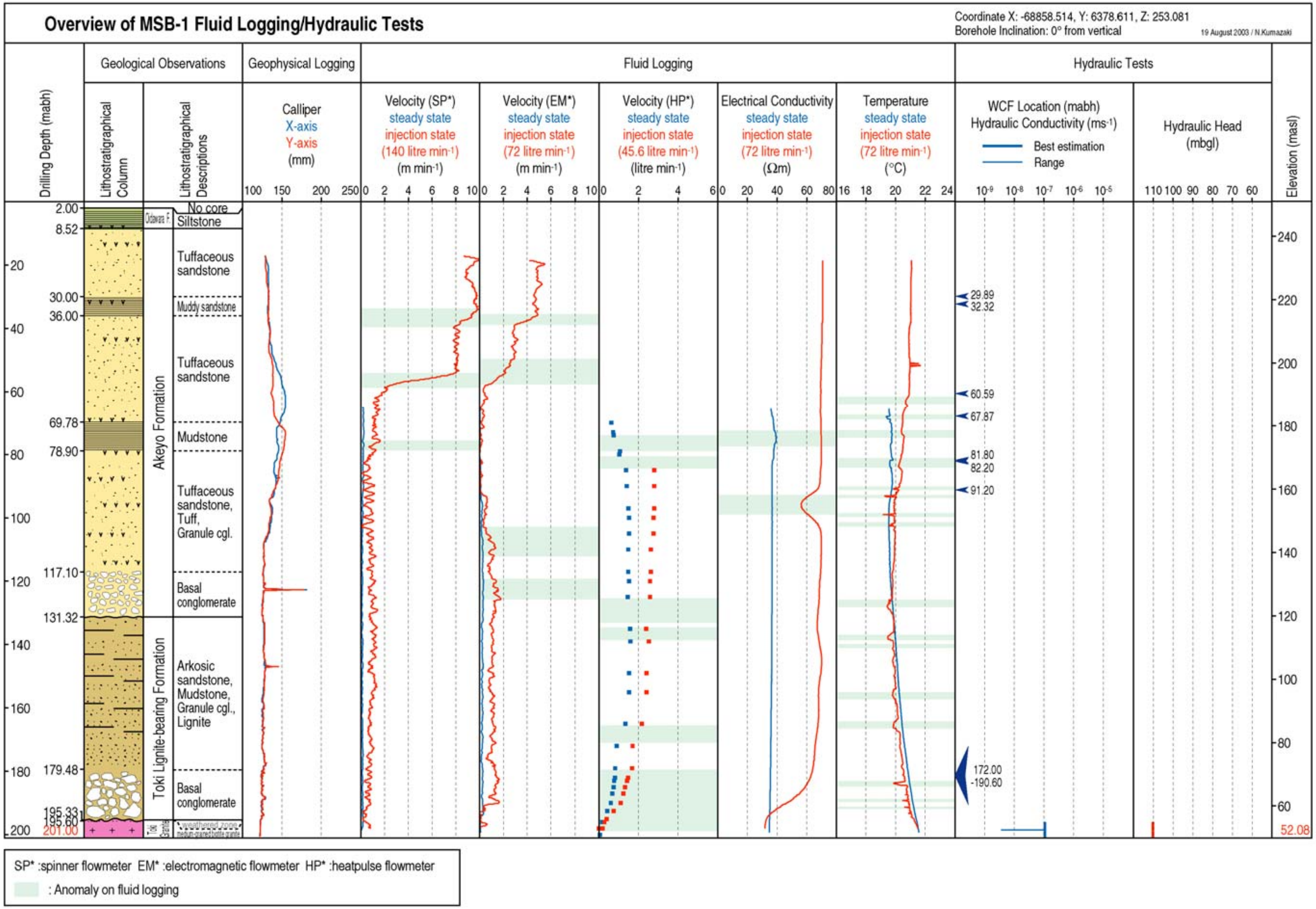

Figure 28 Overview of MSB-1 fluid logging/hydraulic tests

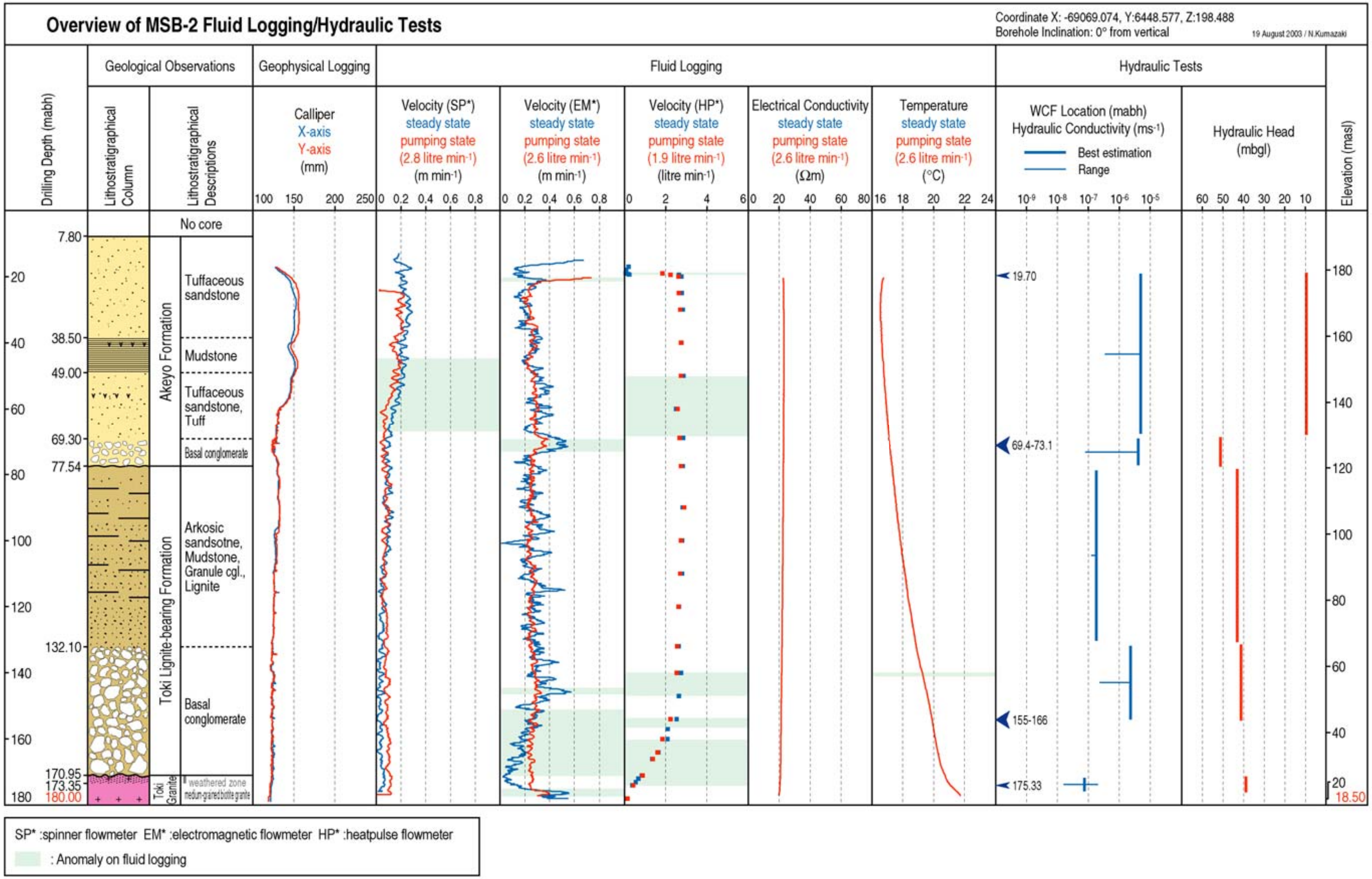

Figure 29 Overview of MSB-2 fluid logging/hydraulic tests

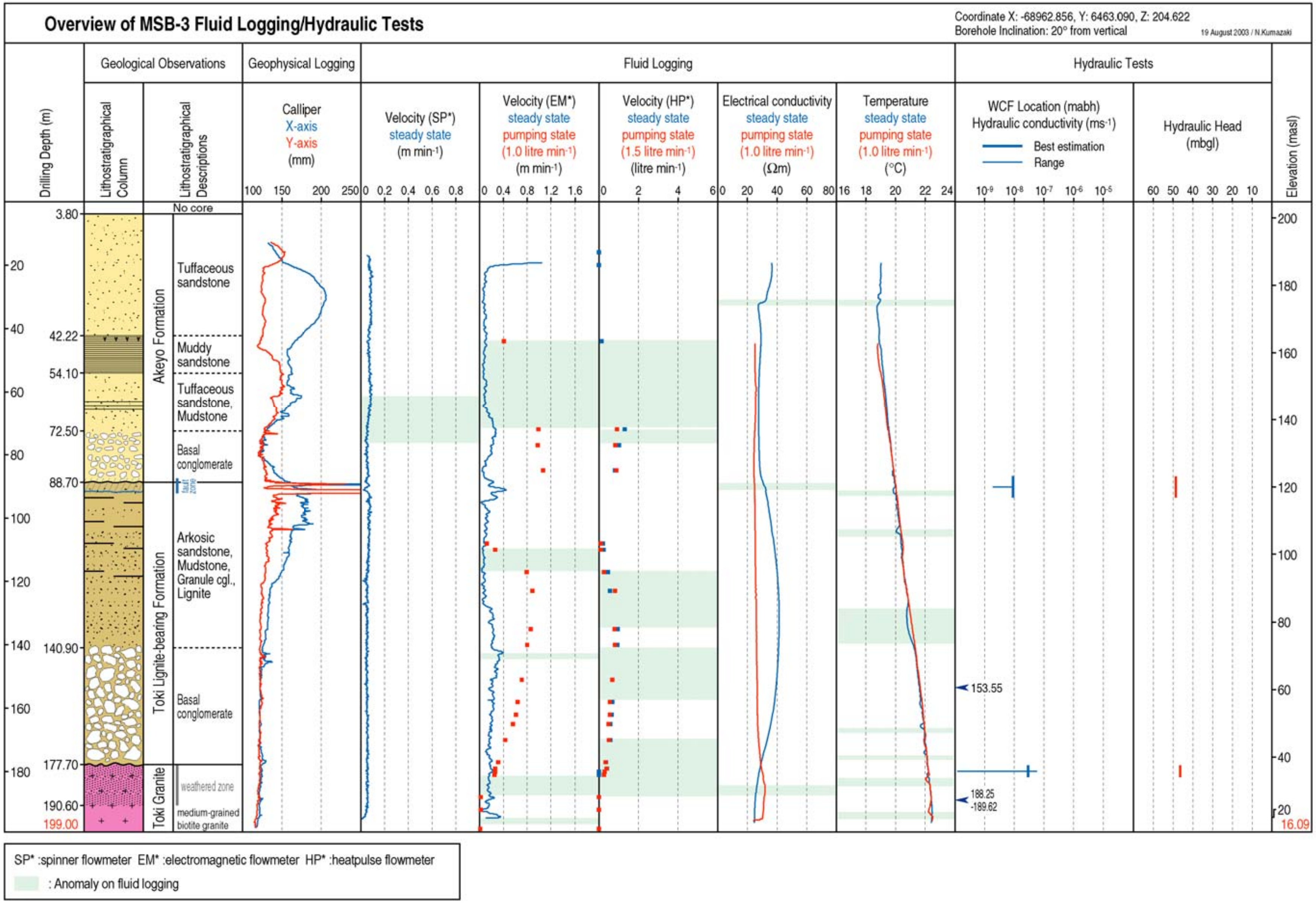

Figure 30 Overview of MSB-3 fluid logging/hydraulic tests

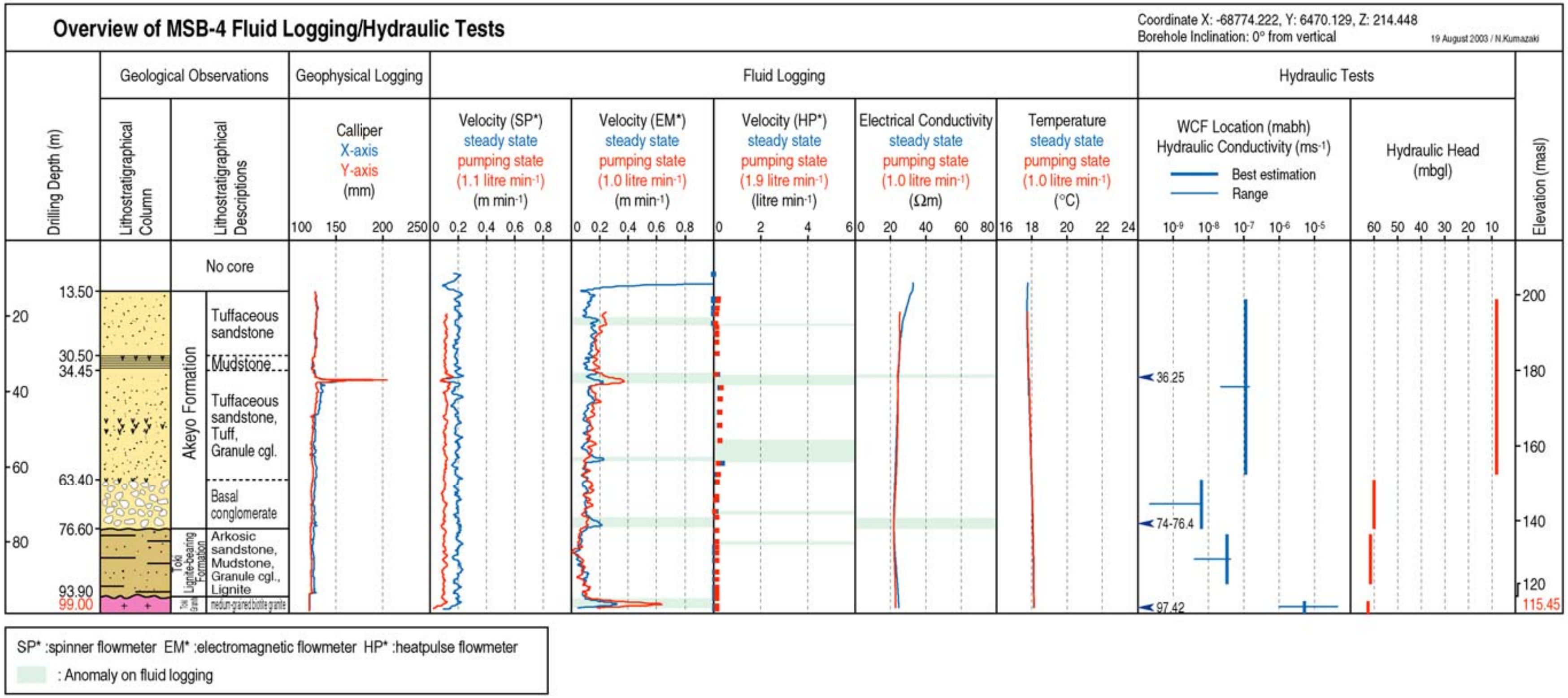

Figure 31 Overview of MSB-4 fluid logging/hydraulic tests

Table 5 Results of hydraulic test evaluation

Geology		Hydraulic Conductivity (ms^{-1})	Hydraulic Head (masl)	Borehole
Akeyo Formation	Main part	4.95×10^{-6}	189.0	MSB-2
		1.13×10^{-7}	206.0	MSB-4
	Basal conglomerate	4.02×10^{-6}	147.4	MSB-2
		6.25×10^{-9}	154.5	MSB-4
Toki Lignite-bearing Formation	Main part	1.84×10^{-7}	155.4	MSB-2
		3.30×10^{-8}	153.1	MSB-4
	Basal conglomerate	2.32×10^{-6}	157.4	MSB-2
Toki Granite	Weathered zone	7.61×10^{-8}	159.6	MSB-2
		2.95×10^{-8}	158.2	MSB-3
	Fresh granite	1.08×10^{-7}	153.0	MSB-1
		5.10×10^{-6}	152.0	MSB-4
NNW fault		9.25×10^{-9}	156.0	MSB-3

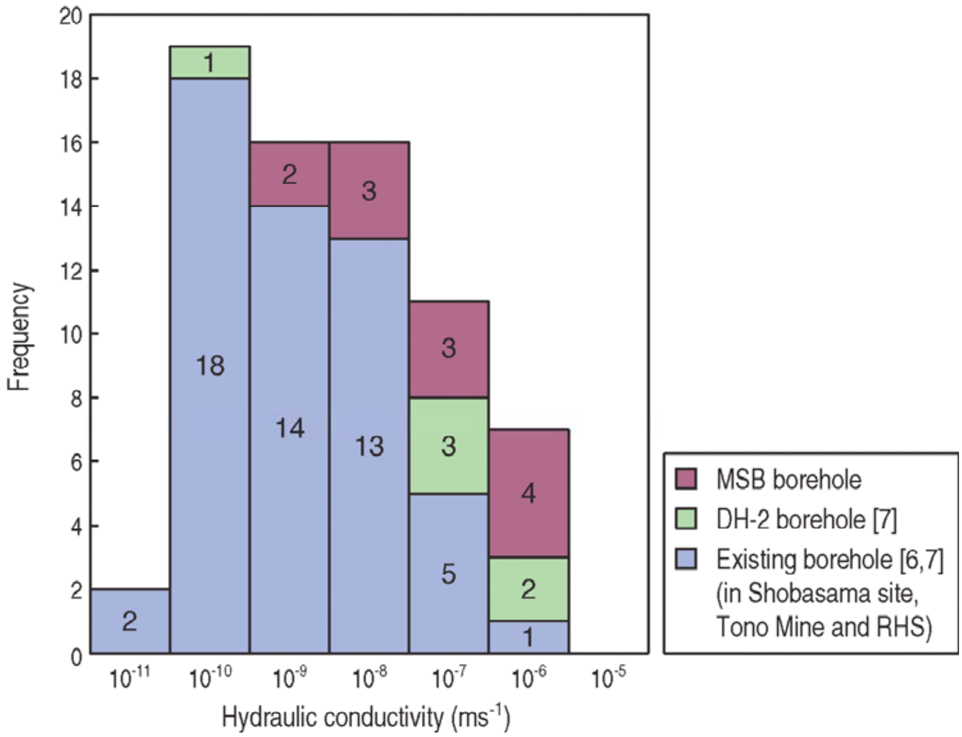

Figure 32 Comparison of hydraulic conductivity in MSB and existing boreholes

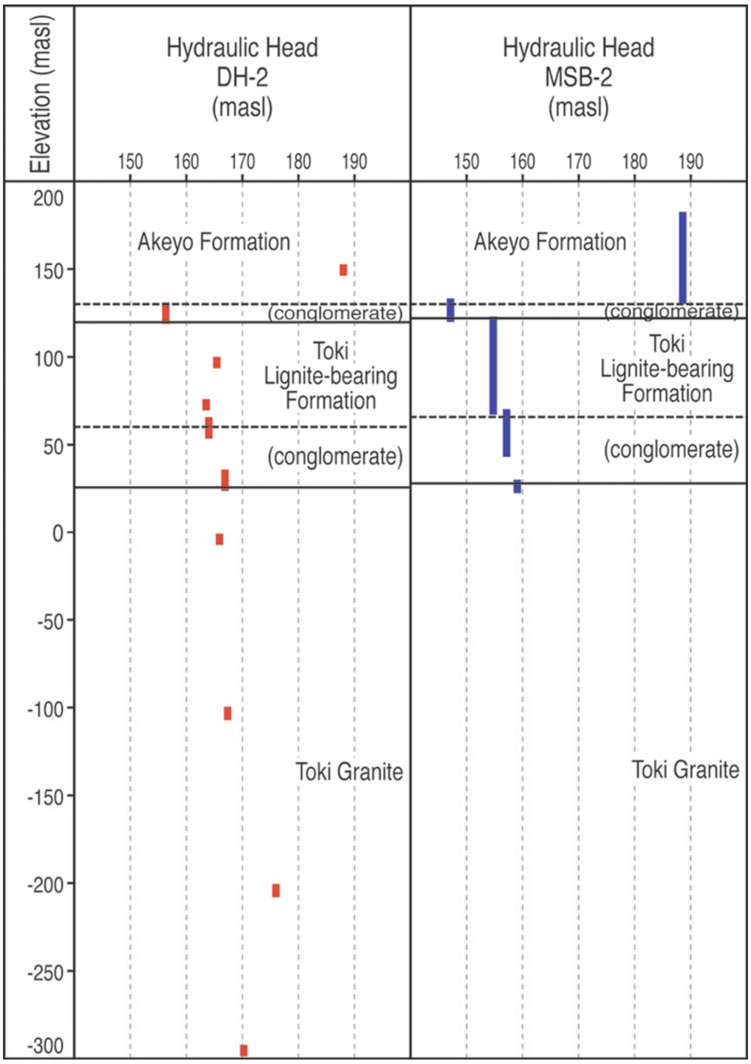

Figure 33 Hydraulic head distributions in DH-2 and MSB-2

2.4.5 Lessons learned

- If the hydraulic conductivity and head of a test interval is too low to perform a pumping test, such as was the case in MSB-1 and 4, a pulse or slug injection test can be done.
- Hydraulic conductivity of the basal conglomerate of the Akeyo Formation determined by pumping after the installation of the MP System^{TM} in MSB-4, was two orders of magnitude higher than the conductivity determined with the injection tests in MSB-4 (6.25×10^{-9}, Table 5). This difference presumably resulted from sludge accumulation in the pore spaces of the sedimentary rocks, which temporarily caused a reduction in transmissivity in the section during injection testing. Therefore, if a hydraulic test in an injection state is conducted in soft rocks similar to this site, it is necessary to flush the borehole wall as cleanly as possible.
- Significant inflow or outflow points in a borehole can affect the fluid logging measurements at greater depth. Therefore, it is advisable to try to exclude or diminish the effects or the influence of such anomalous flow by applying other methods (*e.g.* electrical conductivity logging) capable of accurately detecting anomalies in these situations.