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Oskarshamn site investigation

Borehole: KSH01A

Determination of P-wave velocity, transverse borehole core

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Norwegian Geotechnical Institute

November 2003

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Summary

The Norwegian Geotechnical Institute has carried out P-wave measurements on drill cores from borehole KSH01A at Simpevarp in May 2003. Sixty three P-wave velocity measurements have been carried out from a total of 903 m of core.

The results from the P-wave velocity measurements show a consistent pattern down to about 590 m depth with maximum velocities between 6000–6250 m/s and a low anisotropy ratio of between 1 to 1.04. From 590 m to 810 m the maximum velocities are between 5750–6000 m/s with a low anisotropy ratio of between 1.02 to 1.08, with a few measurements with lower velocities or higher anisotropy. Below 810 m there is a wide variation in velocities and anisotropy. The trend of the maximum velocity reduces with depth to under 5000 m/s with some values as low as 4150 m/s. The anisotropy ratio is also very variable between 1.00 and a maximum value of 1.16 though it is generally less than 1.10.

The foliation was weakly developed or not identifiable over large sections of the core and, in these areas, the orientation of the principal velocities could not be identified. In those sections where the foliation direction could be identified (300–500 m and below 800 m depth) there is no consistent or preferred orientation of the principal velocities with respect to the foliation direction.

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1 Introduction

The Norwegian Geotechnical Institute (NGI) has carried out P-wave velocity measurements on cores from borehole KSH01A at Simpevarp in Sweden in accordance with SKB Activitetsplan AP 400-03-23 (SKB internal controlling document).

The work was carried out by Panayiotis Chryssanthakis and Paweł Jankowski during the period 5^{th} – 8^{th} May 2003 in accordance with SKB's method description MD 190.002 version 1.0 (SKB internal controlling document).

2 General information

2.1 Description of the test specimens

Sixtythree core specimens of length ca 200–500 mm and diameter about 50.0 mm were selected from borehole KSH01A while the complete length of the borehole (depth 100 m – 1003 m) was displayed on the racks in the core shed at Simpevarp. These specimens represent the granite, granodiorite, vulcanite found over most of the length of the borehole. The specimens were selected together by NGI and Rolf Christiansson representing SKB.

The depths used to describe the location are those marked on the core and core boxes at the time. Detailed description of the specimens is available from the detailed core log by SKB. At the time of sampling, the core had been exposed to the atmosphere at room temperature for an extended period and may be presumed to be air-dried, though no measurements of the moisture content were made.

2.2 Equipment

The measurements were conducted using Panametrics Videoscan transducers with a natural frequency of 0.5 MHz. These were mounted in a special frame to hold them in contact with the core. Special wave guides, metal shoes with a concave radius similar to the core, were installed between the transducers and the core. The equipment was designed and constructed specially for this contract by NGI, based on the information presented in SKB report entitled Detection of Anisotropy by Diametral Measurements of Longitudinal Wave Velocities on Rock Cores by /Andreas Eitzenberger, 2002/. The equipment set up is shown in Figure 2-1. The apparatus for measuring acoustic P-wave travel time is shown on Figure 2-2.

Figure 2-1. *NGI's equipment set up for measuring acoustic P-wave travel time transverse borehole core.*

Figure 2-2. *Detail of NGI's apparatus for measuring acoustic P-wave travel time transverse borehole core. The aluminium cylinder for calibration of the device is on the left.*

A strong sine-wave pulse at the natural frequency of the transducers was used as the acoustic signal source. The arrival of the signals was measured using a PC with a high speed data acquisition board and software to emulate an oscilloscope (see previous work by /Chryssanthakis and Tunbridge, 2003/). The time pick for the first break was taken as the beginning of the first transition, i.e. the point where the received signal first diverges from the zero volts line. In order to provide consistent interpretation of the time pick, one operator made all the interpretations. The time pick could be measured with a precision better than 0.01 µs. The instrumentation was calibrated using a cylinder of aluminium of known acoustic velocity of the same diameter as the core. Several measurements were taken each day on the calibration piece to check operation of the system.

A thick honey was used as a coupling medium as this proved to be one of the most effective medium and was easily removed by washing without damaging or contaminating the cores.

2.3 Test method

Tests were made at 30º intervals around the core, starting at 0º parallel with the foliation. The cores were all oriented such that successive measurements were made clockwise looking down the borehole (see Figure 2-3). The cores were marked by attaching a piece of self-adhesive tape that had been previously cut to the appropriate length and marked up with the locations for the tests. These marks were then transferred to the core with permanent a marker. The cores may thus be checked at any time to ascertain the location and orientation of the tests.

Each test sample comprised a minimum of two consecutive determinations of acoustic pulse travel time at each of six locations around the core (at 0º, 30º, 60º, 90º, 120º and 150º) at one cross section. The seating of the transducers and application of the coupling medium was adjusted in cases where there was a significant difference between the time picks, and additional measurements were made until two similar time picks were obtained. The average of the two measured time picks was recorded.

As the travel time includes a number of other factors such as travel through the wave guides, time pick method, and delay due to the oscilloscope triggering on the rising part of the sine-wave, the determination of the true travel time was calibrated using an aluminium cylinder with known P-wave velocity. The correction factor determined in the calibration tests was subtracted from all the measurements on the rock cores.

The diameter of the core was measured and the P-wave velocity determined by dividing the diameter (in mm) by the travel time (in µs) and multiplying by 1000 to obtain the velocity in m/s.

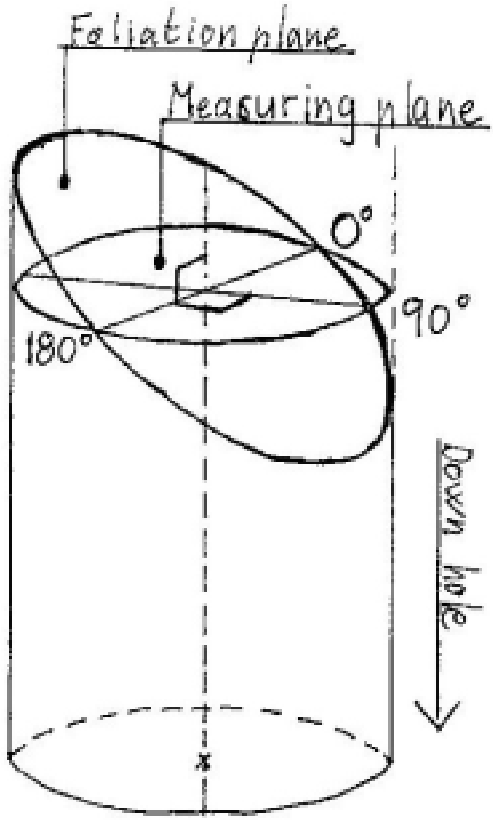

Figure 2-3. *Orientation of measurements.*

Analysis

Since the acoustic velocity is dependant on the elastic properties of the material the results were analysed similarly to determining the stress or strain tensor in the material. In this case the velocity in the orientation θ is given by:

$$V_\theta = V_x\cos^2\theta + V_y\sin^2\theta + 2\cdot V_{xy}\sin\theta\cos\theta \qquad (1)$$

A simple regression analysis of the six measurements was used to determine the values of V_x, V_y, and V_{xy} (where the X-axis is parallel with the foliation where identifiable).

These values were used to model the complete velocity profile around the core.

The magnitude and orientation of the principal velocities was determined from the Eigen values and vectors of the 2D tensor matrix:

$$\begin{vmatrix} V_x & V_{xy} \\ V_{xy} & V_y \end{vmatrix} \qquad (2)$$

3 Results

3.1 Summary of results

The results of measured values of travel time and velocity for all the tests are presented Table 3-1, and the velocity and anisotropy are shown diagrammatically against depth in Figures 3-1 and 3-2.

The results of calculated principal velocities and their orientations are shown diagrammatically against depth in Figures 3-3 to 3-5. The anisotropy of the principal velocities and the orientation are also shown for selected data with clearly defined foliation and high anisotropy against depth in Figures 3-6 to 3-8.

The results of calibration determinations for the system are shown in the Appendix. The results are also reported to SICADA (FN 175).

3.2 Discussion

Accuracy and Repeatability

Calibration tests on an aluminium cylinder indicated a variation of ±0.03 μs in determination of the time pick. Some of this variation may be explained by temperature variations, thickness of coupling medium and seating of the shoes. Similar variations may be expected from the measurements on the cores.

Generally there is a good fit between the measurements and the best fit line which suggests that random type errors are relatively small. Typically in the whole series of tests the deviation between the measured value and the model fit is about 0.7%, with a maximum average error of 1.3%.

Previous work /Chryssanthakis and Tunbridge, 2003/ concluded that:

- the repeatability of the reported results for velocities is probably in the region of ±100–200 m/s;
- the error in the orientation of the principal velocities is probably in the region of ±10°–20° where the anisotropy ratio is greater than 1.1 with greater errors below this limit;
- errors in determining the anisotropy ratio and orientation are partly mitigated by the redundant data and regression analysis and it is considered that the error in the anisotropy ratio is in the region of ±0.02–0.05;
- the magnitude of the anisotropy suggests that errors of this magnitude will not have a large effect on the determination of the anisotropy ratio and orientation, and this appears to be confirmed by the generally consistent results obtained.

No additional work has been done to quantify the errors. The deviation between the model fitted to the data and the measured data is slightly better than in the previous work which may be attributable in part to increased operator experience. The results of determinations in the upper part of the borehole are also very consistent. It is therefore concluded that the measurement errors are probably somewhat less than those determined in the previous work. More work needs to be done to quantify the accuracy and repeatability errors in the measurements.

Conclusions

The results from the P-wave velocity measurements show a consistent pattern down to about 590 m depth with maximum velocities between 6000–6250 m/s and a low anisotropy ratio of between 1 to 1.04. From 590 m to 810 m the maximum velocities are between 5750–6000 m/s with a low anisotropy ratio of between 1.02 to 1.08, with a few measurements with lower velocities or higher anisotropy. Below 810 m there is a wide variation in velocities and anisotropy. The trend of the maximum velocity reduces with depth to under 5000 m/s with some values as low as 4150 m/s. The anisotropy ratio is also very variable between 1.00 and a maximum value of 1.16, though it is generally less than 1.10.

The foliation was weakly developed or not identifiable over large sections of the core and, in these areas, the orientation of the principal velocities could not be identified. In those sections where the foliation direction could be identified (300–500 m and below 800 m depth) there is no consistent or preferred orientation of the principal velocities with respect to the foliation direction.

Table 3-1. Measurements of acoustic velocity, transverse core in borehole KSH01A, Simpevarp.
(orientation clockwise looking down hole, 0º is parallel with foliation where identified)

Depth	Diameter	Corrected time, mS						Velocity m/S						
		Parallel foliation			Perpendicular foliation			Parallel foliation			Perpendicular foliation			
m	mm	0º	30º	60º	90º	120º	150º	0º	30º	60º	90º	120º	150º	Anisotropy ratio
108,00	50,10	8,22	8,12	8,16	8,06	8,08	8,17	6097	6172	6141	6218	6202	6134	1,02
164,20	50,00	8,09	8,06	8,18	8,14	8,14	8,09	6182	6205	6114	6144	6144	6182	1,01
223,20	50,02	7,94	8,08	8,00	7,99	8,03	8,05	6301	6192	6254	6262	6231	6215	1,02
262,60	50,00	8,40	8,57	8,58	8,48	8,45	8,46	5954	5836	5829	5898	5919	5912	1,02
311,25	50,00	8,36	8,32	8,17	8,37	8,38	8,41	5982	6011	6122	5975	5968	5947	1,03
349,20	50,00	8,10	8,12	8,21	8,13	8,07	8,01	6175	6159	6092	6152	6197	6244	1,02
381,60	50,00	8,19	8,34	8,29	8,15	8,25	8,22	6107	5997	6033	6137	6062	6084	1,02
403,55	50,00	8,12	8,25	8,19	8,31	8,30	8,19	6159	6062	6107	6018	6026	6107	1,02
413,60	49,52	8,31	8,26	8,33	8,32	8,23	8,31	5961	5997	5946	5953	6019	5961	1,01
456,40	50,00	8,09	8,27	8,24	8,18	8,17	8,19	6182	6048	6070	6114	6122	6107	1,02
476,40	50,00	8,41	8,29	8,16	8,15	8,40	8,45	5947	6033	6129	6137	5954	5919	1,04
495,70	50,00	8,11	8,20	8,08	7,99	8,10	8,18	6167	6099	6190	6260	6175	6114	1,03
507,40	50,00	8,25	8,28	8,47	8,65	8,47	8,39	6062	6040	5905	5782	5905	5961	1,05
529,50	50,00	8,12	8,18	8,11	8,21	8,17	8,14	6159	6114	6167	6092	6122	6144	1,01
549,00	50,00	8,45	8,46	8,41	8,29	8,30	8,27	5919	5912	5947	6033	6026	6048	1,02
576,25	50,00	8,09	8,17	8,26	8,21	8,12	8,12	6182	6122	6055	6092	6159	6159	1,02
590,25	50,00	8,70	8,77	8,88	8,91	8,98	8,87	5749	5703	5632	5613	5569	5638	1,03
635,80	50,00	8,74	8,69	8,90	9,08	9,04	8,76	5722	5755	5619	5508	5532	5709	1,04
657,15	50,00	8,53	8,67	8,86	8,88	8,75	8,62	5863	5768	5645	5632	5716	5802	1,04
675,40	50,00	8,90	9,02	8,81	8,70	8,76	8,85	5619	5545	5677	5749	5709	5651	1,04
700,38	50,00	8,76	8,61	8,64	8,68	8,89	8,81	5709	5809	5789	5762	5626	5677	1,03
712,64	50,00	9,92	9,87	9,87	9,47	9,56	9,82	5041	5067	5067	5281	5231	5093	1,05
715,75	50,00	8,66	9,08	9,32	9,35	9,11	8,84	5775	5508	5366	5349	5490	5658	1,08
740,23	50,00	8,60	8,63	8,66	8,61	8,49	8,49	5815	5795	5775	5809	5891	5891	1,02
762,47	50,00	8,50	8,43	8,34	8,35	8,48	8,54	5884	5933	5997	5990	5898	5856	1,02
774,40	50,00	9,31	9,53	9,62	9,45	9,35	9,30	5372	5248	5199	5292	5349	5378	1,03
783,90	50,00	8,87	8,99	9,05	9,05	9,04	9,04	5638	5563	5526	5526	5532	5532	1,02
796,30	50,00	9,09	8,90	8,89	8,62	8,80	8,89	5502	5619	5626	5802	5683	5626	1,05
806,80	50,00	8,83	8,86	8,93	9,03	9,19	9,03	5664	5645	5600	5538	5442	5538	1,04
824,10	50,00	10,74	11,03	10,61	9,91	9,89	10,34	4656	4534	4714	5047	5057	4837	1,12
827,90	50,00	9,68	9,67	9,64	9,59	9,70	9,90	5166	5172	5188	5215	5156	5052	1,03
829,25	50,00	9,49	9,84	10,20	10,13	9,70	9,48	5270	5082	4903	4937	5156	5275	1,08
837,70	50,00	10,11	10,32	10,56	10,35	10,08	9,91	4947	4846	4736	4832	4961	5047	1,07
842,70	50,00	9,84	10,06	10,41	10,57	10,24	9,79	5082	4971	4804	4731	4884	5108	1,08
849,50	50,00	9,44	9,49	9,40	9,36	9,25	9,42	5298	5270	5320	5343	5407	5309	1,03
858,00	50,00	11,50	11,51	11,48	11,50	11,45	11,39	4349	4345	4356	4349	4368	4391	1,01
864,30	49,90	9,41	9,44	9,49	9,62	9,69	9,62	5304	5287	5259	5188	5151	5188	1,03
874,90	50,00	10,51	10,26	10,35	10,55	10,46	10,60	4758	4874	4832	4740	4781	4718	1,03
883,35	50,00	11,20	10,89	11,34	11,57	11,56	11,25	4465	4592	4410	4322	4326	4445	1,06
887,85	50,00	11,75	11,52	11,31	11,21	11,54	11,80	4256	4341	4422	4461	4334	4238	1,05
894,90	50,00	9,34	9,44	9,61	9,43	9,24	9,12	5355	5298	5204	5303	5413	5484	1,05
897,00	50,00	8,93	8,98	8,90	8,86	8,82	8,83	5600	5569	5619	5645	5670	5664	1,02
900,70	50,00	11,15	11,38	11,31	11,09	10,80	10,86	4485	4395	4422	4509	4631	4605	1,05
903,65	50,00	9,07	8,86	8,88	9,12	9,29	9,24	5514	5645	5632	5484	5383	5413	1,05
908,20	50,00	9,21	9,08	9,15	9,21	9,09	9,06	5430	5508	5466	5430	5502	5520	1,02
912,30	50,00	9,18	9,19	9,07	8,98	9,19	9,22	5448	5442	5514	5569	5442	5424	1,03
916,35	49,70	10,73	11,42	11,68	11,08	10,34	10,38	4633	4353	4256	4486	4808	4789	1,13
919,85	49,80	8,59	8,62	8,64	8,52	8,65	8,63	5799	5779	5765	5847	5759	5772	1,02
922,50	49,90	9,43	9,49	9,88	9,85	9,84	9,44	5293	5259	5052	5067	5072	5287	1,05
926,50	50,00	8,46	8,42	8,45	8,46	8,47	8,40	5912	5940	5919	5912	5905	5954	1,01
929,80	49,80	10,20	9,68	9,64	9,88	10,13	10,41	4883	5146	5167	5042	4917	4785	1,08
935,80	49,80	9,71	9,63	9,76	9,88	10,04	10,01	5130	5173	5104	5042	4961	4976	1,04
940,80	49,90	10,40	10,58	10,26	10,16	10,23	10,22	4799	4717	4865	4912	4879	4884	1,04
945,50	49,90	10,16	10,38	10,43	10,08	9,66	9,59	4912	4808	4785	4951	5167	5205	1,09
949,80	50,00	8,48	8,45	8,48	8,52	8,55	8,52	5898	5919	5898	5870	5849	5870	1,01
952,45	50,00	10,75	10,60	10,19	9,80	9,83	10,29	4652	4718	4908	5103	5088	4860	1,10
956,30	50,00	10,91	10,92	10,85	11,29	12,04	11,85	4584	4580	4609	4430	4154	4220	1,11
965,25	50,00	9,85	9,95	10,02	9,87	9,74	9,64	5077	5026	4991	5067	5135	5188	1,04
969,85	50,00	10,20	10,32	10,28	10,14	10,11	10,10	4903	4846	4865	4932	4947	4952	1,02
974,10	50,00	10,24	10,28	10,50	10,77	10,60	10,43	4884	4865	4763	4643	4718	4795	1,05
991,95	50,00	10,19	10,72	11,61	11,85	11,47	10,40	4908	4665	4307	4220	4360	4809	1,16
998,40	50,00	10,04	10,06	10,28	10,28	10,31	10,27	4981	4971	4865	4865	4851	4870	1,03
1003,00	50,00	10,51	10,30	10,09	10,39	10,76	10,97	4758	4855	4956	4813	4648	4559	1,09

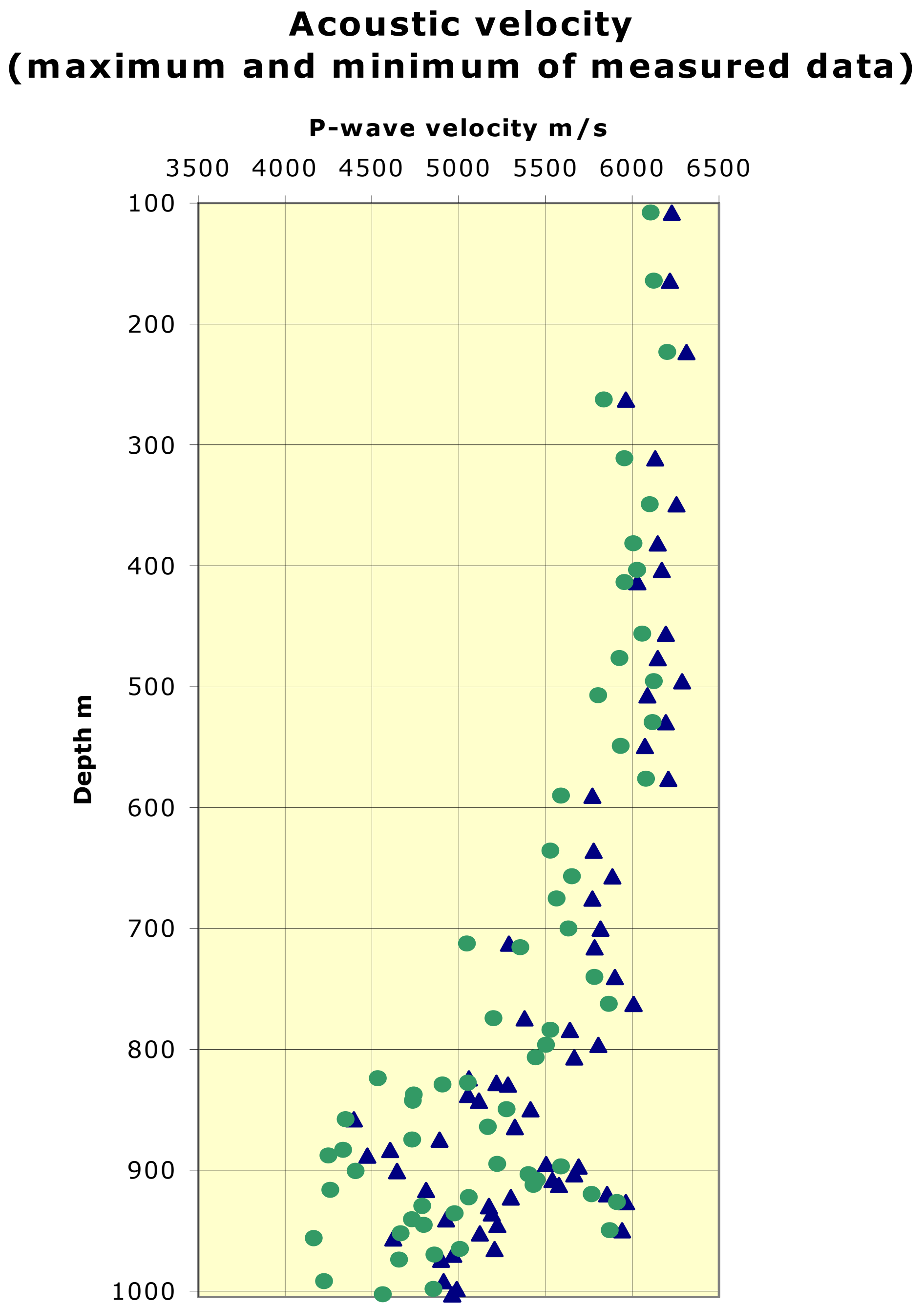

Figure 3-1. *Measured values of maximum and minimum acoustic velocities plotted against depth down borehole KSH01A.*

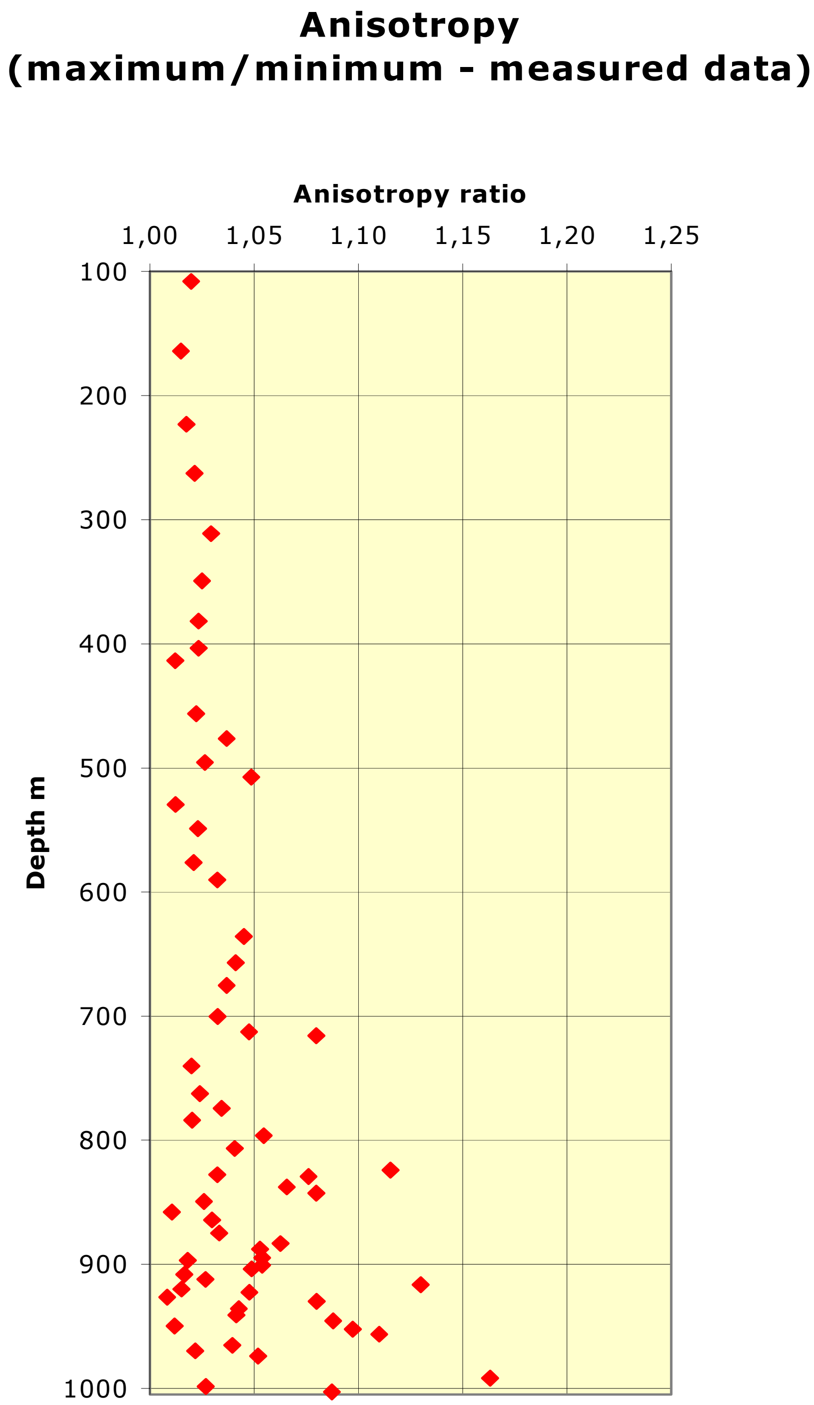

Figure 3-2. Measured values of acoustic velocities anisotropy plotted against depth down borehole KSH01A.

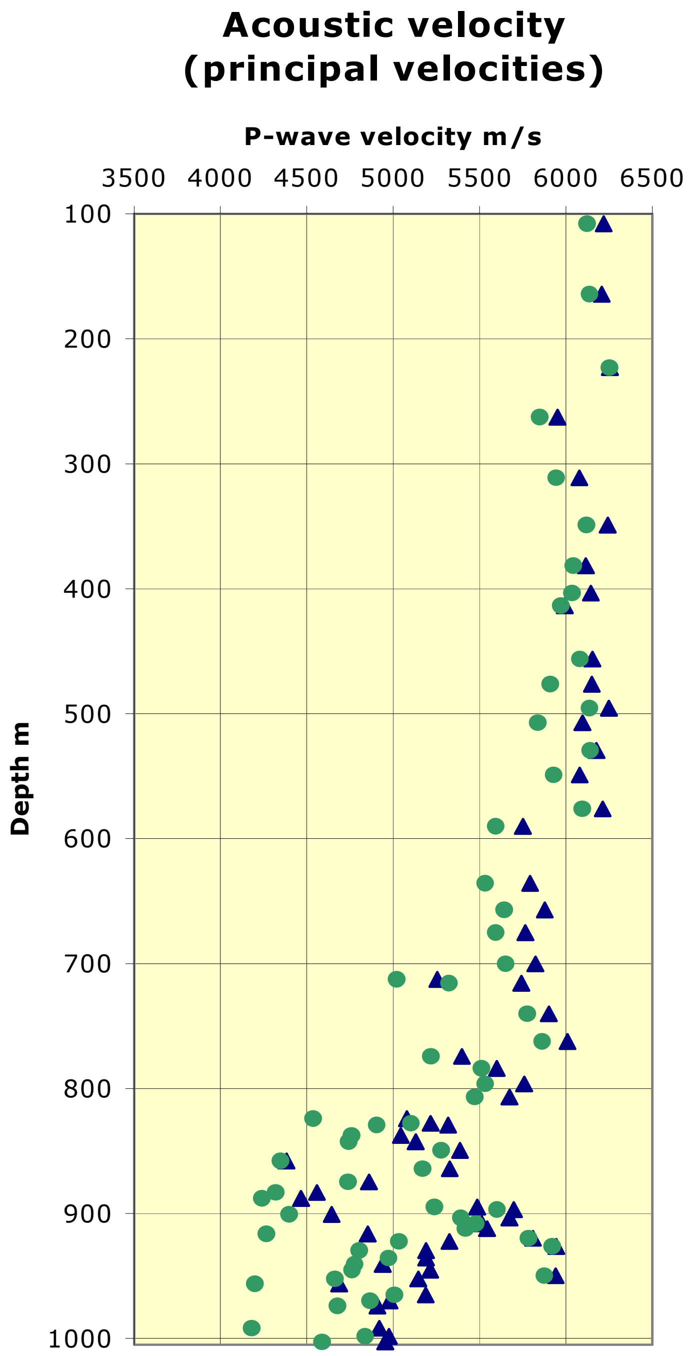

Figure 3-3. *Calculated values of maximum and minimum principal acoustic velocities plotted against depth down borehole KSH01A.*

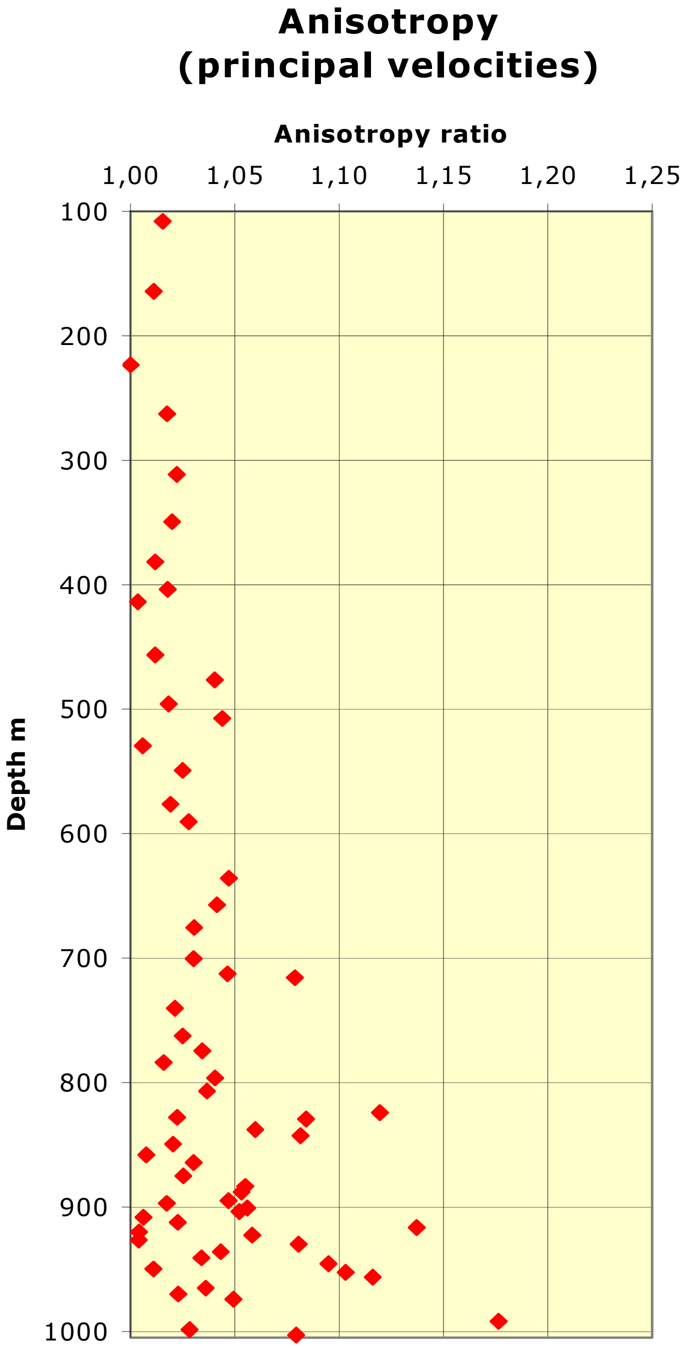

Figure 3-4. *Calculated values of maximum and minimum principal acoustic velocity anisotropy plotted against depth down borehole KSH01A.*

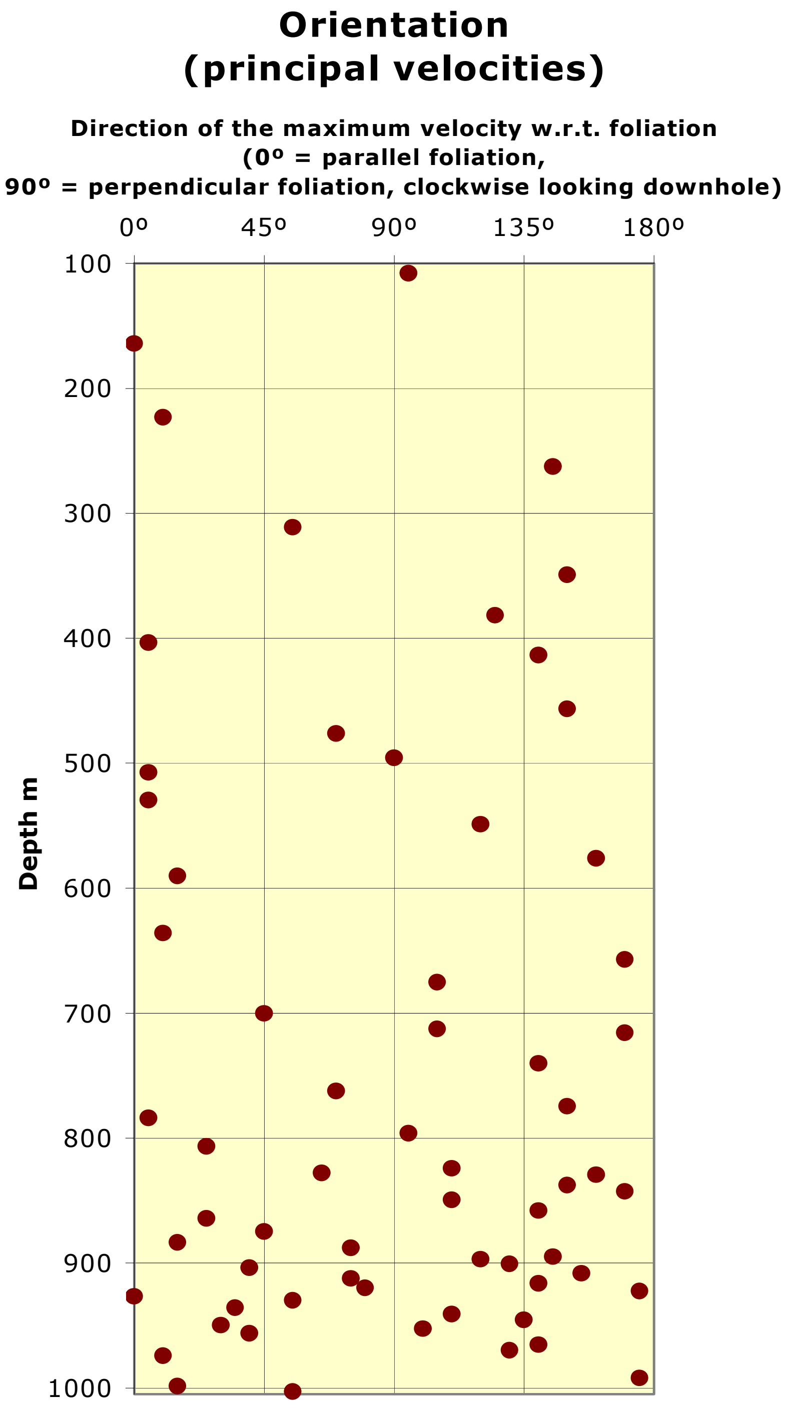

Figure 3-5. *Calculated orientation of the maximum principal acoustic velocity plotted against depth down borehole KSH01A.*

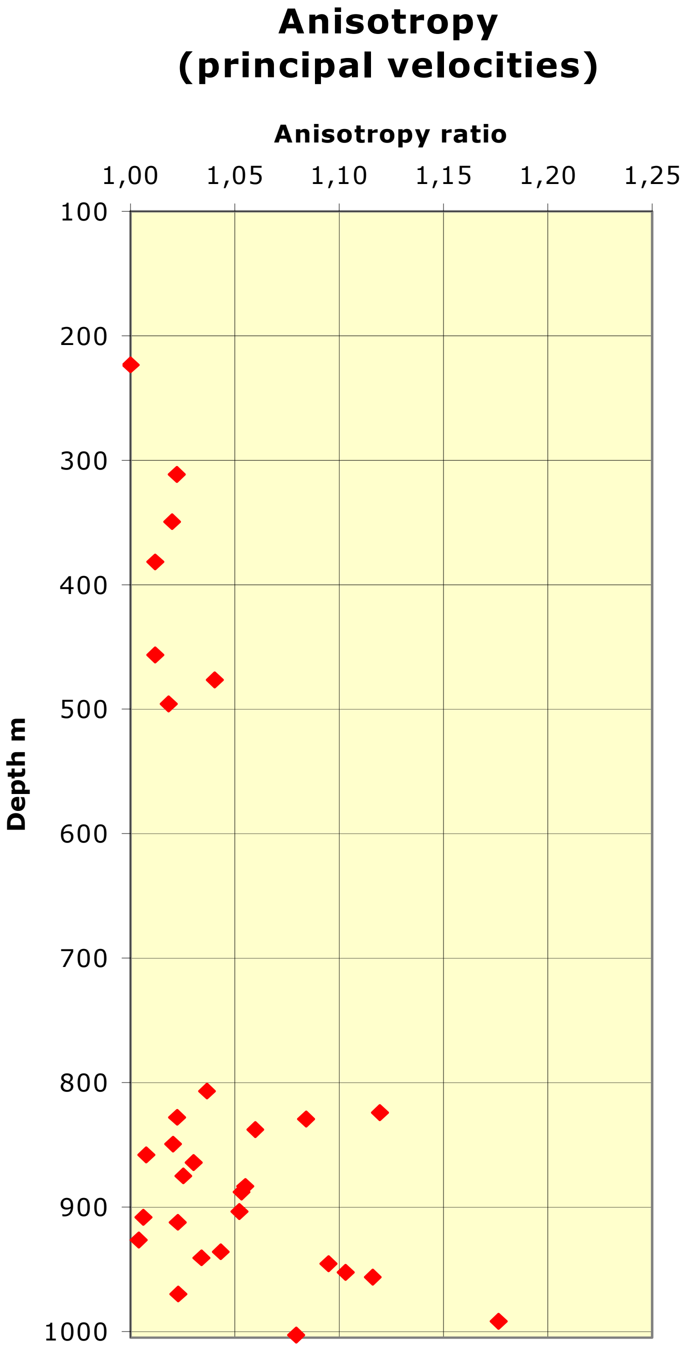

__Figure 3-6.__ Calculated values of maximum and minimum principal acoustic velocity anisotropy plotted against depth down borehole KSH01A for core with clearly identified foliation.

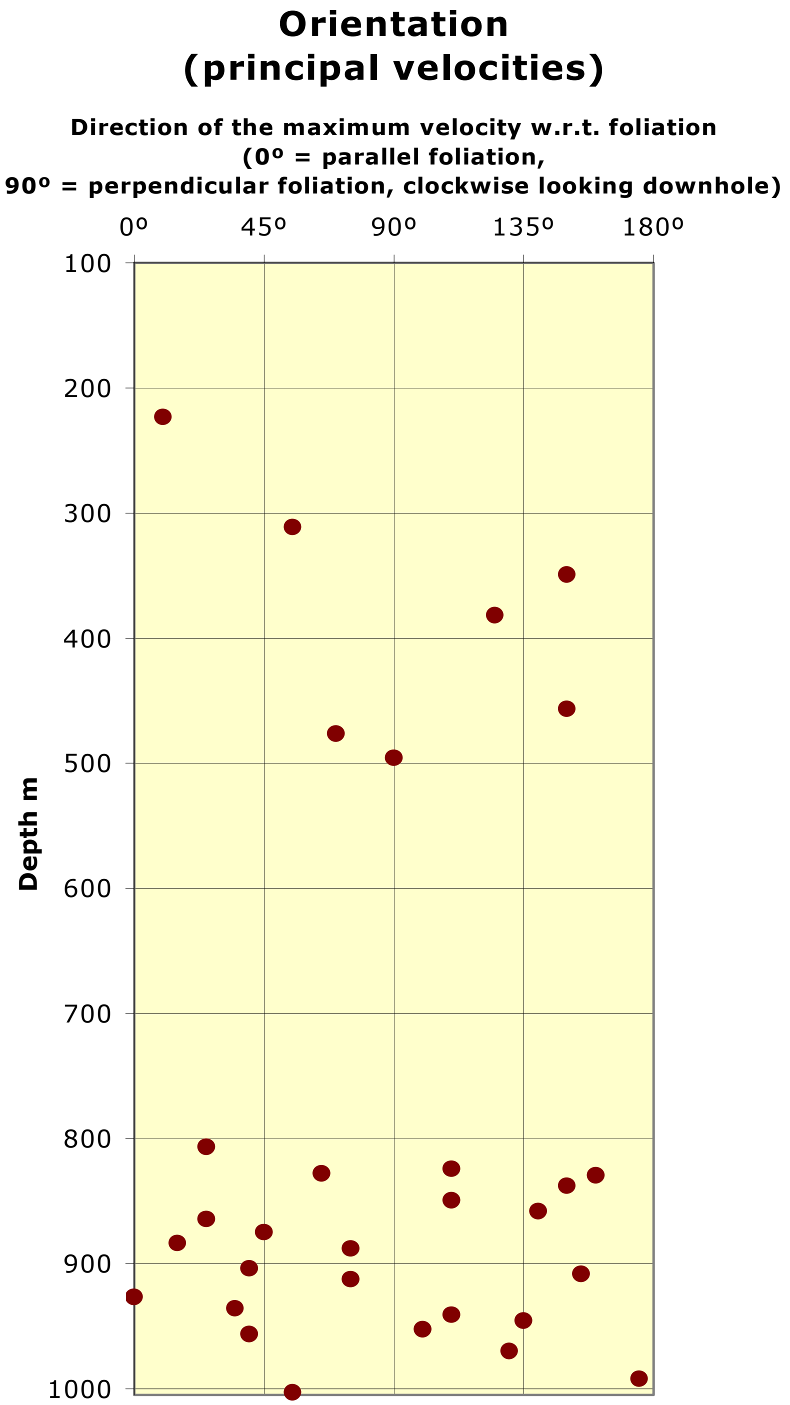

Figure 3-7. Calculated orientation of the maximum principal acoustic velocity plotted against depth down borehole KSH01A for core with clearly identified foliation.

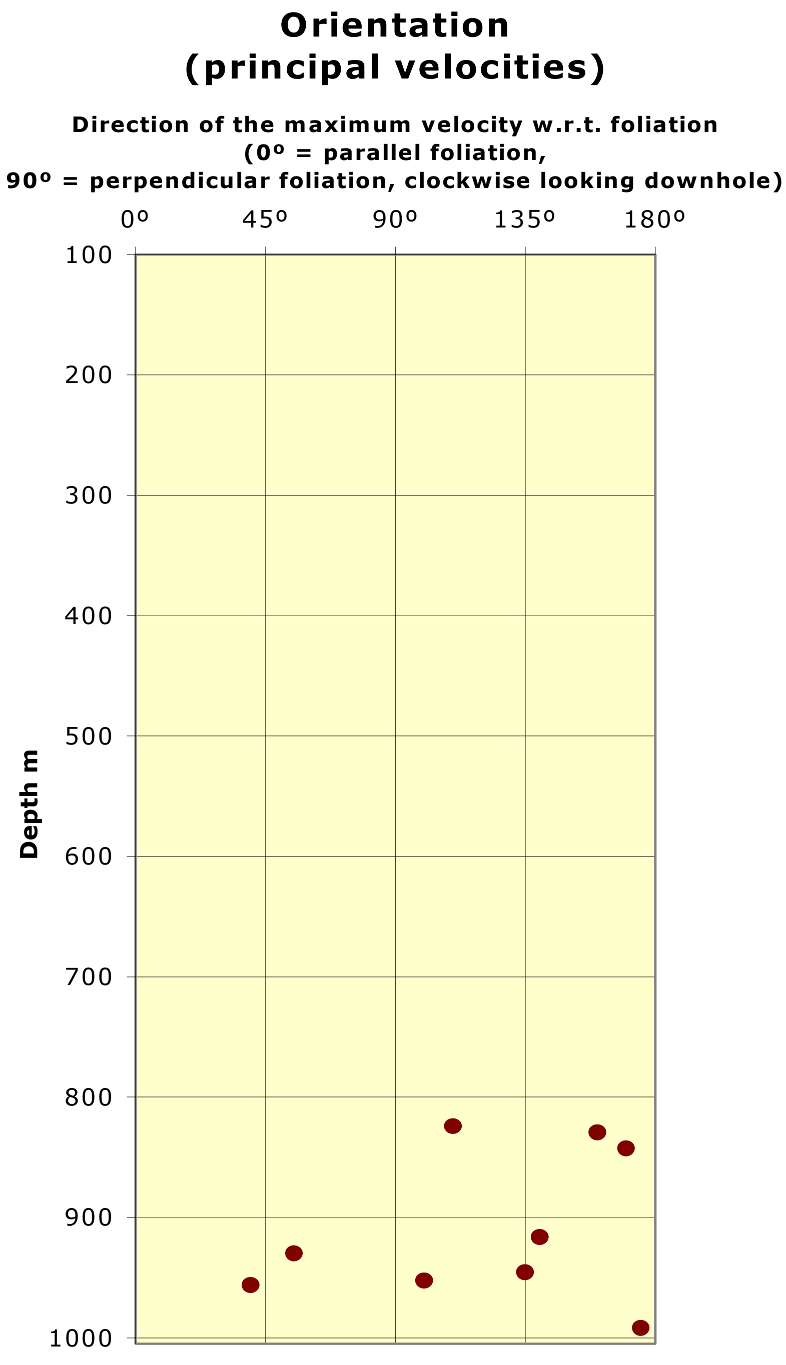

__Figure 3-8.__ Calculated orientation of the maximum principal acoustic velocity plotted against depth down borehole KSH01A for core with foliation and an anisotropy ratio of 1.08 or more.

4 References

Chryssanthakis P, Tunbridge L, 2003. Site investigation, Forsmark. Borehole: KFM 01A. Determination of P-wave velocity, transverse borehole core, NGI.

Eitzenberger, Andreas, 2002. Detection of Anisotropy by Diametral Measurements of Longitudinal Wave Velocities on Rock Cores, SKB report in press.

Appendix

Calibration measurements on aluminium cylinder diameter 50,90 mm with known velocity 6320 m/s (this page).

Data table as supplied on Excel file for SICADA database.

Calibration measurements on aluminium cylinder diameter 50,90 mm with known velocity 6320 m/s.

Date and time	Known velocity m/S	Diameter mm	Time		
			Measured µS	Calculated µS	Correction µS
2003.05.07 13:00	6320	50,9	9,23	8,05	–1,18
2003.05.07 18:30	6320	50,9	9,25	8,05	–1,20
2003.05.08 13:30	6320	50.9	9.22	8.05	–1.17
2003.05.08 14:00	6320	50.9	9.19	8.05	–1.14
2003.05.08 18:00	6320	50,9	9.19	8,05	–1,14
Average			**9.22**		**–1.16**