P-04-180

# Forsmark site investigation

# Borehole KFM03A
# Determination of P-wave velocity, transverse borehole core

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Norwegian Geotechnical Institute, Oslo

October 2003

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*Keywords:* AP PF 400-03-77, Field note no Forsmark 189, Rock mechanics, P-wave velocity, Anisotropy.

Summary

The Norwegian Geotechnical Institute (NGI) has carried out P-wave measurements on drill cores from borehole KFM03A at Forsmark, in October 2003. Sixty-five P-wave velocity measurements were performed on samples from a total of 900 m drill cores. Besides, three additional P-wave measurements were made on drill cores from borehole KFM03B.

The results from the P-wave velocity measurements show a generally consistent pattern over the whole length of the borehole with maximum velocities between 5,200–6,000 m/s and a variable anisotropy ratio of generally between 1.03 to 1.14. Six results from borehole KFM03A and B indicate somewhat lower velocities of between 5,120–5,650 m/s down to 220 m. From 220 m the maximum velocity of 5,800–6,000 m/s reduces gradually to about 5,650–5,750 m/s at 600 m with a more variable spread of values between 5,050–5,900 m/s between 400 m–524 m depth. Below 600 m the maximum velocity is relatively constant between 5,450–5,750 m/s, with values of about 5,250 m/s at about 695 m and 905 m depth, and consistent anisotropy ratios of between 1.07–1.15.

The orientation of the maximum velocity is quite variable relative to the foliation with no consistent or preferred direction, and it is neither parallel nor perpendicular to the foliation as might have been expected.

# Sammanfattning

Norges Geotekniska Institut (NGI) har under oktober 2003 utfört P-vågsmätningar på borrkärnor från borrhål KFM03A i Forsmark. Sammanlagt utfördes 65 st hastighetsbestämningar av P-vågen på kärnprover som utvalts från borrkärnor med en sammanlagd längd av 900 m. Dessa mätningar har kompletteras med tre extra P-vågsmätningar på borrkärnor från borrhål KFM03B.

Resultaten uppvisar ett konsistent mönster längs hela borrkärnelängden med en maximihastighet på mellan ca 5 200–6 000 m/s och en anisotropikvot varierande mellan 1,03 och 1,14. Sex resultat från borrhål KFM03A och B ner till 220 meters djup indikerar en lägre hastighet på mellan 5 120–5 650 m/s. Från 220 m reduceras maximihastigheten gradvis från 5 800–6 000 m/s ner till ca 5 650–5 750 m/s vid 600 m med en större spridning vid nivån 400–524 m på mellan 5 050–5 900 m/s. Under nivå 600 m är maximihastigheten relativt konstant, 5 450–5 750 m/s, med ett värde på 5 250 m/s vid 695 m och 905 m, och en anisotropikvot på mellan 1,07 och 1,15.

Maximihastighetens orientering är relativt varierande mot foliationsriktningen, utan någon konsistent eller dominerande riktning. Orienteringen är heller inte parallell eller vinkelrät mot foliationen, vilket hade förväntats.

# Contents

# 1 Introduction

The Norwegian Geotechnical Institute (NGI) has carried out P-wave velocity measurements on cores from boreholes KFM03A and KFM03B at Forsmark in Sweden in accordance with SKB Activity Plan AP PF 400-03-77, Version 1.0 (SKB internal controlling document).

The work was carried out by Panayiotis Chryssanthakis and Pavel Jankowski during the period October 6$^{th}$–9$^{th}$, 2003, in compliance with SKB's method description MD 190.002, Version 1.0 (SKB internal controlling document).

# 2 Objective and scope

The purpose of the testing is to determine the P-wave velocity transverse to the core axis. The P-wave velocity is a parameter used in the rock mechanical model which will be established for the candidate area selected for site investigations at Forsmark.

The number of tests performed and the number of joint sets are given in Table 2-1.

The results from the P-wave velocity measurements are presented in this report by means of tables, figures and spreadsheets.

**Table 2-1. Total number of P-wave velocity specimens and measurements.**

| Borehole | P-wave velocity test specimens | P-wave velocity measurements |
|---|---|---|
| KFM03A | 65 | 68 |
| KFM03B | 3 | 3 |

# 3 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 the SKB report entitled "Detection of Anisotropy by Diametrical Measurements of Longitudinal Wave Velocities on Rock Cores" /Eitzenberger, 2002/. The equipment is shown on the photograph in Figure 3-1.

Figure 3-2 shows the apparatus for measuring acoustic P-wave travel time.


***Figure 3-1.*** *NGI's equipment set-up for measuring acoustic P-wave travel time transverse the drill core.*

*__Figure 3-2.__ Detail of NGI's apparatus for measuring acoustic P-wave travel time transverse the drill 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 Figure 3-3). 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 volt line. In order to provide a consistent interpretation of the time pick, one operator (PC) made all the interpretations. The time pick was 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 made each day on the calibration piece to check the status of operation of the system.

A thick layer of honey (from a honey pot) was used, as a coupling medium as this proved to be one of the most effective of different media tested and was easily removed by washing without damaging or contaminating the cores.

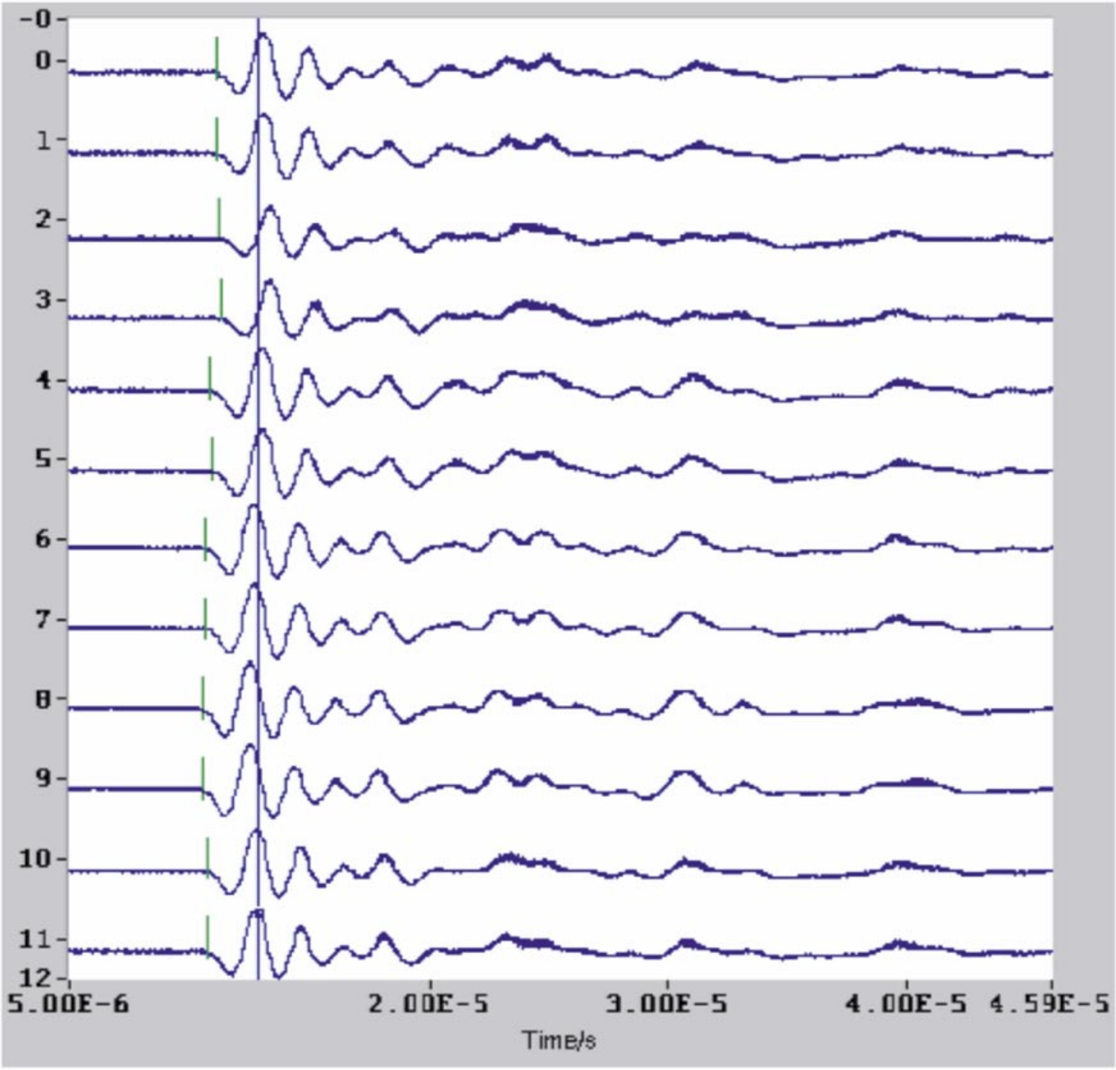



***Figure 3-3.*** *Example traces from 12 measurements of P-wave travel time transverse the drill core (two from each orientation). Time picks marked with green lines. Picture captured from NGI's oscilloscope emulation software.*

# 4 Execution

## 4.1 Sampling

Sixty-five core specimens of lengths c 200–500 mm and a diameter of about 50 mm were selected from borehole KFM03A, while the complete core length of the borehole (102 m–1,001 m) was displayed on the racks in the core shed at Forsmark. Boreholes KFM03A and B are both near-vertical and thus the vertical depth is approximately the same as the borehole length. In addition to that, three extra tests were run on drill cores from borehole KFM03B with a length of about 100 m that was also displayed on the racks (depth 5 m–101.5 m). The specimens were jointly selected by NGI and SKB.

These specimens represent the foliated granite-gneiss, granodiorite and tonalite with same veins of amphibolite and pegmatite, found over most of the length of the borehole. Geological logging of the core has previously been carried out by SKB. No detailed geological description has been attempted by NGI.

The depths used to describe the location are those marked on the core and core boxes at the time of sampling. 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.

## 4.2 Test method

Tests were made at 30° intervals around the core, starting at 0° parallel with the foliation. The cores were all oriented such that successive measurements were made clockwise looking down the borehole (see Figure 4-1). The cores were marked by attaching a piece of self-adhesive tape that had been previously cut to the appropriate lengths and marked up with the locations for the tests. These marks were then transferred to the core with a permanent 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 0°, 30°, 60°, 90°, 120° and 150°) 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 1,000 to obtain the velocity in m/s.

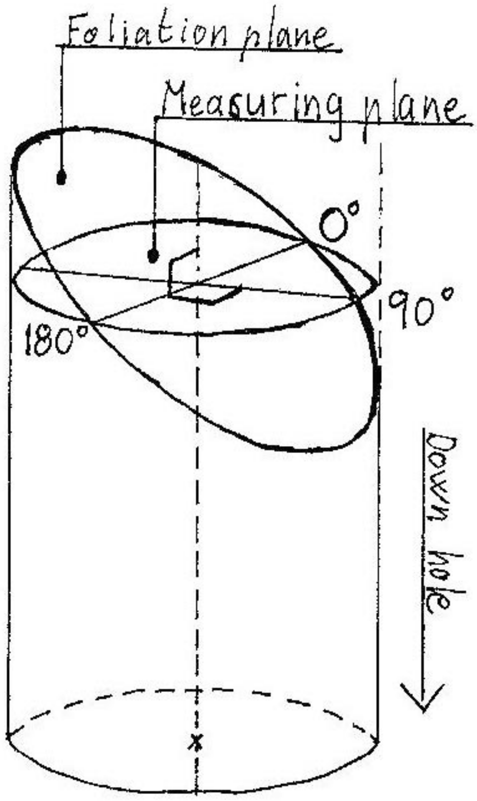



***Figure 4-1.*** *Orientation of measurements.*

### *Analysis*

Since the acoustic velocity is dependent 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 were determined from the Eigen values and vectors of the 2D tensor matrix:

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

## 4.3 Nonconformities

Tests were made at 30° intervals around the core instead of 45° intervals, which were suggested in the Method Description. This was the only nonconformity to the controlling documents.

# 5 Results

## 5.1 Summary of results

The results of the determinations of the travel time and velocity for all the tests are presented in Table 5-1, and the velocity and anisotropy are shown diagrammatically versus borehole length in Figures 5-1 and 5-2. It may be noted that two tests were performed on amphibolite samples from borehole KFM03A. These tests revealed P-wave velocities significantly higher than for the rest of the samples from the borehole, and therefore these values are not reported here.

The results of calculated principal velocity, the anisotropy and the orientations of the principal velocities are shown diagrammatically versus borehole length in Figures 5-3 to 5-5.

The results of calibration determinations for the system are shown in Appendix A. The results are also reported to SICADA (field note no Forsmark 189).

## 5.2 Discussion

### *Accuracy and repeatability*

Calibration tests on an aluminium cylinder indicated a variation of ± 0.05 μs in determination of the time pick, equivalent to differences in velocity of about ± 20 m/s. Some of this variation may be explained by variations in temperature, thickness of coupling medium and seating of the shoes. Similar variations may be expected from the measurements on the cores.

Tests on cores were repeated at two locations, 336.25 m, 670.80 m and 906.60 m, after the first series of tests were completed. These tests were repeated to investigate and determine typical values for the repeatability of velocity determinations. At 336.25 m the difference in magnitude of the velocities is about 10–100 m/s, the anisotropy ratio is the same, and there is about 5° difference in orientation. At 670.80 m the difference in magnitude of the velocities is about 20–55 m/s, the anisotropy ratio differs by 0.01 and there is no difference in orientation. Finally, at 906.60 m the difference in magnitude of the velocities is about 30–70 m/s, the anisotropy ratio is the same and there is about 5° difference in orientation.

The differences in the measured velocities on the calibration cylinder and rock cores are presumably due to temperature changes, the problems associated with seating the transducers and obtaining a good signal contact with the material and also due to the interpretation of the time pick.

Generally there is a good fit between the measurements and the best fit line which suggests that random type errors are relatively small. At 336.25 m the maximum difference was about 20 m/s, at 670.80 m about 30 m/s, and at 906.60 m about 20 m/s, see Figure 5-6.

Typically in the entire series of tests, the deviation between the measured value and the model fit is about 0.34% (about 20 m/s), with a maximum average error of 1.3% (about 75 m/s).

The deviation between the model fitted to the data and the measured data is somewhat better than in the previous work, for the SKB's site investigations /Chryssanthakis and Tunbridge, 2003a, b, c, d/. The results are also very consistent. It is therefore concluded that the measurement errors are probably somewhat less than those determined in the previous work with the repeatability of velocity measurements better than ± 100 m/s, the error in the anisotropy ratio better than ± 0.02 and the error in the orientation better than ± 10°. This is probably attributed to increasing operator experience.

### *Conclusions*

The results from the P-wave velocity measurements show a generally consistent pattern over the whole length of the borehole with maximum velocities between 5,200–6,000 m/s and a variable anisotropy ratio of generally between 1.03 to 1.14. Six results from borehole KFM03A and B indicate somewhat lower velocities of between 5,120–5,650 m/s down to 220 m. From 220 m the maximum velocity of 5,800–6,000 m/s reduces gradually to about 5,650–5,750 m/s at 600 m with a more variable spread of values between 5,050–5,900 m/s between 400 m–524 m depth. Below 600 m the maximum velocity is relatively constant between 5,450–5,750 m/s, with values of about 5,250 m/s at about 695 m and 905 m depth, and consistent anisotropy ratios of between 1.07–1.15.

The orientation of the maximum velocity is quite variable relative to the foliation, with no consistent or preferred direction and it is neither parallel nor perpendicular to the foliation as might have been expected.

**Table 5-1. Measurements of acoustic velocity, transverse core in borehole KFM03A, Forsmark (orientation clockwise looking down hole, 0° is parallel with foliation where identified).**

| Depth m | Diameter mm | Corrected time, m/S<br>Parallel foliation<br>0° | 30° | 60° | Perpendicular foliation<br>90° | 120° | 150° | Velocity m/S<br>Parallel foliation<br>0° | 30° | 60° | Perpendicular foliation<br>90° | 120° | 150° | Anisotropy ratio |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 181.90 | 50.66 | 9.10 | 9.25 | 9.64 | 9.88 | 9.78 | 9.40 | 5,570 | 5,480 | 5,258 | 5,130 | 5,183 | 5,392 | 1.09 |
| 197.65 | 50.75 | 9.73 | 10.10 | 10.10 | 9.95 | 9.63 | 9.39 | 5,218 | 5,027 | 5,027 | 5,103 | 5,273 | 5,408 | 1.08 |
| 216.55 | 50.76 | 9.48 | 10.04 | 10.05 | 9.63 | 9.24 | 9.12 | 5,357 | 5,058 | 5,053 | 5,274 | 5,496 | 5,569 | 1.10 |
| 229.05 | 50.63 | 8.49 | 8.47 | 8.48 | 8.46 | 8.52 | 8.61 | 5,967 | 5,981 | 5,974 | 5,988 | 5,946 | 5,884 | 1.02 |
| 240.50 | 50.66 | 8.84 | 9.15 | 9.53 | 9.41 | 9.00 | 8.69 | 5,734 | 5,540 | 5,319 | 5,386 | 5,632 | 5,833 | 1.10 |
| 253.20 | 50.62 | 8.85 | 8.53 | 8.49 | 8.65 | 9.00 | 9.10 | 5,723 | 5,938 | 5,966 | 5,855 | 5,628 | 5,566 | 1.07 |
| 263.25 | 50.72 | 8.60 | 9.01 | 9.13 | 9.09 | 8.87 | 8.67 | 5,901 | 5,632 | 5,558 | 5,583 | 5,721 | 5,853 | 1.06 |
| 281.75 | 50.72 | 8.97 | 9.36 | 9.46 | 9.20 | 8.69 | 8.53 | 5,658 | 5,422 | 5,364 | 5,516 | 5,840 | 5,950 | 1.11 |
| 302.60 | 50.68 | 8.43 | 8.52 | 8.76 | 8.74 | 8.69 | 8.52 | 6,015 | 5,952 | 5,789 | 5,802 | 5,835 | 5,952 | 1.04 |
| 324.50 | 50.69 | 8.55 | 8.61 | 8.82 | 8.89 | 8.77 | 8.65 | 5,932 | 5,891 | 5,750 | 5,705 | 5,783 | 5,863 | 1.04 |
| 336.25 | 50.79 | 9.44 | 9.60 | 9.37 | 8.99 | 8.70 | 8.86 | 5,383 | 5,293 | 5,423 | 5,653 | 5,841 | 5,736 | 1.10 |
| 348.05 | 50.65 | 9.53 | 9.26 | 8.87 | 8.73 | 8.94 | 9.42 | 5,318 | 5,473 | 5,713 | 5,805 | 5,669 | 5,380 | 1.09 |
| 370.23 | 50.55 | 9.41 | 8.97 | 9.00 | 9.34 | 9.96 | 9.99 | 5,375 | 5,639 | 5,620 | 5,415 | 5,078 | 5,063 | 1.11 |
| 380.40 | 50.62 | 8.90 | 8.93 | 9.49 | 9.92 | 10.13 | 9.66 | 5,691 | 5,672 | 5,337 | 5,105 | 4,999 | 5,243 | 1.14 |
| 392.80 | 50.78 | 9.02 | 9.36 | 9.63 | 9.60 | 9.21 | 9.04 | 5,633 | 5,428 | 5,276 | 5,292 | 5,517 | 5,620 | 1.07 |
| 410.48 | 50.87 | 12.01 | 11.88 | 11.06 | 10.30 | 10.16 | 10.81 | 4,237 | 4,284 | 4,602 | 4,941 | 5,009 | 4,708 | 1.18 |
| 427.10 | 50.64 | 9.24 | 9.07 | 8.78 | 8.73 | 8.80 | 9.13 | 5,483 | 5,586 | 5,771 | 5,804 | 5,758 | 5,550 | 1.06 |
| 444.35 | 50.81 | 9.80 | 9.45 | 9.30 | 8.98 | 9.21 | 9.52 | 5,187 | 5,380 | 5,466 | 5,661 | 5,520 | 5,340 | 1.09 |
| 461.77 | 50.81 | 8.76 | 8.83 | 8.92 | 8.91 | 8.76 | 8.56 | 5,804 | 5,757 | 5,699 | 5,706 | 5,804 | 5,939 | 1.04 |
| 478.90 | 50.65 | 9.06 | 9.07 | 9.51 | 9.79 | 9.48 | 9.20 | 5,594 | 5,587 | 5,329 | 5,176 | 5,346 | 5,508 | 1.08 |
| 493.00 | 50.59 | 9.02 | 9.24 | 9.55 | 9.74 | 9.43 | 9.01 | 5,612 | 5,478 | 5,300 | 5,197 | 5,368 | 5,618 | 1.08 |
| 507.30 | 50.71 | 9.96 | 9.93 | 9.57 | 9.44 | 9.56 | 9.77 | 5,094 | 5,109 | 5,302 | 5,375 | 5,307 | 5,193 | 1.06 |
| 525.50 | 50.74 | 10.14 | 10.53 | 10.17 | 9.62 | 9.38 | 9.66 | 5,006 | 4,821 | 4,992 | 5,277 | 5,412 | 5,255 | 1.12 |
| 540.00 | 50.71 | 9.37 | 9.14 | 8.79 | 8.90 | 9.07 | 9.31 | 5,415 | 5,551 | 5,772 | 5,701 | 5,594 | 5,450 | 1.07 |
| 558.07 | 50.69 | 9.49 | 9.13 | 8.79 | 8.90 | 8.98 | 9.44 | 5,344 | 5,555 | 5,770 | 5,697 | 5,648 | 5,373 | 1.08 |
| 573.65 | 50.63 | 8.97 | 8.92 | 9.11 | 9.20 | 9.23 | 9.12 | 5,647 | 5,679 | 5,561 | 5,506 | 5,488 | 5,555 | 1.03 |
| 589.20 | 50.75 | 9.20 | 9.58 | 9.82 | 9.66 | 9.29 | 8.96 | 5,519 | 5,300 | 5,171 | 5,256 | 5,466 | 5,667 | 1.10 |
| 603.80 | 50.77 | 8.88 | 8.96 | 9.16 | 9.39 | 9.45 | 9.19 | 5,721 | 5,669 | 5,546 | 5,410 | 5,375 | 5,527 | 1.06 |
| 616.95 | 50.85 | 9.45 | 9.31 | 9.23 | 9.16 | 9.29 | 9.31 | 5,384 | 5,465 | 5,512 | 5,554 | 5,477 | 5,465 | 1.03 |
| 630.75 | 50.84 | 9.47 | 9.17 | 9.31 | 9.71 | 10.23 | 10.08 | 5,371 | 5,547 | 5,464 | 5,239 | 4,972 | 5,046 | 1.12 |
| 639.25 | 50.61 | 9.72 | 10.37 | 10.28 | 9.75 | 9.17 | 9.18 | 5,209 | 4,883 | 4,926 | 5,193 | 5,522 | 5,516 | 1.13 |
| 649.75 | 50.72 | 9.78 | 9.39 | 9.15 | 9.24 | 9.56 | 9.85 | 5,189 | 5,404 | 5,546 | 5,492 | 5,308 | 5,152 | 1.08 |
| 663.20 | 50.71 | 8.97 | 8.94 | 9.14 | 9.79 | 9.88 | 9.44 | 5,656 | 5,675 | 5,551 | 5,182 | 5,135 | 5,375 | 1.11 |
| 670.80 | 50.72 | 10.01 | 9.58 | 9.08 | 8.96 | 9.26 | 9.74 | 5,069 | 5,297 | 5,589 | 5,664 | 5,480 | 5,210 | 1.12 |
| 684.70 | 50.71 | 10.01 | 10.27 | 10.14 | 9.42 | 9.11 | 9.33 | 5,068 | 4,940 | 5,003 | 5,386 | 5,569 | 5,438 | 1.13 |
| 695.60 | 50.63 | 9.62 | 10.09 | 10.56 | 10.82 | 10.53 | 9.85 | 5,266 | 5,020 | 4,797 | 4,681 | 4,810 | 5,143 | 1.12 |
| 712.10 | 50.77 | 9.06 | 9.32 | 9.62 | 9.56 | 9.30 | 8.86 | 5,607 | 5,450 | 5,280 | 5,313 | 5,462 | 5,733 | 1.09 |
| 719.25 | 50.71 | 9.26 | 9.63 | 9.97 | 9.46 | 9.07 | 8.94 | 5,479 | 5,269 | 5,089 | 5,363 | 5,594 | 5,675 | 1.12 |
| 731.50 | 50.61 | 9.60 | 9.52 | 9.07 | 8.80 | 9.05 | 9.36 | 5,275 | 5,319 | 5,583 | 5,754 | 5,595 | 5,410 | 1.09 |
| 742.97 | 50.78 | 9.34 | 9.63 | 9.68 | 9.17 | 8.83 | 9.02 | 5,440 | 5,276 | 5,249 | 5,541 | 5,754 | 5,633 | 1.10 |
| 752.30 | 50.75 | 9.63 | 9.79 | 9.50 | 8.95 | 8.85 | 9.03 | 5,273 | 5,186 | 5,345 | 5,674 | 5,738 | 5,623 | 1.11 |
| 767.35 | 50.87 | 9.83 | 9.30 | 9.18 | 9.49 | 10.07 | 10.11 | 5,178 | 5,473 | 5,544 | 5,363 | 5,054 | 5,034 | 1.10 |
| 781.45 | 50.53 | 8.98 | 9.07 | 9.57 | 10.05 | 9.89 | 9.35 | 5,630 | 5,574 | 5,283 | 5,030 | 5,112 | 5,407 | 1.12 |
| 794.60 | 50.55 | 9.33 | 9.23 | 9.55 | 10.44 | 10.86 | 10.17 | 5,421 | 5,480 | 5,296 | 4,844 | 4,657 | 4,973 | 1.18 |
| 805.20 | 50.78 | 8.78 | 8.97 | 9.19 | 9.36 | 9.22 | 8.92 | 5,787 | 5,664 | 5,529 | 5,428 | 5,511 | 5,696 | 1.07 |
| 812.60 | 50.52 | 8.83 | 9.21 | 9.57 | 9.59 | 9.18 | 8.85 | 5,725 | 5,488 | 5,282 | 5,271 | 5,506 | 5,712 | 1.09 |
| 814.80 | 50.67 | 8.91 | 9.34 | 9.49 | 9.38 | 9.06 | 8.84 | 5,690 | 5,428 | 5,342 | 5,405 | 5,596 | 5,735 | 1.07 |
| 816.70 | 50.71 | 9.92 | 9.70 | 9.22 | 9.08 | 9.53 | 9.86 | 5,114 | 5,231 | 5,503 | 5,588 | 5,324 | 5,146 | 1.09 |
| 823.82 | 50.68 | 9.44 | 9.34 | 9.59 | 9.94 | 10.10 | 9.66 | 5,371 | 5,429 | 5,287 | 5,101 | 5,020 | 5,249 | 1.08 |
| 831.70 | 50.69 | 8.92 | 9.59 | 9.95 | 10.08 | 9.47 | 8.85 | 5,686 | 5,288 | 5,097 | 5,031 | 5,355 | 5,731 | 1.14 |
| 834.60 | 50.74 | 9.47 | 8.93 | 8.90 | 9.22 | 9.82 | 9.82 | 5,361 | 5,685 | 5,704 | 5,506 | 5,170 | 5,170 | 1.10 |
| 841.60 | 50.71 | 9.64 | 9.18 | 8.91 | 9.13 | 9.50 | 9.82 | 5,263 | 5,527 | 5,695 | 5,557 | 5,341 | 5,167 | 1.10 |
| 850.70 | 50.63 | 10.19 | 10.06 | 9.44 | 9.24 | 9.32 | 9.70 | 4,971 | 5,035 | 5,366 | 5,482 | 5,435 | 5,222 | 1.10 |
| 866.60 | 50.76 | 9.19 | 9.74 | 9.97 | 9.71 | 9.22 | 9.04 | 5,526 | 5,214 | 5,094 | 5,230 | 5,508 | 5,618 | 1.10 |
| 873.50 | 50.77 | 8.84 | 8.99 | 9.55 | 9.96 | 9.85 | 9.22 | 5,746 | 5,650 | 5,319 | 5,100 | 5,157 | 5,509 | 1.13 |
| 885.86 | 50.80 | 10.44 | 9.87 | 9.38 | 9.41 | 9.66 | 10.20 | 4,868 | 5,149 | 5,419 | 5,401 | 5,261 | 4,983 | 1.11 |
| 897.05 | 50.74 | 9.16 | 9.33 | 9.82 | 10.32 | 10.09 | 9.39 | 5,542 | 5,441 | 5,170 | 4,919 | 5,031 | 5,406 | 1.13 |
| 906.60 | 50.81 | 9.81 | 10.18 | 11.01 | 11.07 | 10.55 | 9.82 | 5,182 | 4,994 | 4,617 | 4,592 | 4,818 | 5,177 | 1.13 |
| 918.05 | 50.69 | 9.18 | 9.62 | 10.35 | 10.50 | 10.10 | 9.33 | 5,525 | 5,272 | 4,900 | 4,830 | 5,021 | 5,436 | 1.14 |
| 929.20 | 50.63 | 9.15 | 8.81 | 9.03 | 9.53 | 9.78 | 9.67 | 5,536 | 5,750 | 5,610 | 5,315 | 5,180 | 5,238 | 1.11 |
| 935.53 | 50.69 | 9.27 | 8.84 | 9.05 | 9.55 | 9.90 | 9.82 | 5,471 | 5,737 | 5,604 | 5,311 | 5,123 | 5,165 | 1.12 |
| 940.95 | 50.79 | 9.61 | 9.47 | 9.01 | 8.84 | 8.96 | 9.41 | 5,288 | 5,366 | 5,640 | 5,749 | 5,672 | 5,400 | 1.09 |
| 953.27 | 50.81 | 9.15 | 9.02 | 9.48 | 9.99 | 10.24 | 9.74 | 5,556 | 5,636 | 5,363 | 5,089 | 4,964 | 5,219 | 1.14 |
| 965.43 | 50.92 | 9.07 | 9.14 | 9.73 | 10.21 | 10.01 | 9.48 | 5,617 | 5,574 | 5,236 | 4,990 | 5,089 | 5,374 | 1.13 |
| 981.70 | 50.63 | 9.34 | 9.24 | 9.85 | 10.31 | 10.44 | 9.75 | 5,424 | 5,482 | 5,143 | 4,913 | 4,852 | 5,195 | 1.13 |
| 336.35 | 50.81 | 9.52 | 9.59 | 9.29 | 8.85 | 8.72 | 9.02 | 5,340 | 5,301 | 5,472 | 5,744 | 5,830 | 5,636 | 1.10 |
| 670.80 | 50.72 | 10.04 | 9.63 | 9.17 | 9.00 | 9.29 | 9.70 | 5,054 | 5,270 | 5,534 | 5,639 | 5,463 | 5,232 | 1.12 |
| 906.60 | 50.80 | 9.75 | 10.32 | 11.07 | 11.00 | 10.39 | 9.76 | 5,213 | 4,925 | 4,591 | 4,620 | 4,892 | 5,208 | 1.14 |
| Measurements from borehole KFM03B | | | | | | | | | | | | | | |
| 21.65 | 50.82 | 10.27 | 10.28 | 10.08 | 9.94 | 9.99 | 10.17 | 4,951 | 4,946 | 5,044 | 5,115 | 5,090 | 4,999 | 1.03 |
| 52.35 | 50.89 | 9.60 | 9.66 | 9.70 | 9.73 | 9.65 | 9.64 | 5,304 | 5,271 | 5,249 | 5,233 | 5,276 | 5,282 | 1.01 |
| 87.85 | 50.84 | 9.08 | 9.04 | 9.37 | 9.61 | 9.55 | 9.22 | 5,602 | 5,627 | 5,429 | 5,293 | 5,326 | 5,517 | 1.06 |

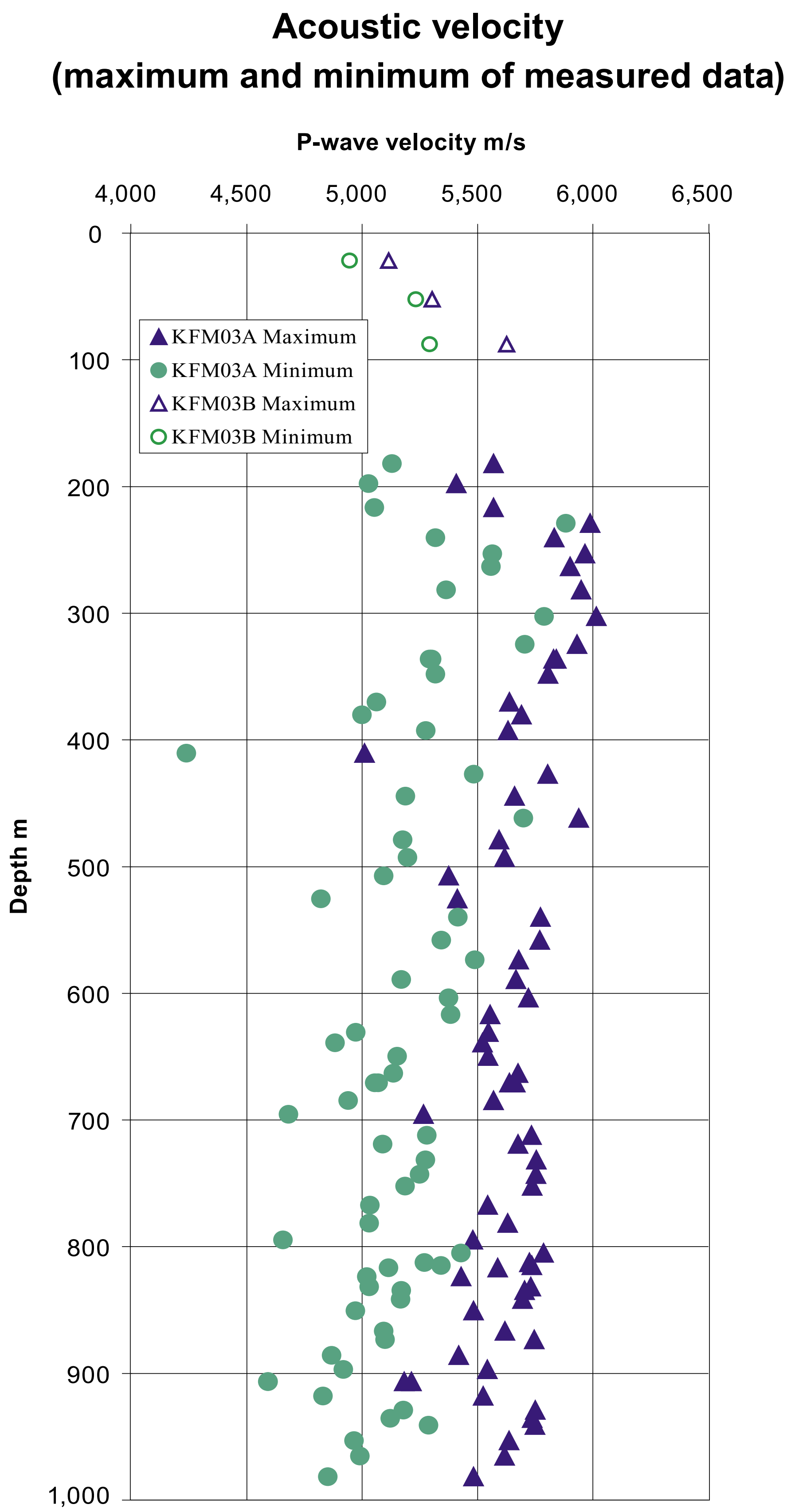



***Figure 5-1.*** *Measured values of maximum and minimum acoustic velocities plotted versus borehole length in KFM03A and 03B.*

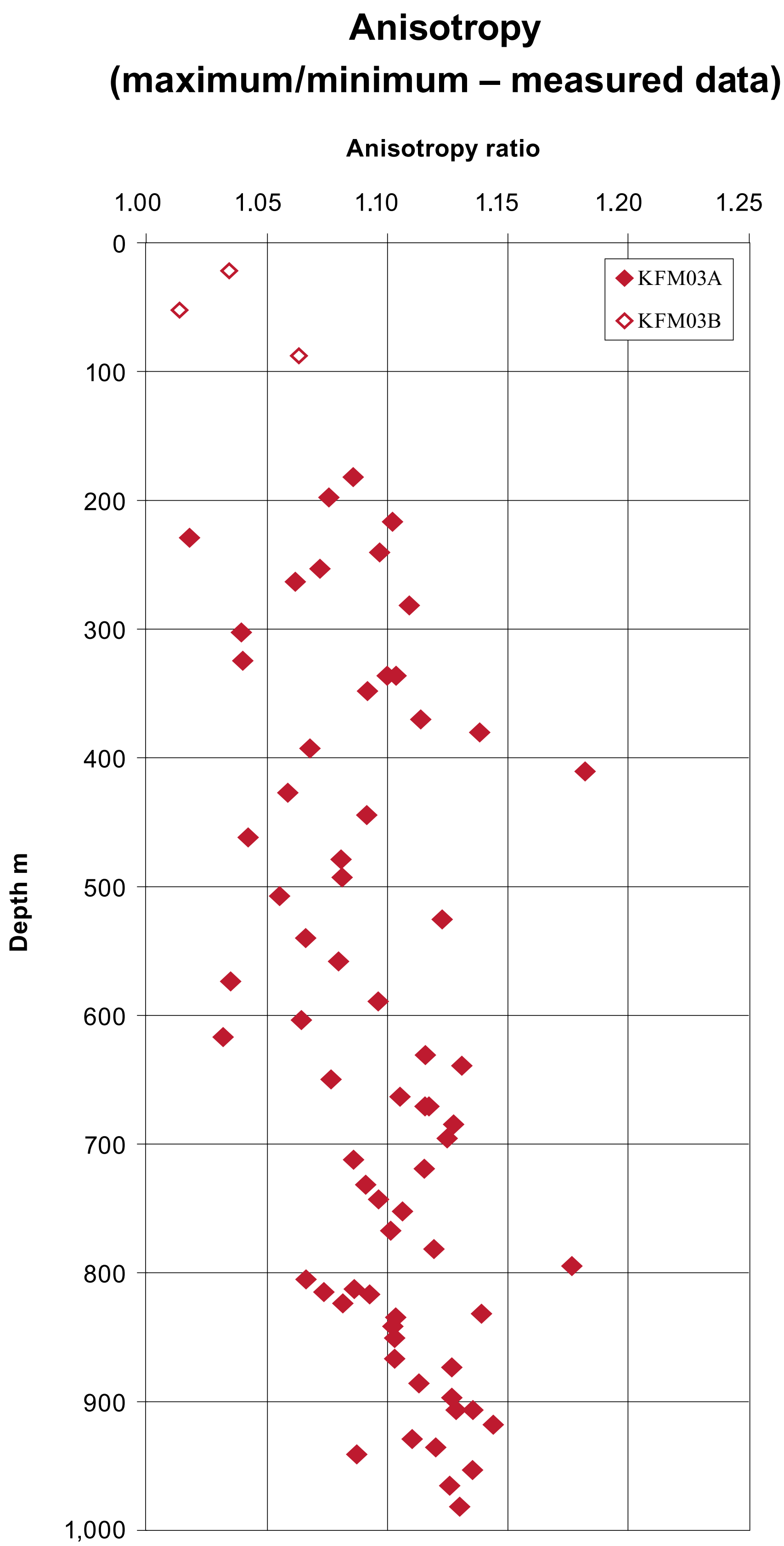



***Figure 5-2.*** *Measured values of anisotropy in acoustic velocity plotted versus borehole length in KFM03A and 03B.*

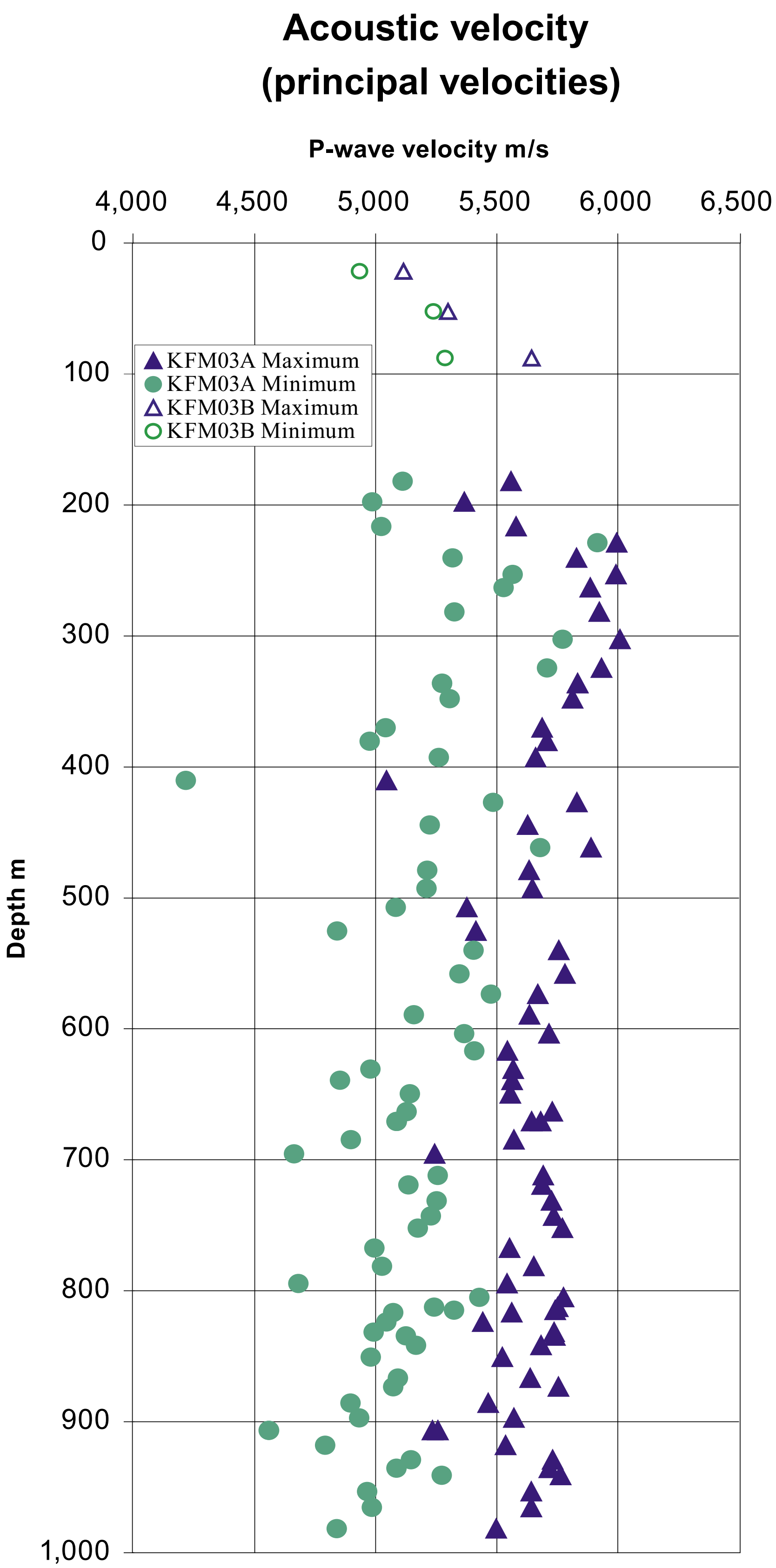



***Figure 5-3.*** *Calculated values of maximum and minimum principal acoustic velocities plotted versus borehole length in KFM03A and 03B.*

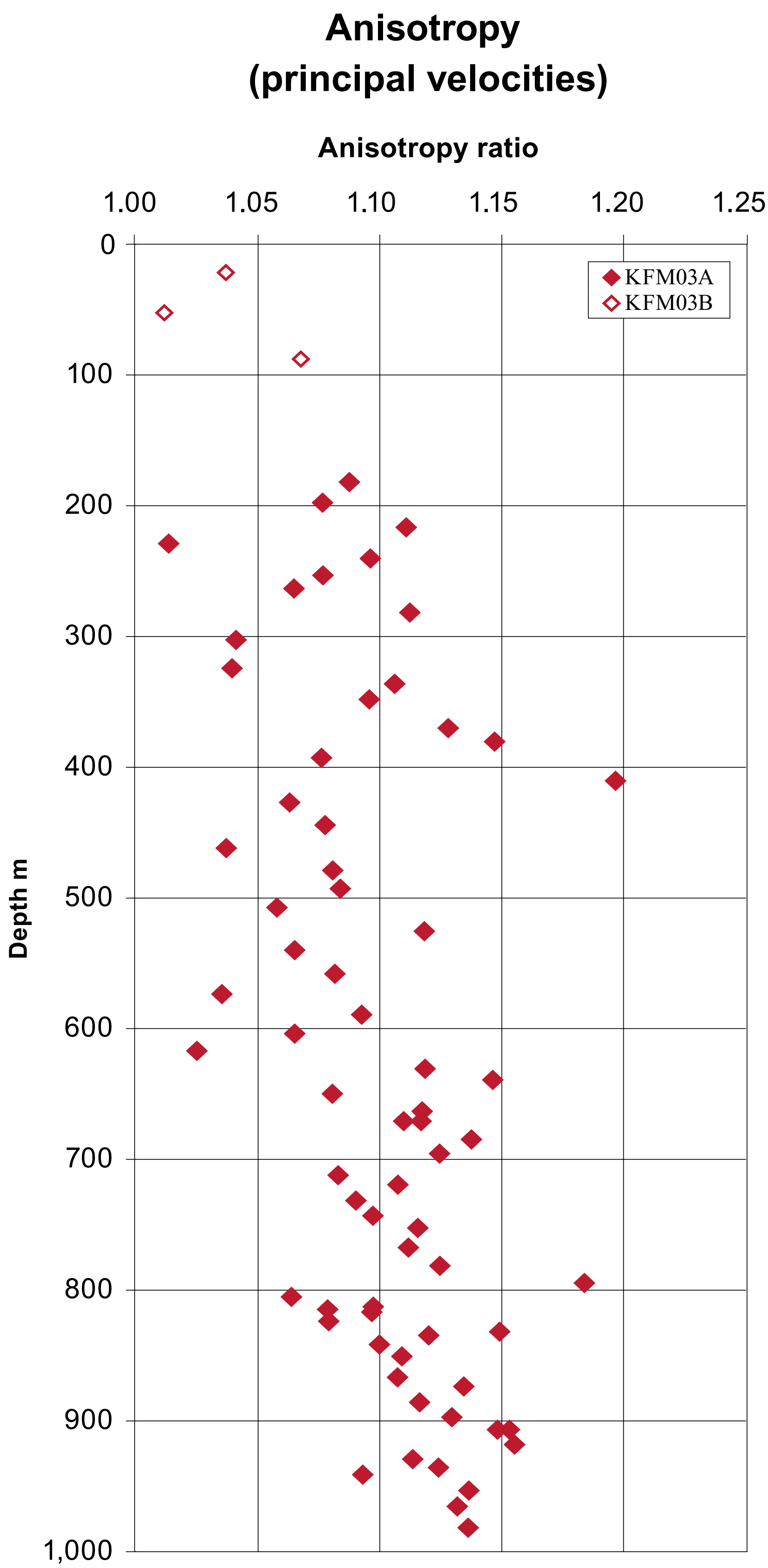



***Figure 5-4.*** *Calculated values of maximum and minimum anisotropy in principal acoustic velocity plotted versus borehole length in KFM03A and 03B.*

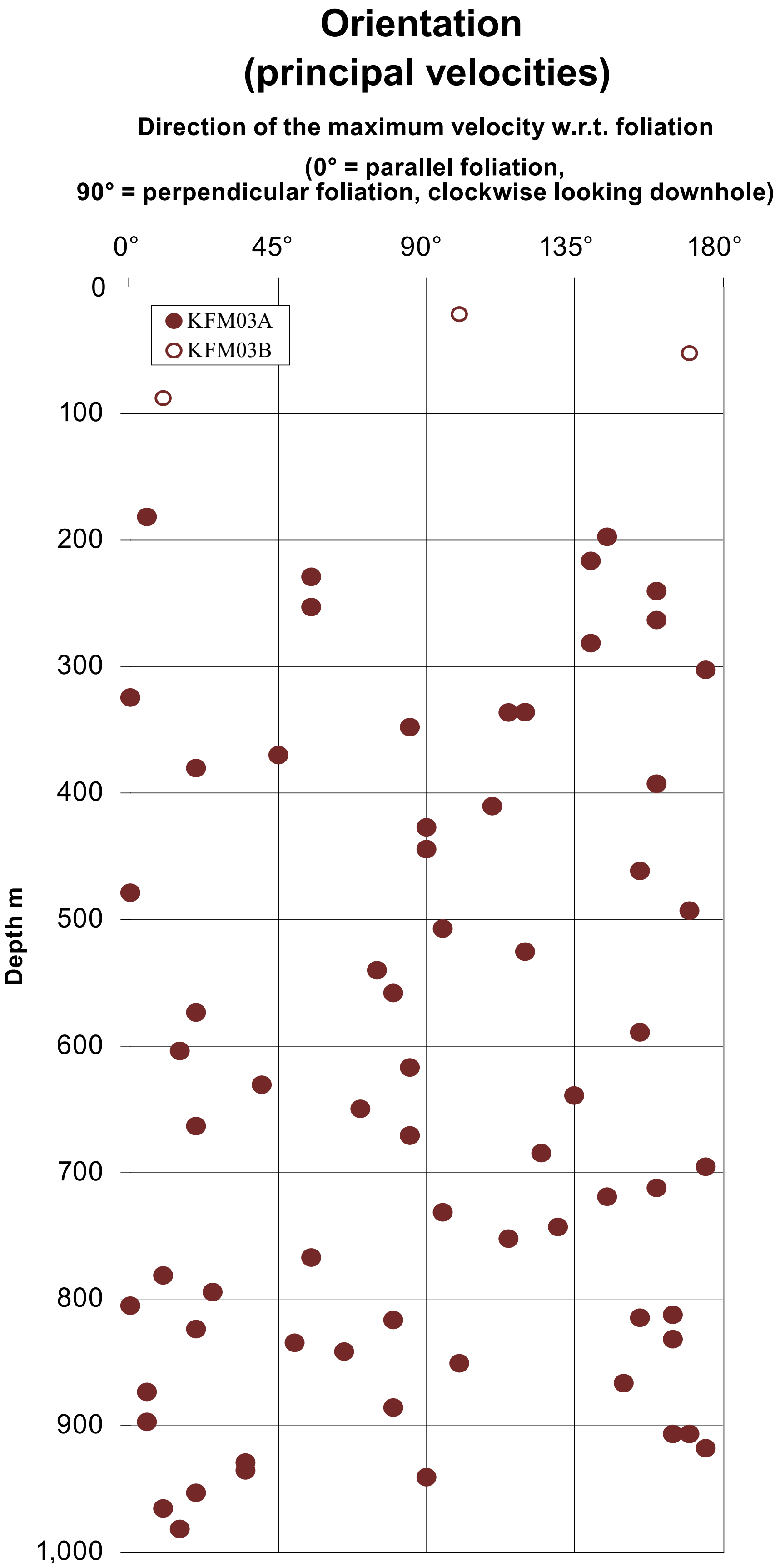
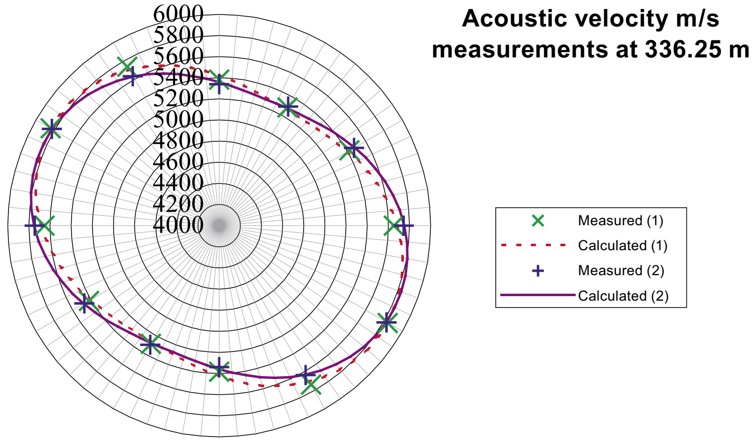
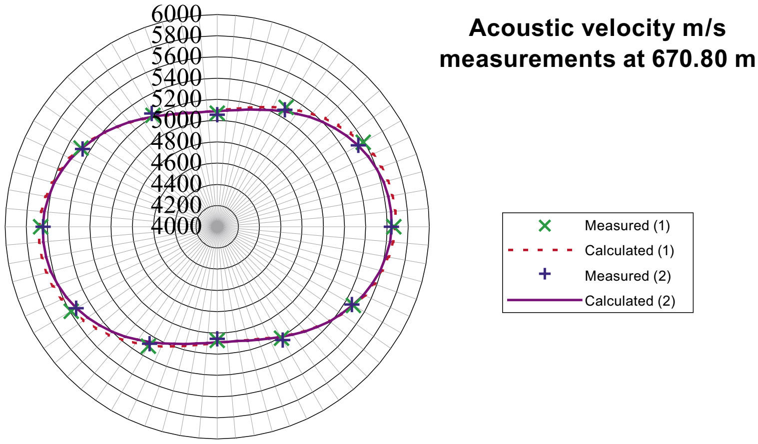



***Figure 5-5.*** *Calculated orientation of the maximum principal acoustic velocity plotted versus borehole length in KFM03A and 03B.*



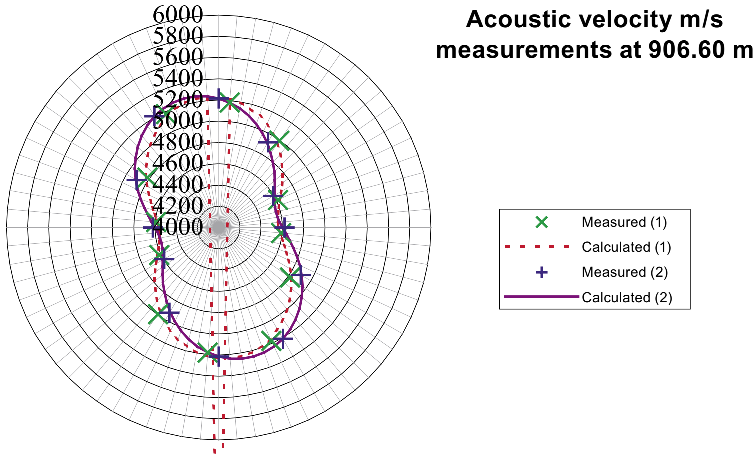




***Figure 5-6.*** *Comparison of measured and calculated values (model fit) of acoustic velocity for each of three determinations at the same depths in borehole KFM03A.*

# References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# Appendix A

## Calibration measurements on aluminium cylinder, diameter 50.90 mm, with known velocity 6,320 m/s

| **Date and time** | **Known velocity m/s** | **Diameter mm** | **Time measured μS** | **calculated μS** | **correction μS** |
|---|---|---|---|---|---|
| 20031007 – 0900 hrs | 6,320 | 50.90 | 9.14 | 8.05 | 1.09 |
| 20031007 – 1330 hrs | 6,320 | 50.90 | 9.12 | 8.05 | 1.07 |
| 20031007 – 1715 hrs | 6,320 | 50.90 | 9.15 | 8.05 | 1.10 |
| 20031008 – 0900 hrs | 6,320 | 50.90 | 9.16 | 8.05 | 1.11 |
| 20031008 – 1330 hrs | 6,320 | 50.90 | 9.17 | 8.05 | 1.12 |
| 20031008 – 1710 hrs | 6,320 | 50.90 | 9.14 | 8.05 | 1.09 |
| 20031009 – 0900 hrs | 6,320 | 50.90 | 9.17 | 8.05 | 1.12 |
| 20031009 – 1200 hrs | 6,320 | 50.90 | 9.14 | 8.05 | 1.09 |
| **Average** | | | **9.149** | | **1.095** |