# Battery Compression Test

## *Summary*

Previous tests by Bluefin at MBARI in April 2003 had demonstrated a negative buoyancy change in the Thales AUVs. This buoyancy change appeared to occur at depths as shallow as 200m. The initial hypothesis was that compression of the Li polymer batteries accounted for the loss in displacement. In order to confirm this hypothesis, MBARI performed a test where a 3.5kWhr battery was visually observed during an ROV dive to a depth of 1100m. This test measured a .5in compression of the battery over the course of the dive.

## *Test Setup*

A test frame was constructed to which the battery was mounted. One end of the battery was free to move, while the other end was attached to the frame using 10-32 bolts threaded into the battery's T-nut inserts. Aluminum rulers where bolted to the box to measure the change in length. This frame was then mounted onto the toolsled of the ROV Ventana. A color video camera and light were mounted on the frame to image the upper corner of the battery. The battery test was performed on April 28 2003 along the main axis of the Monterey Canyon. The battery tested was serial number 52.

The depth, temperature, and salinity profiles of the dive are shown in figure 2. The ROV descended continuously at a rate of approximately 28 m/minute. Images were acquired every 50 meters to measure compression. The ROV spent approximately 90 minutes on the bottom, then ascended. Ascent rate was slightly slower, and several stops were performed during the ascent to test other systems as well as steady the battery camera for frame grabs.

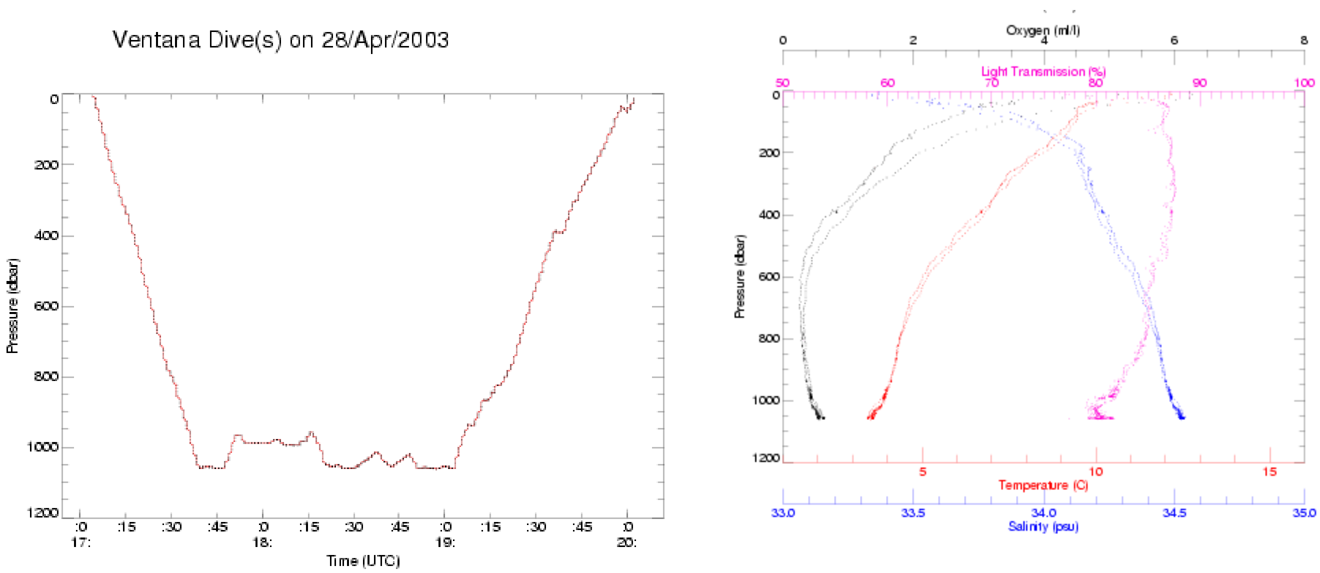



**Figure 1 Pressure, Temperature, & Salinity Profiles**

## *Test Results*

During the dive 43 still frame grabs of the batteries were obtained, as well as BetaCam video. The change in length of the battery in its longest dimension was measured in each frame and is recorded in table 1.

| Pressure (dbar) | Compression(inch) | image name | image time (GMT) |
|---|---|---|---|
| 2.3 | 0 | 00_00_00_00-01.rgb | 14:46:38 |
| 2.3 | 0 | 00_06_36_16.jpg | 16:57:14 |
| 59.34 | 0.0625 | 00_09_37_08.jpg | 17:06:06 |
| 100.55 | 0.125 | 00_10_46_06.jpg | 17:07:15 |
| 154.78 | 0.1875 | 00_12_20_18.jpg | 17:08:50 |
| 203.43 | 0.25 | 00_13_48_15.jpg | 17:10:18 |
| 253.31 | 0.3125 | 00_15_17_27.jpg | 17:11:48 |
| 303.95 | 0.375 | 00_17_07_24.jpg | 17:13:38 |
| 354.78 | 0.375 | 00_19_18_19.jpg | 17:15:48 |
| 408.83 | 0.375 | 00_21_17_15.jpg | 17:17:48 |
| 458.61 | 0.375 | 00_21_42_13.jpg | 17:19:12 |
| 507.96 | 0.46875 | 00_24_04_26.jpg | 17:20:35 |
| 557.61 | 0.46875 | 00_25_31_23.jpg | 17:22:02 |
| 608.89 | 0.46875 | 00_27_04_19.jpg | 17:23:35 |
| 707.7 | 0.46875 | 00_30_10_14.jpg | 17:26:41 |
| 757.76 | 0.46875 | 00_31_45_26.jpg | 17:28:16 |
| 806.14 | 0.46875 | 00_34_08_06.jpg | 17:30:39 |
| 860.11 | 0.46875 | 00_35_54_03.jpg | 17:32:25 |
| 865.79 | 0.46875 | 00_35_55_03.jpg | 17:32:26 |
| 966.47 | 0.46875 | 00_39_21_27.jpg | 17:35:53 |
| 1055.46 | 0.46875 | 00_45_03_16.jpg | 17:41:35 |
| 887.08 | 0.5 | 01_11_31_04.jpg | 19:11:49 |
| 820.58 | 0.5 | 01_18_03_08.jpg | 19:18:22 |
| 793.32 | 0.5 | 01_20_07_03.jpg | 19:20:26 |
| 557.42 | 0.5 | 01_29_17_02.jpg | 19:29:36 |
| 504.11 | 0.5 | 01_31_16_13.jpg | 19:31:36 |
| 455.15 | 0.5 | 01_33_10_25.jpg | 19:33:31 |
| 404.73 | 0.5 | 01_35_03_06.jpg | 19:35:23 |
| 353.61 | 0.5 | 01_40_08_11.jpg | 19:40:28 |
| 304.71 | 0.5 | 01_42_04_22.jpg | 19:42:25 |
| 253.57 | 0.5 | 01_45_33_01.jpg | 19:45:54 |
| 204.12 | 0.4375 | 01_48_35_11.jpg | 19:48:56 |

| Pressure (dbar) | Compression(inch) | image name | image time (GMT) |
|---|---|---|---|
| 151.24 | 0.375 | 01_51_48_05.jpg | 19:52:09 |
| 103.24 | 0.3125 | 01_54_16_15.jpg | 19:54:38 |
| 74.5 | 0.25 | 01_55_38_13.jpg | 19:56:00 |
| 52.12 | 0.25 | 01_56_51_25.jpg | 19:57:13 |
| 26.58 | 0.1875 | 02_01_20_02.jpg | 20:01:42 |
| 16.25 | 0.125 | 02_01_58_16.jpg | 20:02:20 |
| 2.3 | 0.125 | 02_03_13_13.jpg | 20:03:35 |
| 2.3 | 0.125 | 02_02_21_28.jpg | 20:03:44 |
| 2.3 | 0.0625 | 02_03_31_11-01.jpg | 20:03:44 |
| 2.3 | 0.0625 | 02_03_31_11-02.jpg | 20:03:44 |
| 2.3 | 0.0625 | 02_03_31_11.jpg | 20:24:17 |

**Table 1 Compression Profile**

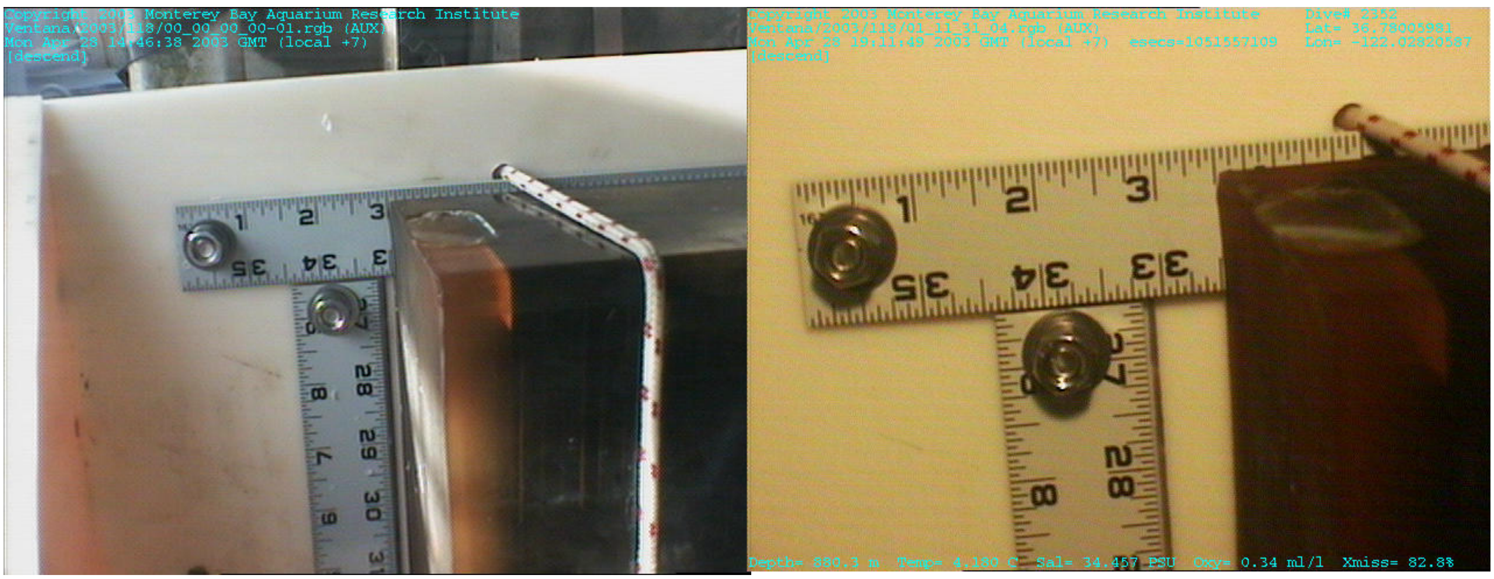
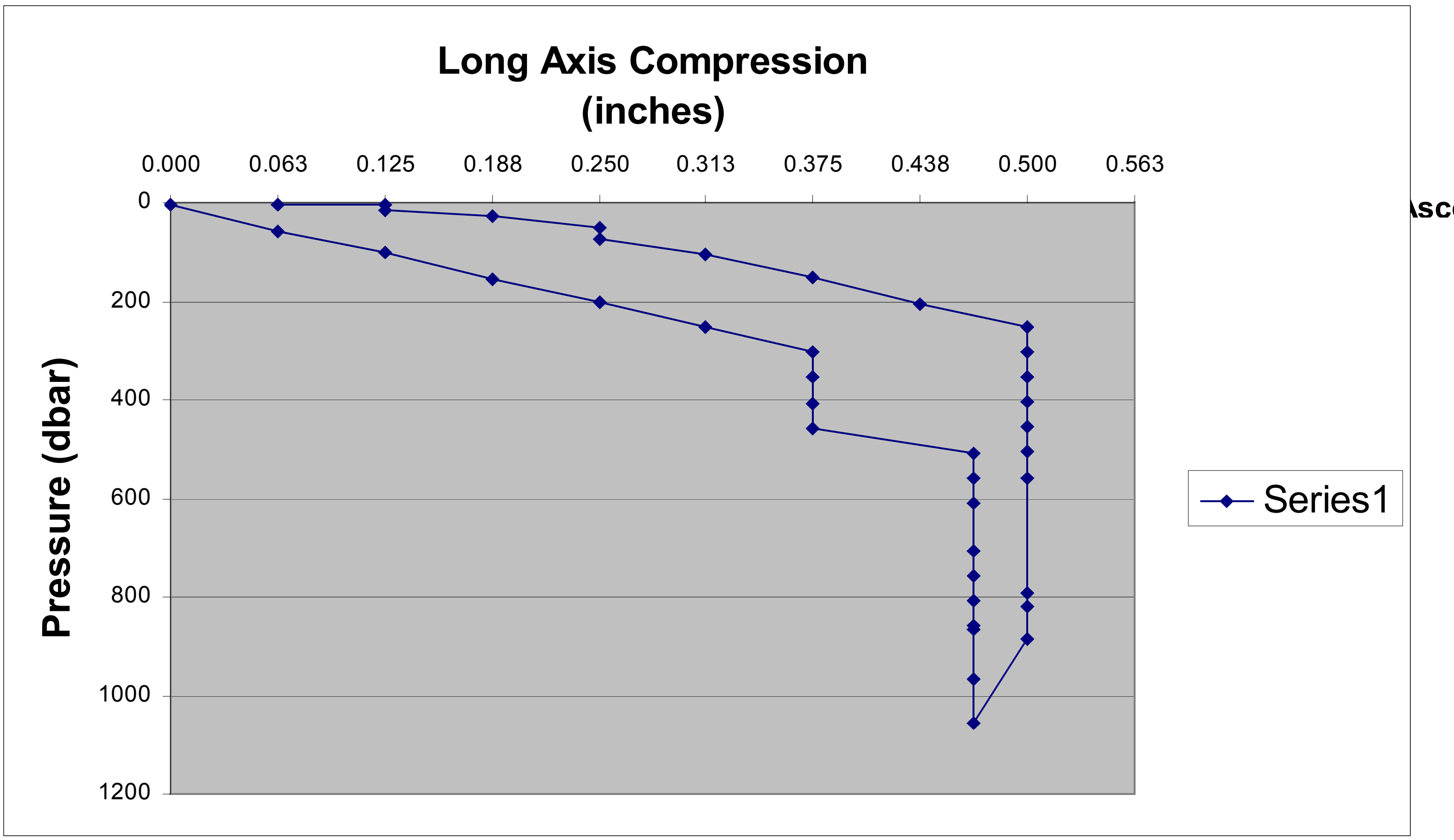



**Figure 2 Image 00_00_00_00-01.rgb (left, at surface), Image 01_11_31_04.rgb (right, at 887 dBar)**

## *Analysis*

The battery exhibited two distinct compression regimes in this test. The first, from surface pressure to 300dBar, results in .375in of compression. The second, from 300 to 1100dBar, results in an additional .125in of compression. The battery exhibited approximately .125in of hysterisis between compression and decompression. During the ascent, the battery expanded to .0625in of compression, and required over 60 minutes on deck to fully expand to its original length.

**Figure 3 Battery Compression**



The exact buoyancy loss due to battery compression is difficult to calculate from this simple test, since the deformation of the battery is most likely non-uniform. For example, tests performed recently at Bluefin (reported by Sam Tolkoff to Hans Thomas by voice on April 29) showed that most of the compression observed in the batteries is due to compression of the cells, rather than the urethane. This would imply that the oil filled volume of the battery would compress much less than the rest of the battery structure. A more accurate measurement of the battery volume and shape change as function of pressure would allow precise buoyancy calculations to be performed, but was beyond what could be done in this dive.

| # of cells | Capacity(kWhr) | Battery Height(cm) | Battery Length(cm) | Battery Width (cm) | Battery Mass (kg) | Battery Displacement(liter) | Cell Stack Height (cm) | Cell Volume(liter) |
|---|---|---|---|---|---|---|---|---|
| 64 | 1 | 27.94 | 26.67 | 12.7 | 15 | 9.46 | 18.56 | 3.94 |
| 128 | 2 | 45.72 | 26.67 | 12.7 | 27 | 15.49 | 37.12 | 7.88 |
| 216 | 3.5 | 72.64 | 26.67 | 12.7 | 42 | 24.61 | 62.64 | 13.29 |

**Table 2 Battery Details**

For the purpose of this analysis, I will look at two different cases for battery compression. In the first case, I'll assume that the entire battery compresses uniformly in each dimension. The observed compression in height used to calculate the percentage change in height, and this fraction is then applied to the other two dimensions, and the resulting volume change can then be calculated. The plot below shows buoyancy change versus depth based on the uniform compression case, for both the 3.5kwhr battery, as well as extrapolated curves for the 2kwhr and 1 kwhr batteries.

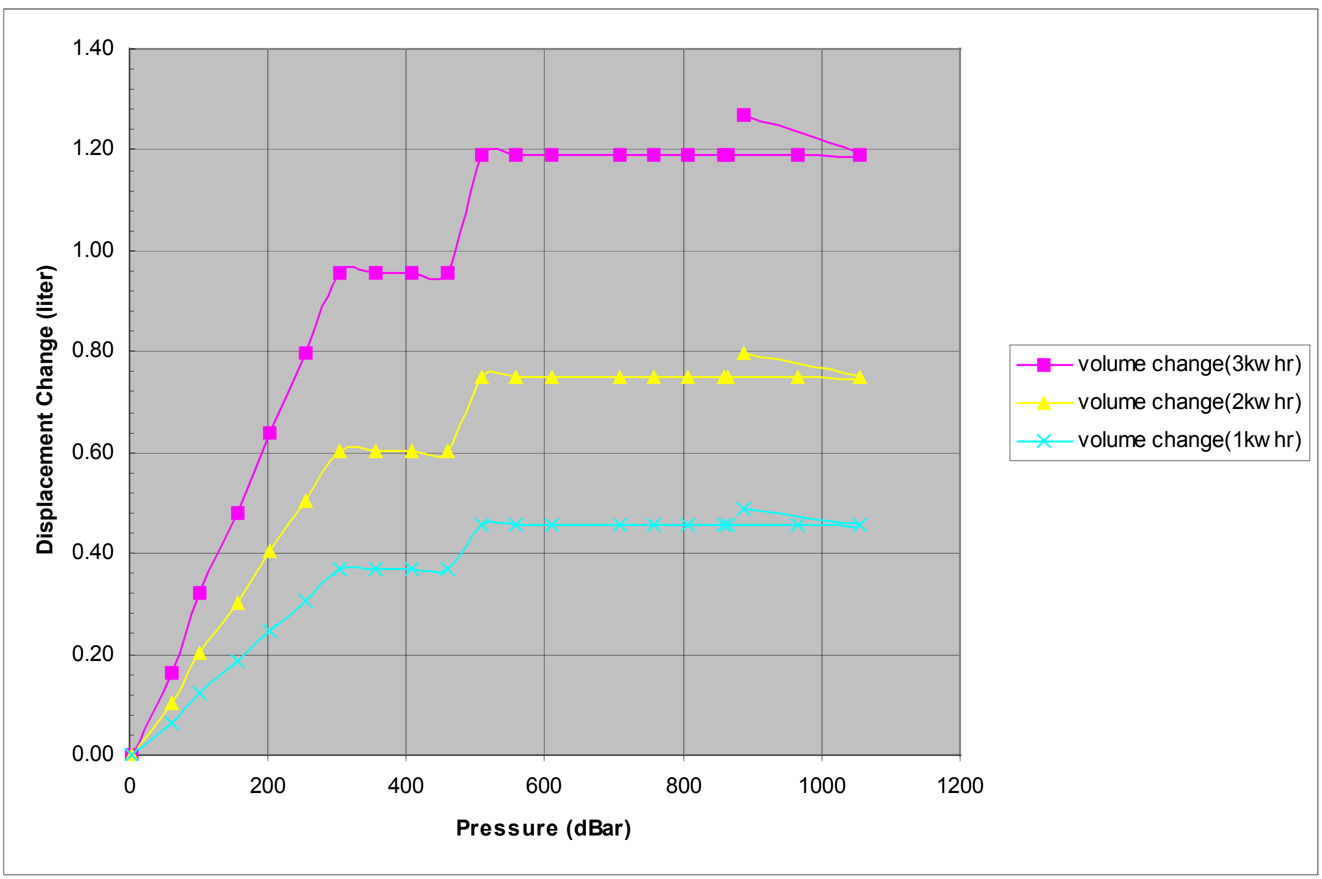



**Figure 4 Displacement Change assuming Uniform Compression of Entire Battery**

In the second case, I'll assume that the battery cells are the only component of the battery to change shape under compression, and that they do so uniformly. Each Valence 446 cell

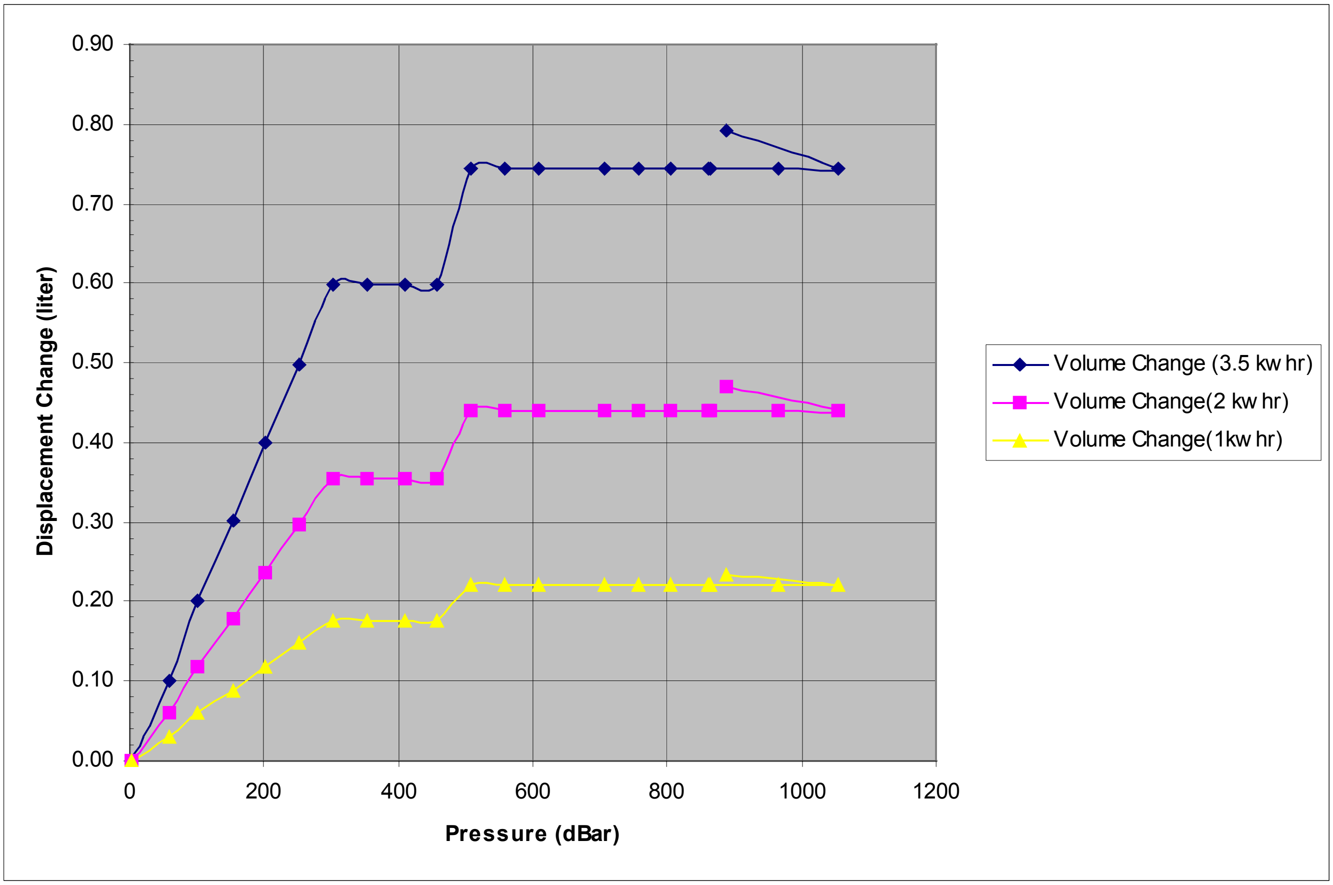



**Figure 5 Displacement Change assuming Uniform Compression of Cells Only**

in the battery is 103mm wide by 103mm long by 5.8mm height, and they are stacked into the batteries in a tandem arrangement. The total cell stack heights and volumes are shown in Table 2 Battery Details. As done in the first case, I'll take the measured dimensional change in height, computing the percentage change (this time of the cell stack height, rather than the battery height), and apply this percentage change to the other two dimensions. The inferred displacement change for the three battery sizes is shown in figure 5.

## *Conclusion*

The compression of the potted Lithium polymer batteries is significant at even modest depths. The large amount of dimensional change in the first 200 dBar is most likely due to compression of gas contained within the battery, either in the cells or in the potting compound. The .125in of compression observed during the final 800m of descent, because of its radically different stress/strain relationship, is most likely caused by mechanical deformation of more rigid elements in the battery. Although the battery seems to behave elastically, the .0625in residual compression seen at the surface might indicate some amount of non-elastic deformation. It might also be an artifact of this test. The buoyancy implications of this compression, indicated in figure 4 and figure 5, can be significant, especially for larger battery configurations. In particular, the volume loss for 3.5kwhr batteries is consistent with the problems encountered by Bluefin during their March testing at MBARI.