LEGIBILITY NOTICE

A major purpose of the Technical Information Center is to provide the broadest dissemination possible of information contained in DOE's Research and Development Reports to business, industry, the academic community, and federal, state and local governments.

Although a small portion of this report is not reproducible, it is being made available to expedite the availability of information on the research discussed herein.

MAR 0 3 1989

Los Alamos National Laboratory is operated by the University of California for the United States Department of Energy under contract W-7405-ENG-36

TITLE Possible Evidence for Non-Newtonian Gravity in the Greenland Ice Cap

LA-UR--89-385

DE89 007746

AUTHOR(S) Mark E. Ander, ESS-3

SUBMITTED TO: American Physical Society
Division of Particles and Fields
1988 Conference Proceedings

Los Alamos

Los Alamos National Laboratory
Los Alamos, New Mexico 87545

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

POSSIBLE EVIDENCE FOR NON-NEWTONIAN GRAVITY IN THE GREENLAND ICE CAP

MARK E. ANDER
Los Alamos National Laboratory
Earth and Space Sciences Division
Geophysics Group, MS-D446
Los Alamos, NM 87545

ABSTRACT

An Airy-type geophysical experiment was conducted down a 2 km deep hole in the Greenland ice cap in order to test for possible violations of Newton's inverse square law by making gravity measurements over a range of 213 m to 1460 m. A significant departure from Newtonian gravity was observed. This result can be explained by the existence of an attractive non-Newtonian component of gravity with a strength of about 3.4% that of Newtonian gravity at a scale of 1460 m. Unfortunately, we can not completely, unambiguously attribute it to a breakdown of Newtonian gravity because we have shown that lateral density variations in the bedrock beneath the ice can cause such apparent departures. If such variations existed, they would have to be rather unusual but certainly not impossible.

Some efforts to produce a unified field theory have suggested that additional gravity-like forces may exist in nature.[1] These forces are predicted to have finite ranges on the order of 100's to 1000's of meters. If such forces exist, they will appear as apparent scale length violations of Newton's inverse square law. Recent geophysical measurements have suggested that such apparent violations may exist.[2,3]

This paper is a short summary of an experiment performed by Ander et al.[4] to search for possible scale dependent non-Newtonian gravity effects over a vertical distance of 213 - 1460 m in glacial ice in the Greenland ice cap. The details of this experiment will be presented in a series of papers that have just been submitted for publication.[4]

Ice was chosen because its density is uniform and well known, thus eliminating one possible major source of uncertainty. The experiment consisted of building a Newtonian model of the gravity gradient through the ice, based on a density model of the surrounding region developed from geophysical measurements, then non-Newtonian effects were searched for by comparing the observed gravity gradients through the ice to the Newtonian model gravity gradients.

The experiment was done in a 2033 m deep well, which penetrated basement rock, located at Dye 3, a Distant Early Warning Station. Dye 3 is 60 km south of the Arctic Circle in the center of Greenland at 2590 m elevation. The density model consists of roughly 2000 m of ice overlying bedrock topography. Gravity values, g_i, measured at depths, z_i, are modeled by

$$g_i = g_{1967} + \gamma z_i + 2\pi\rho_R G(z_d - z_i) + 2\pi\rho_I G(z_i - z_i) + 2\pi\rho_I G(z_i - z_i) + RT_i + IT_i + D_i \qquad (1)$$

where g_{1967} is the theoretical gravity of an ellipsoidal for depth z_d, γ is the free air gradient, ρ_R and ρ_I are the rock and ice densities, RT_i are the terrain corrections due to the ice/rock interfaces at points i, IT_i are the terrain corrections due to the surface of the ice, and D_i are the gravitational corrections due to possible buried rock mass anomalies. Therefore, the model gravity gradient is

$$\Delta g_m = g_{ml} - g_{mu} = \gamma(z_l - z_u) - 4\pi\rho_I G(z_l - z_u) + RT_l - RT_u + IT_l - IT_u + D_l - D_u \qquad (2)$$

where u and l refer to upper and lower gravity points. The anomalous non-Newtonian component is then given by

$$\Delta g_{anom} = \Delta g_o - \Delta g_m = (g_{ol} - g_{ou}) - [\gamma(z_l - z_u) - 4\pi\rho_I G(z_l - z_u)] - RT_l + RT_u - IT_l + IT_u - D_l + D_u \qquad (3)$$

where g_{ol} and g_{ou} are the observed gravity values at depth z_l and z_u. For increased precision, the term in brackets is replaced by a similar term calculated for an ellipsoidal layer in an ellipsoidally earth model.[4,5]

The general physical and chemical properties of ice have been extensively studied and ice samples from Dye 3 have been analyzed in detail.[6] The three important components of an ice density model are pressure, temperature, and air content, all other effects being minor by comparison. Our model, developed from combining the equation of state for ice with the perfect gas law, calculates ice density accurate to 7 parts in 10^4 down the well.

Before proceeding to Greenland we calibrated the borehole gravity meter to within an uncertainty of 0.03 mGal along an absolute calibration range in Alaska and Canada. For details see Sasagawa et al.[4] We also calibrated the length of the wireline, used to lower the borehole gravity meter down the well, both before and after the Greenland experiment to an uncertainty on the order of 1 part in 10^4 in a deep mine shaft in Idaho. For details see Ander et al.[4]

During the Greenland operation, 100 raw measurements of gravity were made down the well. These measurements resulted in eight gravity points from 213 m to 1673 m depth. In addition to the down hole measurements, 25 surface gravity measurements were also made. Electronic distance meters, first order leveling techniques, and a satellite Global Positioning System were used to obtain elevations of the surface gravity sites to within 15 cm and to map the ice surface topography to within 1 m covering a 10 km diameter region centered on the well.

Ice penetrating radar surveys are used to map the ice/rock interface in arctic environments. Airborne, ground, and airborne-ground radar surveys had previously been made in the region surrounding the hole providing good regional coverage out to at least 60 km.[7] We also performed a detailed surface radar survey that consisted of 124 radial lines, each 5 km long and centered on Dye 3 for a total of 42,600 radar reflections from the rock surface. Our surface survey was integrated with previous radar surveys to produce a map of the ice/rock interface. For details of the radar work see Gorman et al. and Fisher et al.[4] This map was then used to calculate out the gravitational effect of bedrock topography at each gravity observation point, both on the ice surface and down hole, using two different techniques. Both methods agreed. Uncertainty in the bedrock topography resulted in large uncertainties in the topography's gravitational effect and is the leading source of uncertainty in the gravity corrections. The maximum uncertainty is 0.5 mGal for the surface gravity data and 0.26 mGal for the gravity data down hole. The gravitational effect of the ice surface topography on the down hole gravity data amounted to less than 0.04 mGal over the entire 1460 m range of measurements and can therefore be neglected.

Newtonian gravity predicts that the total gravity from a 1460 m thick ice slab should be 112.52 mGal. Our experimental result indicates an additional 3.87 ± 0.36 mGal over the Newtonian prediction. This amounts to 3.4% increase in gravity over that predicted by Newton and is consistent with a Yukawa force with a range on the order of a kilometer and a strength of a few percent of the gravitational constant.

Our model does not include the effect of possible lateral density contrasts located within the bedrock beneath our gravity data. Determining the gravitational effects of lateral density anomalies is a very serious problem and is the weakness of all similar geophysical experiments. The crux of the problem is that any given gravity data set admits an infinite variety of density solutions. Although previous investigators have worried about this problem, it is clear that its nature is rather slippery and that others may have severely underestimated its effect on their experiments. At present, there is only one geophysical technique that lends itself to a rigorous study of the problem, gravity ideal body analysis.[8] We have shown that, in general, a small density anomaly located near a vertical gravity survey can produce large vertical gravity gradients, thus leading to possible false conclusions. In our case, we are helped by the fact that such contrasts can not be imediately to the side or just below any of our gravity measurements as in a mine or rock borehole experiment, but must be at least 360 m below our lowest gravity point.

Gravity ideal body analysis shows that our anomalous gradient can be made to disappear if the bedrock contains a suprisingly large percentage, greater than 35%, of high density anomalies that must exceed 2.94 g/cm^3. We know, from geologic and geophysical considerations, that the bedrock has an average density of about 2.7 g/cm^3 and that high density anomalies, due to mafic intrusions, probably exist in the bedrock with densities ranging from 2.8 to 3.0 g/cm^3. We also know that it is rather unlikely (not impossible) that any high density bodies will exceed about 3.0 g/cm^3. Furthermore, geologic mapping of exposed bedrock around the rim of the ice cap indicates that such high density mafic intrusions do exist and occupy only a few percent of the bedrock. In addition, it is difficult, but not impossible, to find an upper crustal geologic environment anywhere that will contain nearly 30% of its volume with high density of the order of 3.0 g/cm^3. A more rigorous discussion and a statistical analysis of our ideal body study is in Ander et al.[4]

In conclusion, our experimental results can be taken as evidence for the existence of non-Newtonian gravity. The results can also be explained in terms of a surprisingly large volume of mafic intrusions within the bedrock.

ACKNOWLEDGEMENTS This research was supported by the National Science Foundation, Los Alamos National Laboratory under the auspices of the Department of Energy, Amoco Production Company, Institute of Geophysics and Planetary Physics, the Air Force Geophysical Laboratory, and the University of Texas at Dallas.

REFERENCES

[1] T. Goldman, R. J. Hughes, M. M. Nieto, Phys. Lett. 171B, 217 (1986), and references therein.

[2] F. D. Stacey, G. J. Tuck, G. I. Moore, S. C. Holding, A. R. Maher, D. Morris, Phys. Rev. D., 23, 1683 (1981).

[3] D. H. Eckhart, C. Jekeli, A. R. Lazarewicz, A. J. Romaides, and R. W. Sands, Phys. Rev. Lett., 60, 2567 (1988).

[4] M. E. Ander, M. A. Zumberge, T. Lautzenhiser, R. L. Parker, C. L. V. Aiken, M. R. Gorman, M. M. Nieto, A. P. R. Cooper, J. Ferguson, E. Fisher, G. A. McMechan, G. Sasagawa, J. M. Stevenson, G. Backus, A. D. Chave, J. Greer, P. Hammer, L. Hansen, J. A. Hildebrand, R. Kelty, C. Sidles, F. N. Spiess, and J. Wirtz, Phys. Rev. Lett., submitted (1988); M. E. Ander, W. Kerr, C. L. V. Aiken, C. C. Glover, and M. A. Zumberge, Geophysics, submitted (1988); E. Fisher, G. A. McMechan, M. R. Gorman, A. P. R. Cooper, C. L. V. Aiken, M. E. Ander, and M. A. Zumberge, J. Geophys. Res., submitted (1988); M. R. Gorman, A. P. R. Cooper, M. E. Ander, C. L. V. Aiken, E. Fisher, and G. A. McMechan, J. Geophys. Res., submitted (1988); G. S. Sasagawa, M. A. Zumberge, J. M. Stevenson, T. Lautzenhiser, J. Wirtz, and M. E. Ander, J. Geophys. Res., submitted (1988).

[5] F. A. Dahlen, Phys. Rev. D., 25, 1735 (1982)

[6] C. C. Langway Jr., H. Oeschger, and W. Dansgaard, Greenland Ice Core: Geophysics, Geochemistry, and the Environment, Geophysical Monograph 33, American Geophysical Union, Washington, DC (1985)

[7] S. Overgaard, Radio Echo Sounding in Greenland, Data Catalog 1978, Technical University of Denmark (1978); S. Overgaard and N. S. Gundestrup, in C. C. Langway Jr., H. Oeschger, and W. Dansgaard, Greenland Ice Core: Geophysics, Geochemistry, and the Environment, Geophysical Monograph 33, American Geophysical Union, Washington, D.C., p. 49 (1985), N. S. Gundestrup, private comm.

[8] R. L. Parker, Geophysics, 39, 644 (1974), Geophys. J. Roy. Astr. Soc. 42, 315 (1975), M. E. Ander and S. P. Huestis, Geophysics, 48, 999 (1983), Geophysics 52, 1265 (1987)