nadian Shield (*12*) (including terranes varying in age from about 1 to 3 $\times 10^9$ years) and of the Finnish Shield (*13*) (including terranes varying in age from 1.7 to 3 $\times 10^9$ years). Because of the fewer samples available, errors in early silicate analytical methods, and the limited amount of data related to lithologic abundances when these studies were made, these estimates should not be regarded as being as accurate as the other estimates in Table 2. It is notable, however, that with the exception of their lower Mg, Mn, and Na:K values, which may or may not be real, both the Canadian and Finnish shields are of approximately the same composition as the Superior Province. If the 2.5 to 3.2 $\times 10^9$ year old graywackes in North America reflect the approximate composition of the North American crust older than 3.2 $\times 10^9$ years, it appears unwarranted to propose major compositional changes in the North American continent during the period between about 1.0 and 3.5 $\times 10^9$ years ago. Furthermore, even though sedimentary rocks younger than 1 $\times 10^9$ years show some secular compositional changes (*1*), the fact that they occupy a very small part of the North American continent seems to indicate that North America has not changed appreciably in composition during the last 3 to 3.5 $\times 10^9$ years.

There are now two popular theories regarding rates of continental growth: (i) one proposes that continents have grown at a rather uniform rate throughout geologic time (*1*), and (ii) the other advocates rapid growth during the early stages of continental evolution, with little subsequent growth (*14*). The conclusion that the North American continent may not have changed appreciably in composition during the last 3.0 to 3.5 $\times 10^9$ years appears to be compatible with either theory. If one assumes that the first is correct, it appears that the composition of new material being added to the continents from the mantle has had approximately the same composition for the last 3.0 to 3.5 $\times 10^9$ years. The second theory makes it appear as though the uniformity of composition was maintained primarily by recycling of crustal material.

In summary, the results of this investigation suggest that: (i) at least part of the ancient North American crust older than 3.2 $\times 10^9$ years was as highly differentiated as most younger North American Precambrian crust, and (ii) the North American crust may not have changed appreciably in composition during the last 3.0 to 3.5 $\times 10^9$ years.

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References and Notes

1. A. E. J. Engel and C. G. Engel, in *Advancing Frontiers in Geology and Geophysics*, A. P. Subramaniam and S. Balakrishna, Eds. (Osmania Univ. Press, Hyderabad, India, 1964), p. 17.
2. W. L. Donn, B. D. Donn, W. G. Valentine, *Geol. Soc. Amer. Bull.* **76**, 287 (1965).
3. E. Catanzaro, *J. Geophys. Res.* **68**, 2045 (1963).
4. ——— and J. L. Kulp, *Geochim. Cosmochim. Acta* **28**, 87 (1964); R. S. Cannon, Jr., R. W. Bayley, T. W. Stern, A. P. Pierce, in Rocky Mtn. Sect. Geol. Soc. Amer. program (1965), p. 27.
5. Detailed geochemical and mineralogic results on the graywackes are in preparation.
6. K. K. Turekian and K. H. Wedepohl, *Geol. Soc. Amer. Bull.* **72**, 175 (1961).
7. S. R. Nockolds, *ibid.* **65**, 1007 (1954).
8. A. E. J. Engel, C. G. Engel, R. G. Havens, *ibid.* **76**, 719 (1965).
9. Compiled from about 15 published papers.
10. G. A. Reilly, thesis, McMaster Univ., 1965.
11. K. E. Eade, W. F. Fahrig, J. A. Maxwell, *Nature* **211**, 1245 (1966).
12. F. F. Grout, *J. Geol.* **46**, 486 (1938).
13. J. J. Sederholm, *Bull. Comm. Geol. Finlande No. 70* (1925).
14. C. Patterson and M. Tatsumoto, *Geochim. Cosmochim. Acta* **28**, 1 (1964).
15. M. Tatsumoto, C. E. Hedge, A. E. J. Engel, *Science* **150**, 886 (1965).
16. Research sponsored by Washington University's NASA multidisciplinary research grant NaG-581. I thank A. M. Stueber for assistance with neutron-activation analysis, and W. D. Johns and W. J. Hannon for reading the manuscript and making suggestions.

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Gravity Increase at the South Pole

Abstract. *Measurements made between December 1957 and January 1966 of the gravity difference between the McMurdo Sound pendulum station, which is on bedrock, and the South Pole station, which is on the Antarctic ice sheet, show a gravity increase at the South Pole of 0.11 milligals per year. The most likely hypothesis for the increase is that it was caused by ice flowing downslope across a gravity gradient and by the sinking of the South Pole station as a result of accumulation of ice. An alternate hypothesis that the gravity increase was caused by a decrease in ice thickness, of about 40 centimeters per year, is theoretically possible but is not supported by direct evidence.*

The Antarctic ice sheet is the largest ice sheet in the world, and any vertical or horizontal movement that can be detected on it has significant glaciological implications. Changes in gravity on the ice sheet at the South Pole are indicated by repeated measurements of the difference in gravity between the South Pole station and McMurdo station from December 1957 (*1*) to January 1966. As McMurdo station is on bedrock, the change presumably occurred at the South Pole.

Recent improvements of gravimeters in sensitivity, calibration, and stability have increased the possibilities of detecting changes in elevation of the earth surface, and measurable changes have been reported (*2*). All measurements, or gravity ties, presented here were made by direct aircraft flight between stations with La Coste Romberg geodetic gravimeters calibrated on the North American calibration range (*3*), with the exception of gravimeter G91, for which the calibration provided by the manufacturer was used. These gravity ties are believed to include all of those made with thermostated gravimeters. Several ties made with Worden gravimeters (*1, 4*) were not included, as the drift closures were too great and there were uncertainties in the calibration due to temperature effects. The original data were recomputed to the nearest 0.01 mgal, earth tide corrections were made, and the values were all adjusted to the Gulf pendulum station at McMurdo station (*5*).

At McMurdo, Sparkman used the pendulum station base (*5*), which is now relatively inaccessible; Behrendt and Rambo used an auxiliary base at the Biological Laboratory, and Den Hartog, Robinson, and Jiracek used an auxiliary base in the U.S. Antarctic Research Program warehouse. At the South Pole (*6*) all observers used the same base. The data are presented in Table 1 and Fig. 1.

Figure 1 shows an apparent decrease in the differences in gravity between McMurdo station and the South Pole station of 0.11 mgal/year, determined by a least-squares fit to the data. As the standard deviation of the data from the line is only about 13 percent of the total change, I believe that the change shown is real. Since the gravity is greater at McMurdo, the net result is an increase in gravity at the South Pole station.

Table 1. Measured difference in gravity between McMurdo pendulum station and the South Pole. Gravity at pendulum station is 982.9919 gal (7).

Date	Difference in gravity (mgal)	Trips between stations	Time interval (hr)	Gravimeter	Observer
5 Dec. 1957	664.22	1	23	L R 1	Sparkman
9–12 Feb. 1961	663.99	2	14 (av.)	G1a	Behrendt
16 Dec. 1961 to 17 Jan. 1962	664.01	5	11 (av.)	G19	Sparkman
19 Nov. 1962	663.73	1	15*	L R 5	Robinson
29 Dec. 1962	663.93	1	12	G19	Den Hartog
19 Jan. 1965	663.52	1	11	G64	Jiracek
19 Jan. 1965	663.32	1	11	G65	Jiracek
19 Jan. 1966	663.51	1	16	G91	Rambo

*One-way tie, not closed at McMurdo.

An increased snow load above the gravity station at the Pole would cause a small gravity decrease, rather than increase. The snow load at the Pole increased from virtually zero in December 1957 to about 7 m in January 1966. This amount of snow corresponds to approximately 2.8 m of water, with a total gravity effect of −0.11

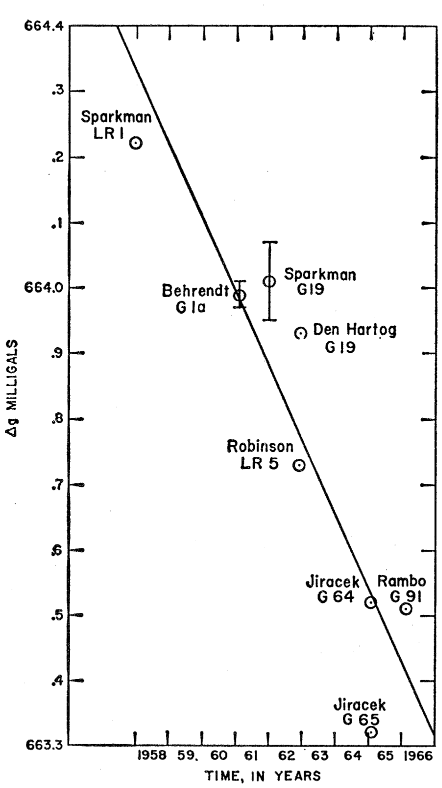

Fig. 1. Change in the gravity interval between the Gulf pendulum station at McMurdo station and T gravity station at South Pole station between December 1957 and January 1966. Observers and gravimeters used are shown. Line is least-squares fit to data; the standard deviation $\sigma = \pm 0.12$ mgal, the slope $S = -0.11$ mgal/year. The error bars shown indicate standard deviation where more than one observation was made. The gravimeter designations are as shown in Table 1.

mgal. The effect of the drift load in excess of accumulation would be an increase in density with depth, with a consequent decrease in elevation of about 0.45 m or a gravity increase of about 0.14 mgal. Thus, the effects of the drift load would tend to cancel.

There are several possible explanations for the observed gravity increase: (i) isostatic depression of the rock surface due to an increased ice load; (ii) decrease in total ice thickness; (iii) sinking of the station to balance accumulation; (iv) horizontal movement of the station across a gravity gradient; and (v) flow toward lower ice-surface elevation.

An increase of 0.11 mgal/year corresponds to a change in elevation of 36 cm/year, with the free air gradient (0.3086 mgal/m) as an approximation. This value is about two orders of magnitude greater than could be expected for isostatic loading. Therefore the gravity change can justifiably be ascribed to ice movement.

Another possible explanation of a gravity increase is a wasting ice sheet with a consequent decrease in surface elevation. The increase of 0.11 mgal/year requires a decrease of 40 cm/year in ice thickness, or 3.2 m during the 8-year period of observation. There is no evidence to support this hypothesis; rather, there has been an increase in the rate of accumulation in the South Pole area (7).

If we assume steady-state equilibrium, the surface of an ice sheet remains at a constant elevation, and a particle deposited on the surface must sink at the rate of snow accumulation. If we used the value 7.5 g cm^{-2} $year^{-1}$ (7) and a density of 0.4 g/cm^3, we would expect a sinking rate of 19 cm/year (1.5 m since 1957). The additional 5.5 m now observed above the station is probably the result of drifting. The sinking would result in a gravity increase of 0.05 mgal/year, about half that observed. Horizontal movement would be required to explain the additional 0.06 mgal/year increase.

Although there have been several astronomic determinations of position at the South Pole, the data scatter has not allowed a determination of the small horizontal motion of the ice sheet. Thus the measurement could be affected by a decrease in elevation caused by the station's movement downslope and across a gravity gradient. Gravity and elevation data taken at 1- to 4-km intervals from the various oversnow traverses radiating about the Pole (8) show about 0.6 mgal/km increase in free-air anomaly toward 45°W, which is the direction of the downward snow-surface slope (about −2 m/km). Flow of ice down hill, carrying the station across the gradient in this direction, would cause the gravity to increase. Based on the ice-surface slope of −2 m/km and the combined effects of the horizontal gravity gradient and the sinking due to snow accumulation, a movement of 50 m/year would account for the change of 0.11 mgal/year observed. This is a reasonable value and is comparable to Bauer's (9) value of 150 m/year for central Greenland. As there is neither a detailed gravity survey nor knowledge of bedrock topography in the immediate vicinity of the station, it is possible that a buried topographic feature could cause a gravity anomaly which would change the gradient locally, even resulting in a decrease in gravity at the station.

In summary, gravity at the South Pole has increased since 1957; the increase is probably the result of horizontal movement of the ice sheet downslope (possibly 50 m/year) across a gravity gradient, combined with the sinking of the station into the ice sheet as a result of ice accumulation. A thinning ice sheet could also explain part or all of the gravity increase, but there is no evidence to support this hypothesis. A detailed gravity survey and more determinations of astronomical position are needed to determine the most likely hypothesis.

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References and Notes

1. E. Thiel, *IGY Glacial Rept. Ser.* I-1 (1959).
2. D. F. Barnes, *J. Geophys. Res.* **71**, 451 (1966); K. Iida, M. Kayakowa, K. Katoyose, *Chishitsu Chosasho Hokoku* **152**, 23 (1952).
3. J. C. Behrendt, *Geophysics* **27**, 889 (1962); gravimeters No. 1, 5, and G1a; R. Iverson, personal communication; gravimeters G-19, G-64, and G-65 were calibrated by the U.S. Army Map Service.
4. J. C. Behrendt, R. J. Wold, T. L. Laudon, *Geophys. J.* **6**, 400 (1962).
5. G. P. Woollard and J. C. Rose, *International Gravity Measurements* (Society of Exploration Geophysicists, Tulsa, Okla., 1963), p. 518.
6. The pendulum station is on a concrete slab over a brass plaque stamped "Gulf Pendulum Station, McMurdo Sound" beneath the wood floor of Building 43 (formerly Building 30); it was last occupied by Den Hartog in 1962. The Biological Laboratory station is located (as of 1966) at the west edge of the center archway of the building about 10 m south of the north entrance. In October 1960 C. R. Bentley measured a difference of —3.06 ± 0.02 mgal (3 ties) between it and the pendulum station. The U.S. Antarctic Research Program warehouse station is on a concrete slab at the center of the east side of the storeroom part of the building, and in November 1962 Den Hartog measured a difference (4 ties) of —3.36 ± 0.01 mgal relative to the pendulum station. The station at the South Pole is on the tunnel floor at the left-hand corner of the science building as the observer faces the end door nearest the ionospheric sounder. The various observers read at locations having an uncertainty of about ± 1 m or less horizontally and about ± 15 cm vertically corresponding to ± 0.04 mgal.
7. M. Giovinetto and W. Schwerdtfeger, *Arch. Meterol. Geophys. Bioklimatol.* **15**, 227 (1966).
8. J. G. Weihaupt, *Geophysics* **28**, 582 (1963); E. S. Robinson, *Univ. of Wisconsin, Geophysical and Polar Res. Cent. Rept.* Ser. No. 62-6, 49 (1962) and No. 64-7, 88 (1964).
9. A. Bauer, *Annals of IGY* **11**, 30 D (1961).

10. I would like to thank C. R. Bentley for furnishing unpublished data. He, G. P. Woollard, E. S. Robinson, J. K. Sparkman, and R. M. Iverson greatly assisted me in obtaining the original data and calibration information for the gravimeters used. The U.S. Geological Survey made the 1966 observation; the earlier data were observed by the Univ. of Wisconsin. Work supported by NSF. The U.S. Navy provided logistic support. Publication authorized by the Director, U.S. Geological Survey.

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Fibrinogen from Human Plasma: Preparation by Precipitation with Heavy-Metal Coordination Complex

Abstract. *Potassium tetrathiocyanato-(S)mercurate II [$K_2Hg(SCN)_4$] is used in a mild and rapid procedure for the isolation of human fibrinogen from fresh plasma. The final product, 94 to 99 percent of which is coagulable by thrombin, represents an average yield of 80 percent and is stable in solution. It is free of plasmin, streptokinase-activatable plasminogen, and coagulation factors II, V, VIII, X and XIII. Sedimentation analysis reveals a single peak with a sedimentation coefficient equal to 7.0S at infinite dilution. Immunodiffusion on cellulose acetate results in two precipitin lines with rabbit antiserum to whole human serum. The fibrinogen precipitates are unusual in that they are flocculent and readily redissolve.*

The techniques commonly used for the isolation of fibrinogen from blood plasma often result in relatively low yields (*1, 2*). The final product is unstable in solution and is invariably contaminated with plasminogen and other coagulation factors, especially fibrin-stabilizing factor (FSF). Furthermore, the conditions used are distinctly nonphysiological, and the protein precipitates obtained are difficult to dissolve and have a tough rubber-like consistency. We report a new method for the isolation and purification of fibrinogen with the use of a heavy-metal coordination complex as a reversible protein precipitant. Many of the problems associated with prior techniques are absent from our procedure.

We now report on our use of mercury thiocyanate anions previously reported as an "interesting" specific precipitant of fibrinogen (*3*). (i) In our study fresh plasma (200 ml) was separated from whole blood collected on Dowex 50W-X-8 (sodium cycle) resin with a Cohn fractionator; the plasma was collected in a plastic vessel containing 10 g (wet weight) of barium sulfate (*4*) and enough ε-aminocaproic acid so that its concentration in the plasma was 0.1 mole/liter. The plasma was gently agitated during the collection to insure dispersion of the barium sulfate and dissolution of ε-aminocaproic acid. Stirring was continued for 1 hour at room temperature or overnight at 2°C. (ii) After the $BaSO_4$ was removed by centrifugation, the plasma supernatant was treated with 5 g of triethyl-aminoethyl-cellulose (wet weight) per 50 ml of plasma. (The cellulose was put on the hydroxyl cycle by exposure to 0.5*M* NaOH, extensively washed with H_2O to neutrality, and then collected by vacuum filtration on a Büchner funnel.) The suspension was stirred intermittently for 10 minutes at room temperature and then centrifuged for 15 minutes at 8000*g*. The cellulose precipitate was washed with one plasma volume of a solution containing 0.15*M* NaCl and 0.1*M* ε-aminocaproic acid, *p*H 7.2. The treated plasma and wash solution were pooled (the pool volume was approximately twice that of the starting plasma). (iii) The diluted TEAE-treated plasma was adjusted to *p*H 7.2, with 0.1*M* sodium acetate, *p*H 4.0, cooled to 0°C, and made 4 m*M* in $K_2Hg(SCN)_4$ by the addition of the appropriate volume of a 50 m*M* solution (*5*). The resulting suspension was allowed to stand for 1 hour at 0°C with occasional mixing and then centrifuged for 15 minutes at 8000*g*. (iv) The fibrinogen-containing precipitate was washed twice with 50 ml of cold buffer (0.15*M* sodium acetate, 0.1*M* ε-aminocaproic acid, *p*H 6.5) to remove occluded protein. The washed precipitate was then readily dissolved at room temperature in 25 ml (one-eighth of the plasma volume) of a solution containing 0.3*M* NaCl and 0.1*M* ε-aminocaproic acid, *p*H 7.2. (v) In order to remove the $K_2Hg(SCN)_4$, the solution (25 ml) was passed through a column of Sephadex G-25 (70 ml) with a solution of 0.3*M* NaCl, *p*H 7.2, as the mobile phase. The column eluate, monitored at 254 mμ, had two peaks. The initial peak contained all the protein, and the second peak contained the coordination complex which absorbed in the ultraviolet. The protein-containing fraction was rendered free of detectable Hg^{++} by the addition of Chelex-100 (4 g/100 ml) (*6*). The resulting solution, after removal of the resin by centrifugation, was the final product and had a protein concentration of 0.7 to 1.2 percent.

If the plasma was not immediately treated with $BaSO_4$ and TEAE as described, the solution was cooled to 0°C and allowed to remain at this temperature overnight. The resultant cold-insoluble fibrinogen (CIF) was collected by centrifugation at 8000*g*, a procedure necessary to insure the complete removal of any CIF formed due to action of thrombin. When fresh plasma was treated immediately with $BaSO_4$ and TEAE, the entire procedure required a maximum of 8 hours.

The final preparation was 94 to 99 percent coagulable by thrombin, as determined by the method of Blombäck and Blombäck (*2*), an average recovery of 80 percent of the fibrinogen present in the starting plasma. The fibrinogen solution obtained by our method has