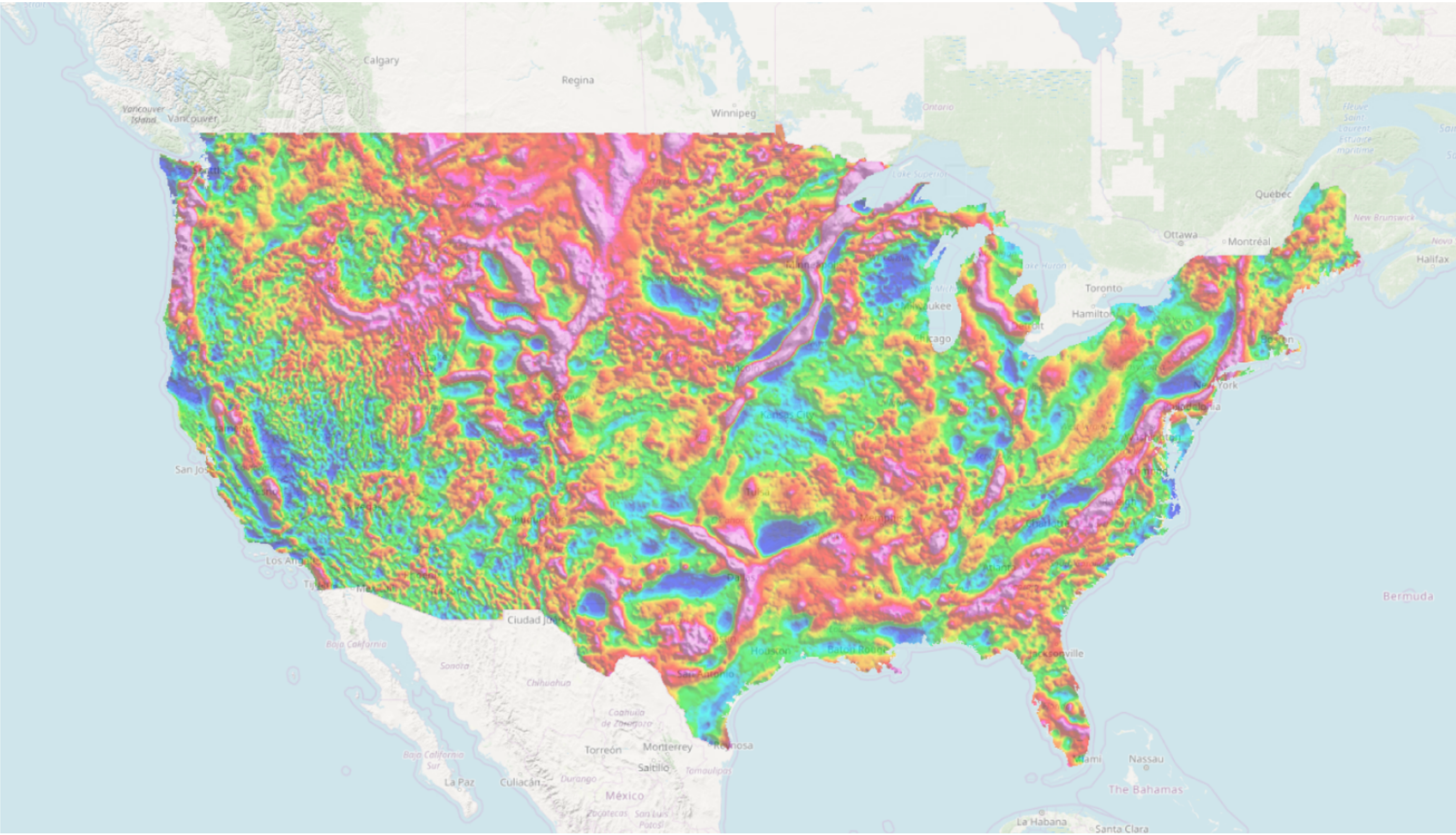
Gravity



Calgary
Regina
Winnipeg
Vancouver Island
Vancouver
Ontario
Québec
New Brunswick
Ottawa
Montréal
Halifax
Toronto
Hamilton
Milwaukee
Chicago
New York
San Jose
Los Angeles
Houston
Jacksonville
Bermuda
Baja California
Sonora
Chihuahua
Coahuila de Zaragoza
Torreón
Monterrey
Saltillo
Tamaulipas
Baja California Sur
La Paz
Culiacán
Durango
México
Nassau
The Bahamas
La Habana
Santa Clara

Upgraded gravity anomaly base of the United States

G. Randy Keller, University of Texas at El Paso, U.S.
Thomas G. Hildenbrand, U.S. Geological Survey, Menlo Park, California, U.S.
Robert Kucks, U.S. Geological Survey, Denver, Colorado, U.S.
Dan Roman, National Oceanic and Atmospheric Administration, Silver Spring, Maryland, U.S.
Allen M. Hittelman, National Oceanic and Atmospheric Administration, Boulder, Colorado, U.S.

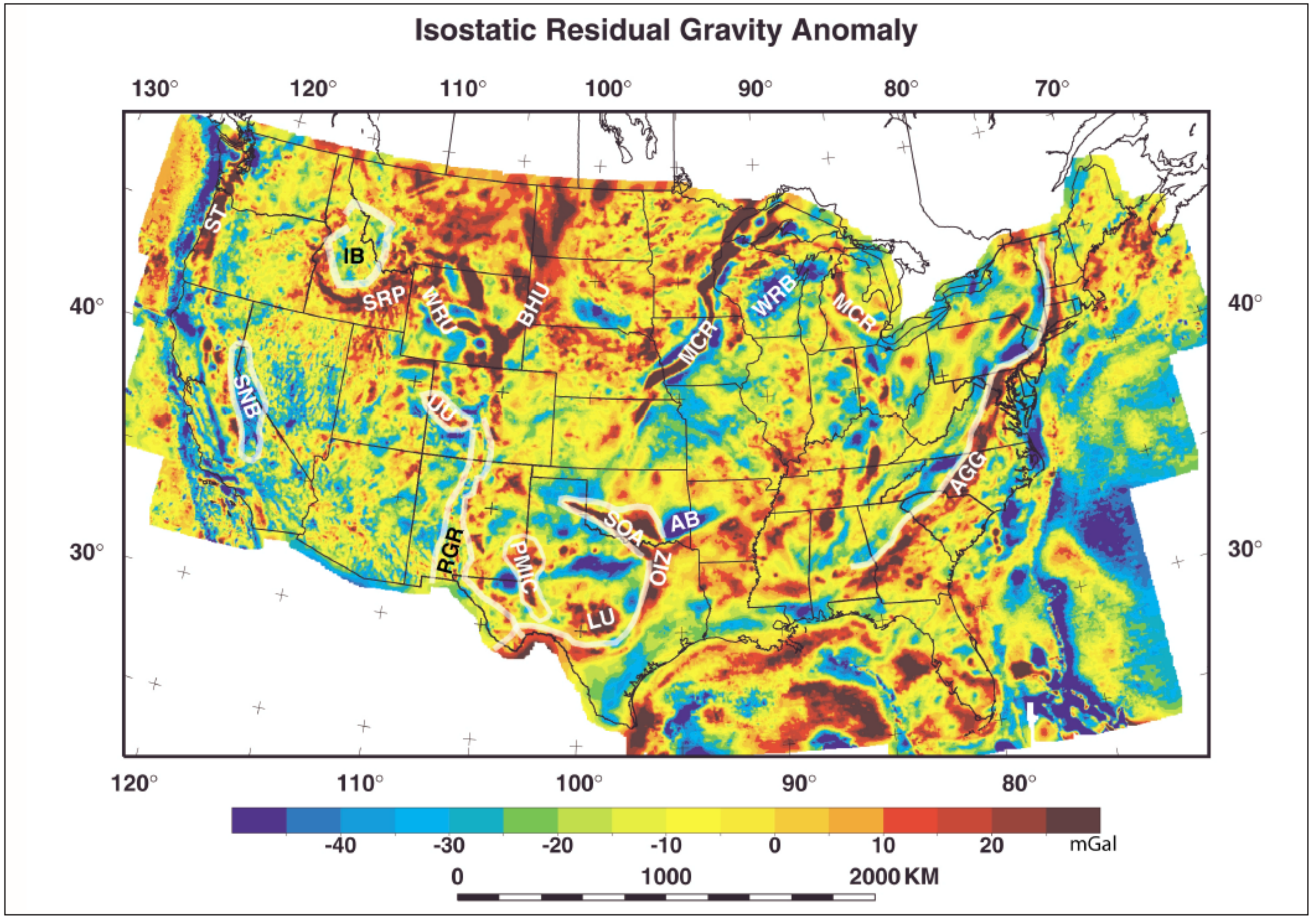
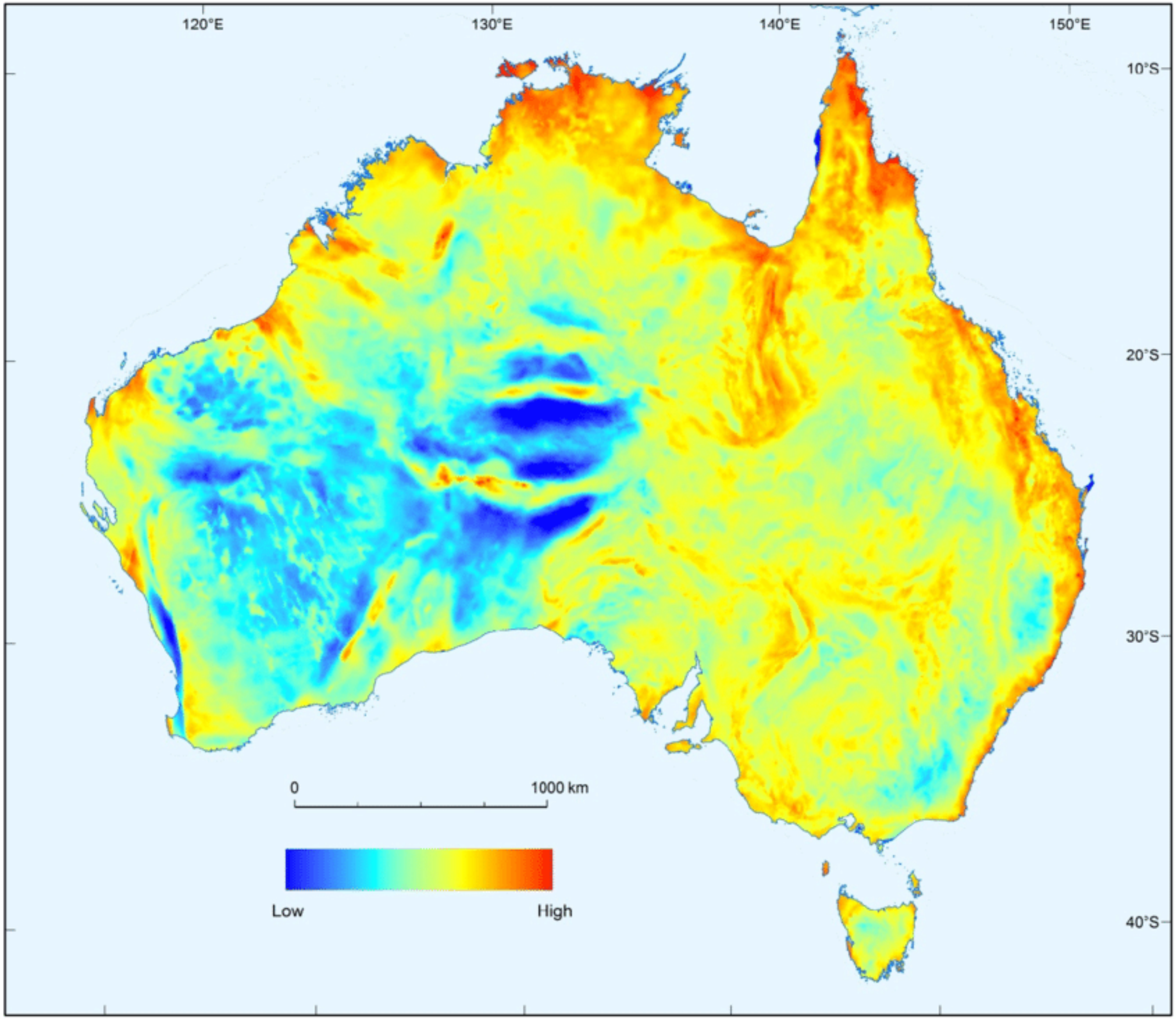
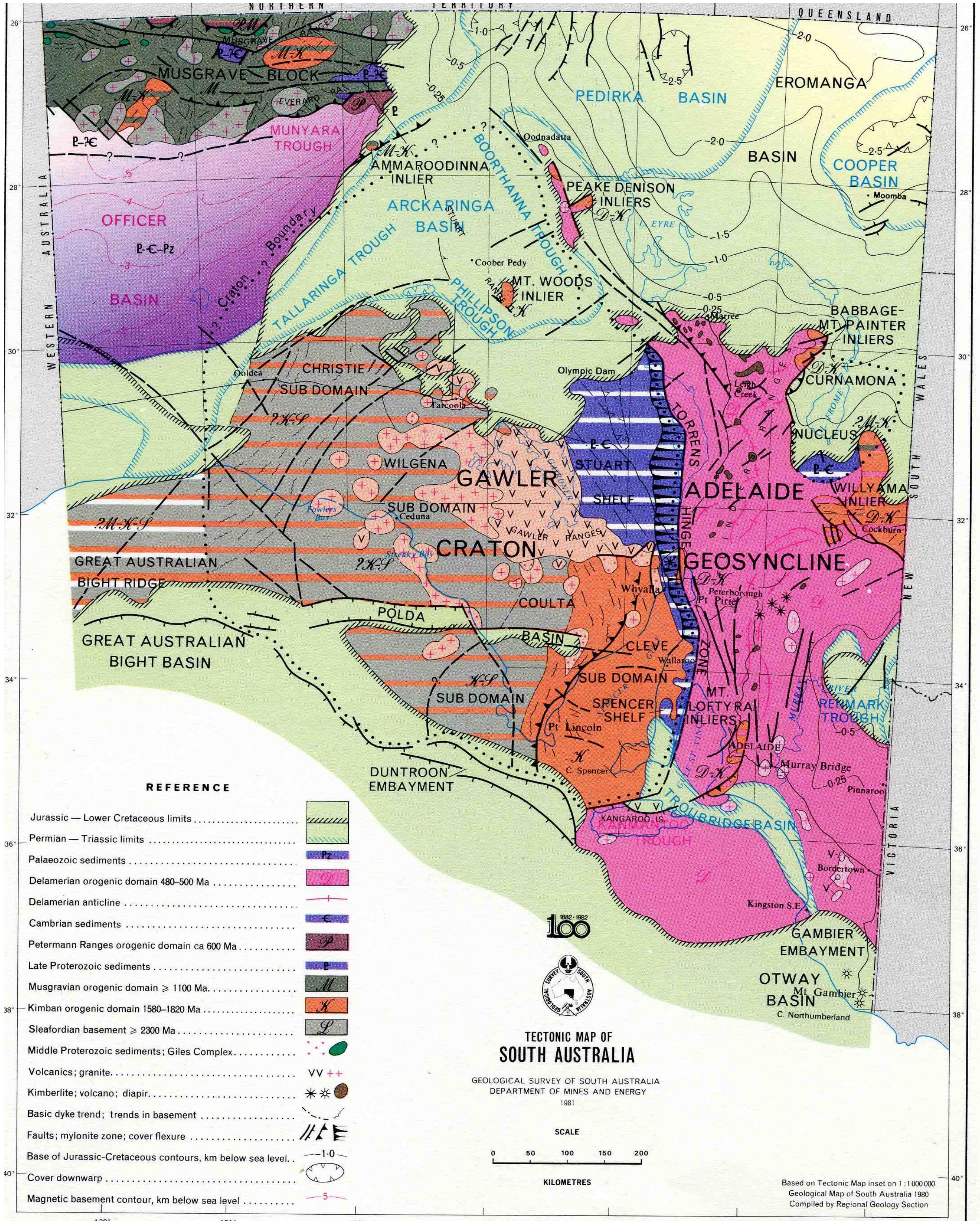
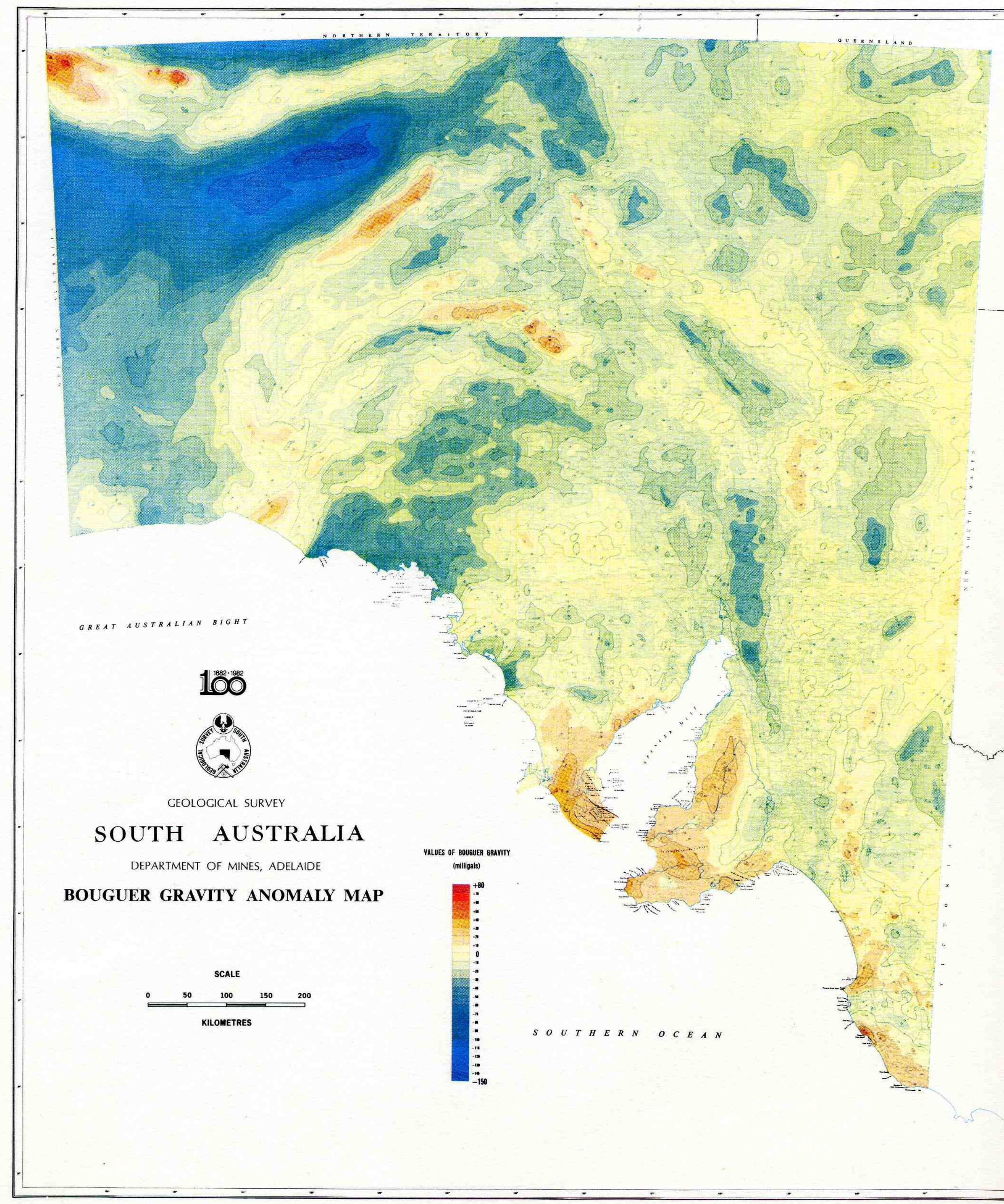


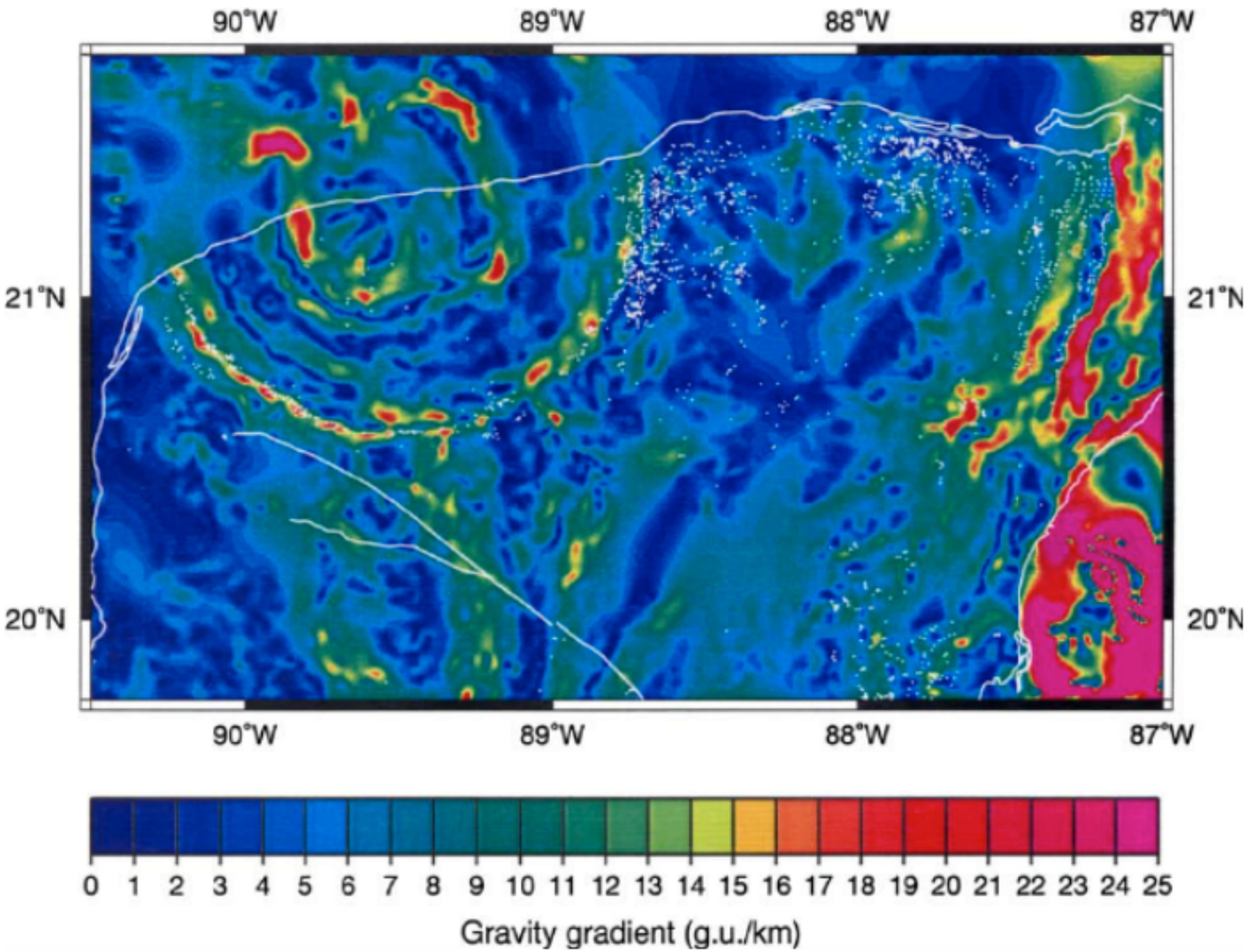
Figure 1. Isostatic residual gravity anomaly map of the conterminous United States (after Simpson et al., 1986). A few major gravity features are highlighted, such as the highs related to the Snake River plain (SRP), Siletz terrane (ST), Midcontinent rift system (MCR), Uncomphagre uplift (UU), Pecos mafic igneous complex (PMIC), Southern Oklahoma aulacogen (SOA), Llano uplift (LU), Black Hills uplift (BHU), Wind River uplift (WRU), and Ouachita interior zone (OIZ) and the lows associated with the Sierra Nevada batholith (SNB), Idaho batholith (IB), Rio Grande rift (RGR), Arkoma basin (AB), and Wolf River batholith (WRB). The Appalachian gravity gradient (AGG) that marks the ancient margin of North America is also labeled.


120°E
130°E
140°E
150°E
10°S
20°S
30°S
40°S
0
1000 km
Low
High





D.J.Woolman, Government Printer.



Gravity anomalies over Chicxulub crater. Horizontal gravity gradient (gravity units per kilometre) showing the concentric circular gravity pattern over the buried Chicxulub structure (data from Connors et al. 1996). Yucatan Peninsula coastline contour is marked by the white curve. Approximate geometric centre is on the coastline at Chicxulub Puerto (see Figure 8).

Shipboard gravimeter

http://zlscorp.com/

LaCoste-Romberg model G

http://deepearthscience.blogspot.com/

Airborne Gradiometers: Bell Aerospace -> Bell Geospace -> Lockheed Martin -> Fugro.

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Graviometry

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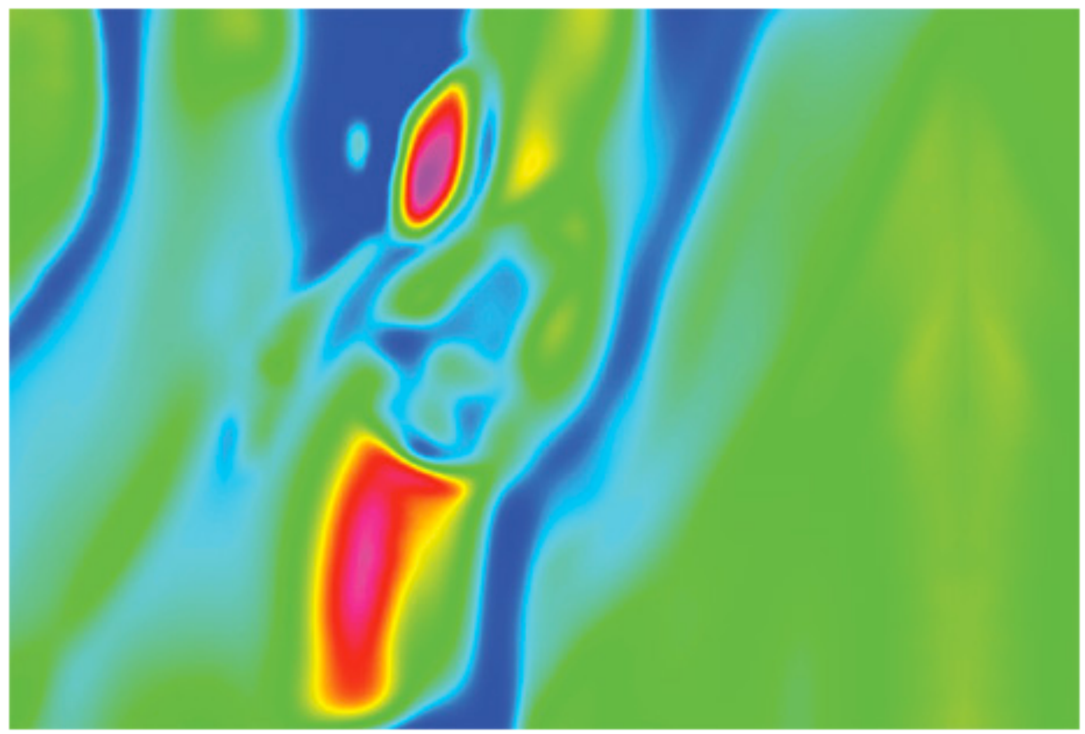


For more than a decade, the Gravity Systems team has provided the world's only moving-base gravity gradiometer capabilities.

Overview

Gravity Gradiometer technology measures minute differences in the earth's density to yield information on geologic structures underground and undersea. This information is used for a variety of applications, including natural resource exploration, navigation, and underground detection and can be deployed on marine ships and aircraft.

For more than three decades, Lockheed Martin has provided the world's only moving-based gravity gradiometer capabilities. Gravity gradient data is

FEATURE STORIES

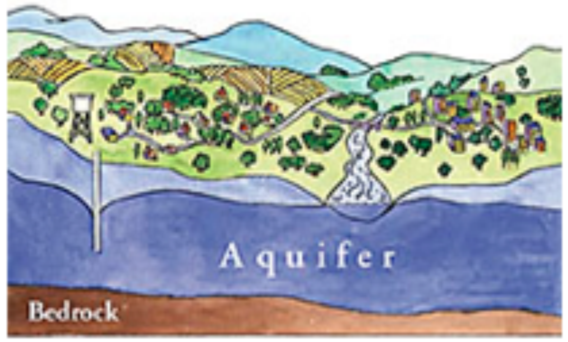
Using Gravity to Detect Underground Threats

ADVANTAGES

- High Spatial Resolution
- Detailed Imagery

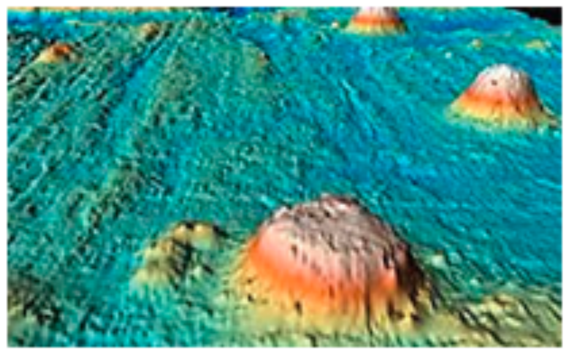
APPLICATIONS

Mineral and hydrocarbon exploration



Aquifer detection

Geothermal Exploration



Underwater navigation and collision avoidance

Terrain estimation

Underground tunnel and void detection

Lockheed Martin

Notice the submarines - that's where the Bell gradiometer probably started - in the "Hunt for Red October" it was leaked that the US was using gravity for terrain following.

DEPLOYMENT PLATFORMS

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The Free Encyclopedia

The Hunt for Red October (film)

From Wikipedia, the free encyclopedia

The Hunt for Red October is a 1990 American submarine spy thriller film directed by John McTiernan, produced by Mace Neufeld, and starring Sean Connery, Alec Baldwin, Scott Glenn, James Earl Jones, and Sam Neill. The film is an adaptation of Tom Clancy's 1984 bestselling novel of the same name. It is the first installment of the film series with the protagonist Jack Ryan.

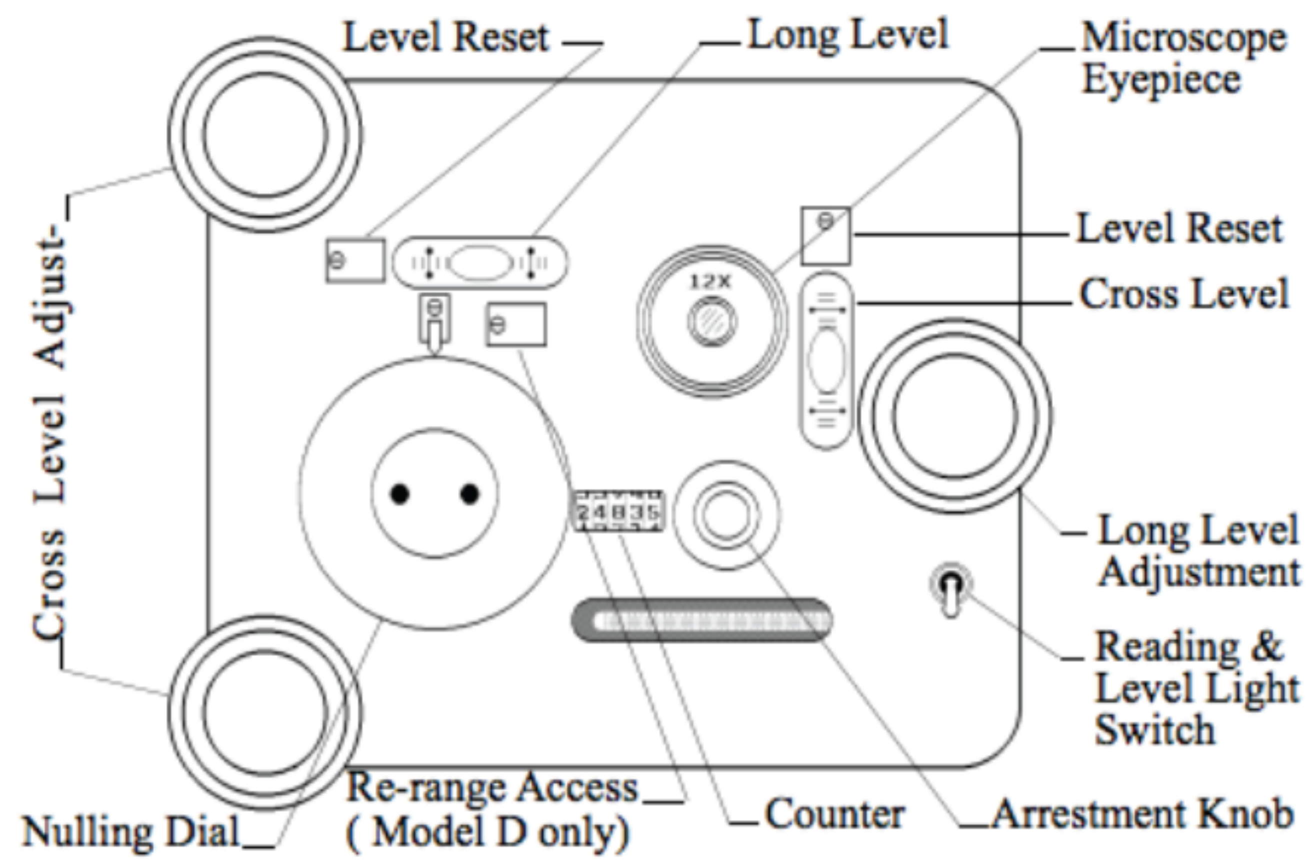
The story is set during the late Cold War era and involves a rogue Soviet naval captain who wishes to defect to the United States with his officers and the Soviet Navy's newest and most advanced ballistic missile submarine, a fictional improvement on the Soviet Typhoon-class submarine. A CIA analyst correctly deduces his motive and must prove his theory to the U.S. Navy before a violent confrontation between the Soviet and the American navies spirals out of control.

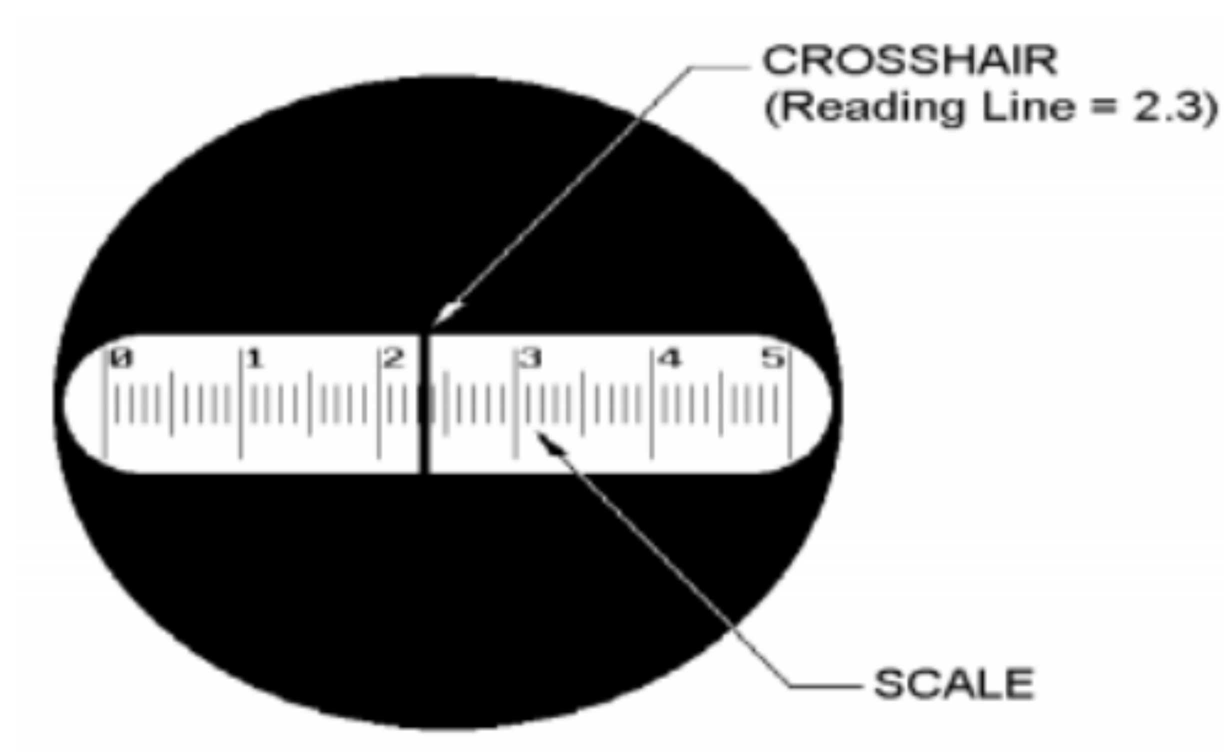
The Hunt for Red October

The film caused a minor sensation in the black projects submarine warfare technology community.[14][15] In one scene, where USS *Dallas* is chasing *Red October* through the submarine canyon, the crew can be heard calling out that they have various "milligal anomalies". This essentially revealed the use of gravimetry as a method of silent navigation in US submarines. Thought to be a billion dollar black project, the development of a full-tensor gravity gradiometer by Bell Aerospace was a classified technology at the time. It was thought to be deployed on only a few *Ohio*-class submarines after it was first developed in 1973. Bell Aerospace later sold the technology to Bell Geospace for oil exploration purposes.[16] The last Typhoon-class submarine was officially laid down in 1986, under the name *TK-210*, but according to sources was never finished and scrapped in 1990.[17]

SIO 182 data collection

75	FIRST AVENUE	LAUREL ST	2067	17192	226.885	* SWBP
76	FIRST AVENUE	LEWIS ST	2141	17192	294.09	SEBP
77	FIRST AVENUE	MAPLE ST	207	1719	230.046	NWBP
78	FIRST AVENUE	MONTECITO WAY	2145	17192	297.189	NEBP
79	FIRST AVENUE	NUTMEG ST	207	1719	236.049	NEBP
80	FIRST AVENUE	PALM ST	208	1719	254.339	NEBP
81	FIRST AVENUE	PENNSYLVANIA AVE	211	1719	275.994	NWBP
82	FIRST AVENUE	QUINCE ST	208	1719	251.047	NEBP
83	FIRST AVENUE	REDWOOD ST	208	1719	249.101	NEBP
84	FIRST AVENUE	ROBINSON AVE	212	1719	281.034	NWBP
85	FIRST AVENUE	SPRUCE ST	209	1719	259.081	NEBP
86	FIRST AVENUE	THORN ST	209	1719	260.977	NWBP
87	FIRST AVENUE	UNIVERSITY AVE	212	1719	284.154	NWBP
88	FIRST AVENUE	UPAS ST	210	1719	263.546	SWBP
89	FIRST AVENUE	WALNUT AVE	210	1719	276.152	NEBP
90	FIRST AVENUE	WASHINGTON ST	2134	17193	290.792	SEBP
91	SECOND AVENUE	ASH ST	2025	17195	72.461	* NEBP
92	SECOND AVENUE	BEECH ST	202	1719	80.898	NWBP
93	SECOND AVENUE	BROADWAY	2010	17198	42.711	* NEBP IN TOP INLET
94	SECOND AVENUE	'C' ST	2013	17194	44.355	* SWBP
95	SECOND AVENUE	ELM ST	2040	17194	121.787	* SWBP
96	SECOND AVENUE	'F' ST	200	1719	25.08	SWBP
97	SECOND AVENUE	'G' ST	199	1719	20.06	SWBP





http://deepearthscience.blogspot.com/

Use of gravimeter number 349.

1) Set the tripod dish firmly in/on the ground in the position of measurement.

2) Open the case and check the beam is locked. Lift the meter out by the levelling screws. Careful! These can come all the way out, so give them a half-turn in (clockwise) to be sure this won't happen.

3) Set the meter in the dish and move into a rough level holding the bottom of the meter.

4) Turn the two screws on the left in opposite directions to get the up/down level.

5) Turn the single screw on the right to get the left-right level. Iterate if needs be.

6) Turn on the meter light.

7) Unlock the beam.

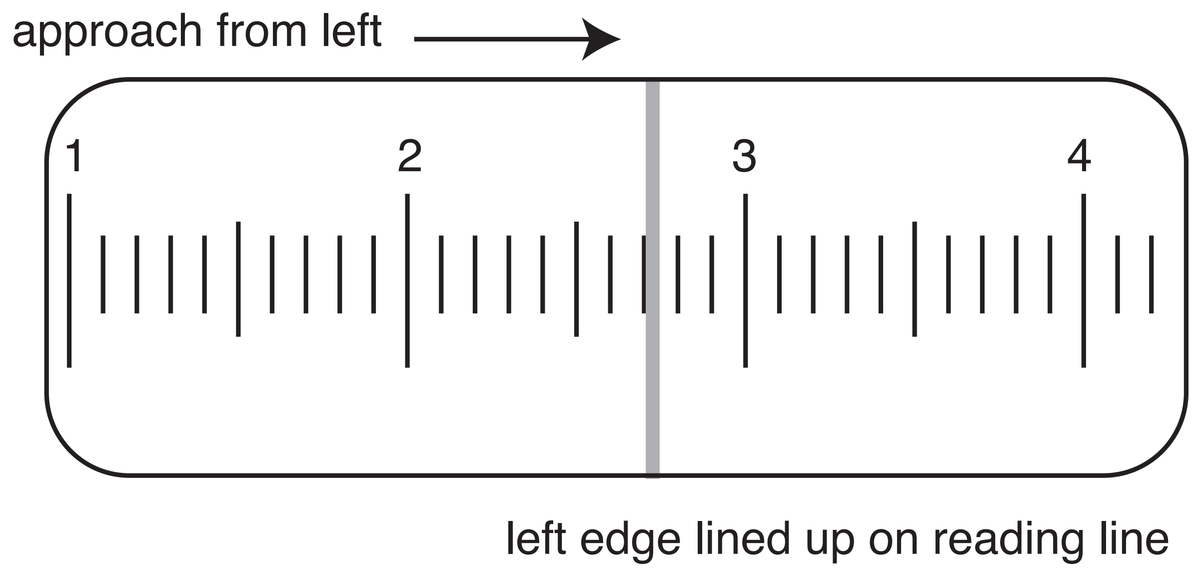
8) Remove your hat.

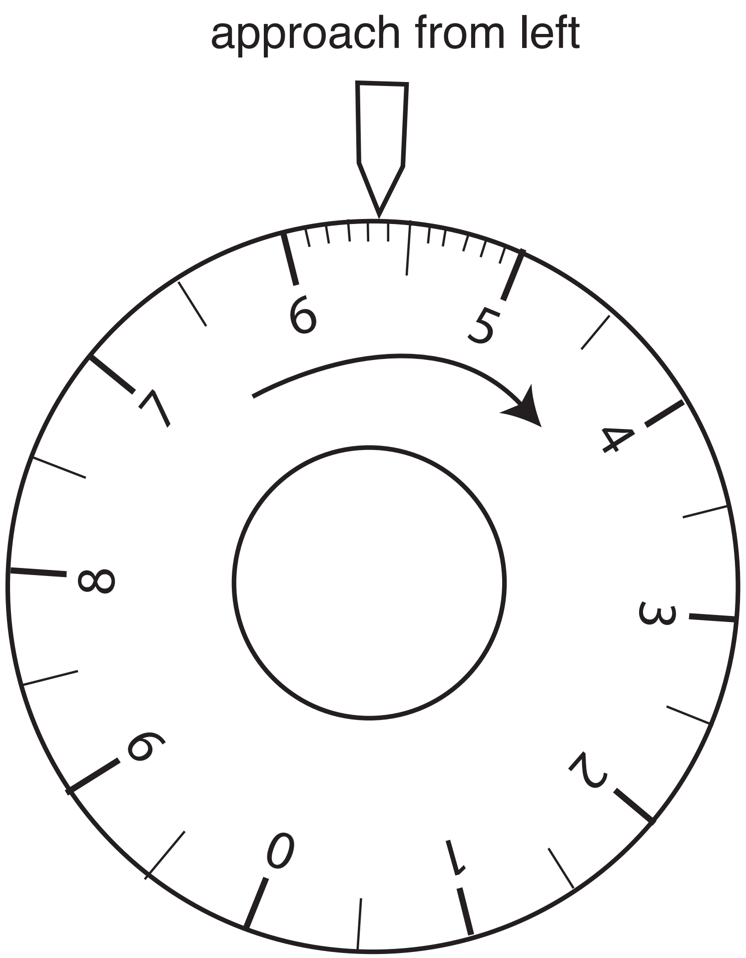
9) Use the main dial to get the beam image to the right of the reading line (2.70). The beam moves in the same direction as the top of the main dial.

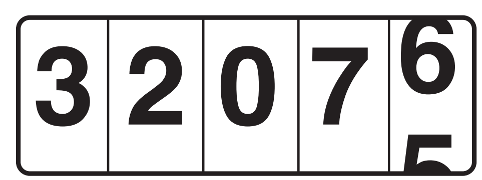
10) Slowly (!!) turn the main dial until the left edge of the beam is aligned with the reading line (2.70). If you overshoot, return to the right side and approach again from the right. This is to avoid 'backlash' in the mechanism.

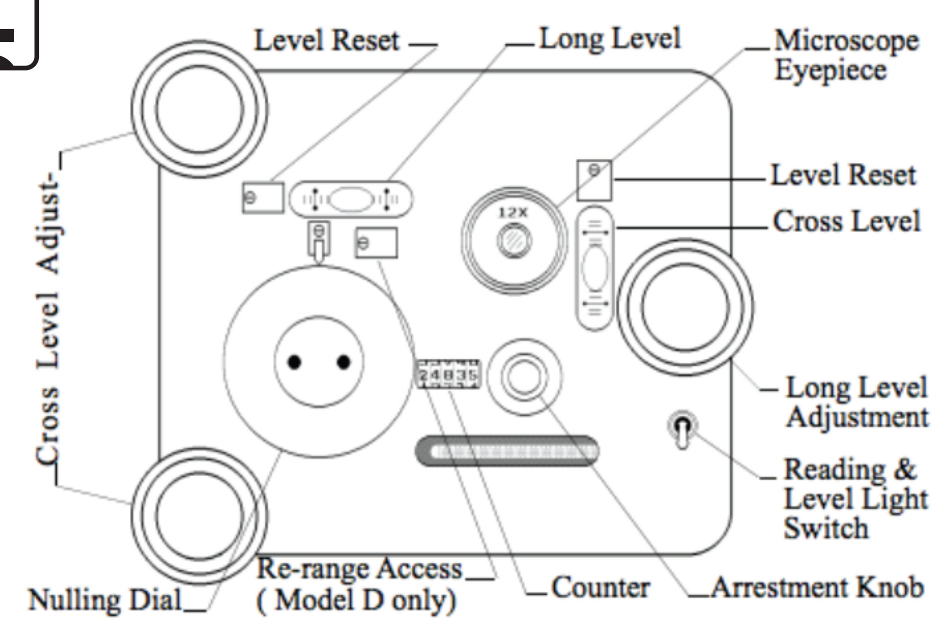
11) Lock the beam. Read the number from the counter. The last number on the counter corresponds to the numbers on the main dial. The main dial can be read to at least 0.05 units.

12) Check the beam lock again. Switch off the meter. Return it to the case.


approach from left
1
2
3
4
left edge lined up on reading line

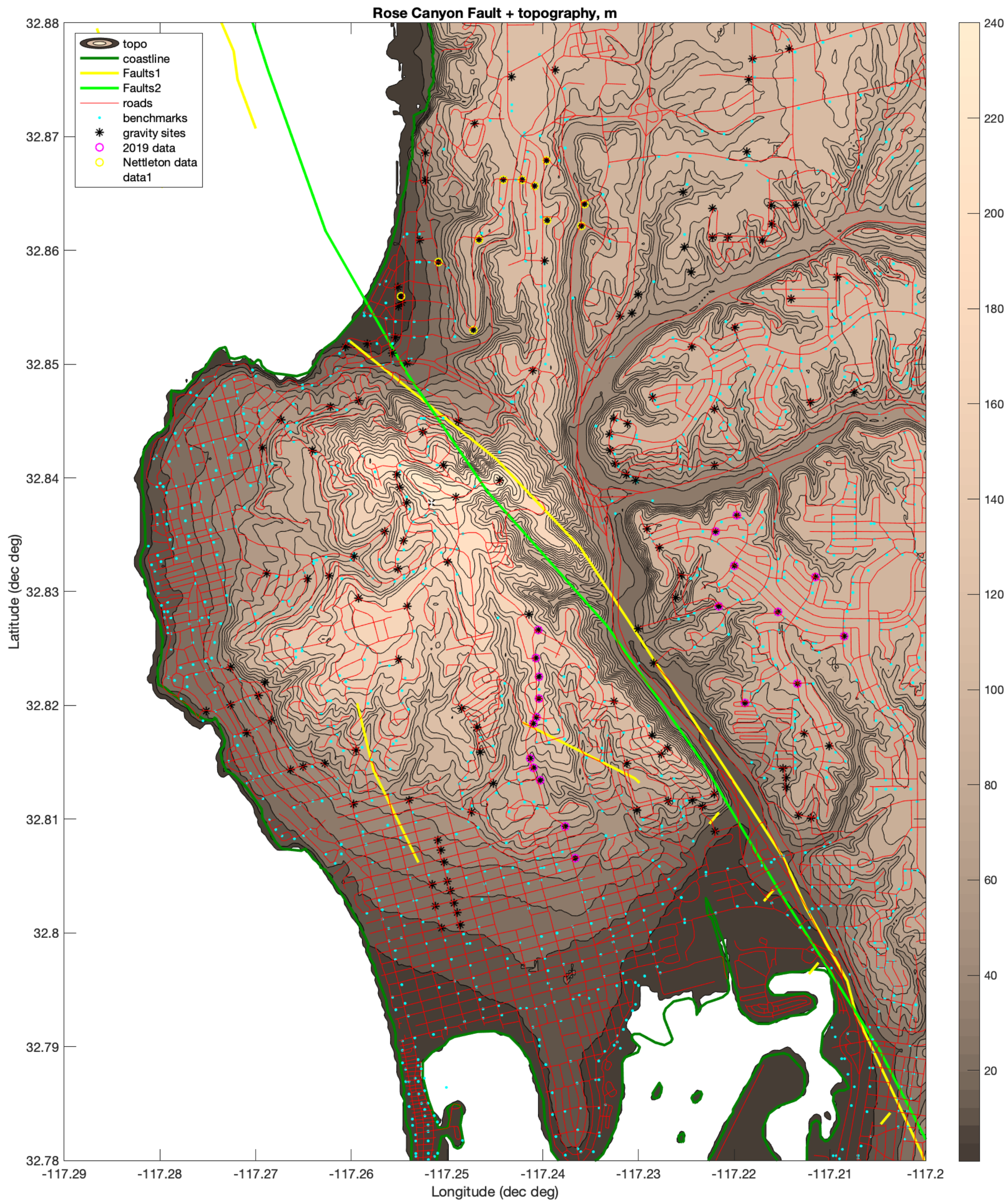

approach from left
6
5
4
3
2
1
0
9
8
7

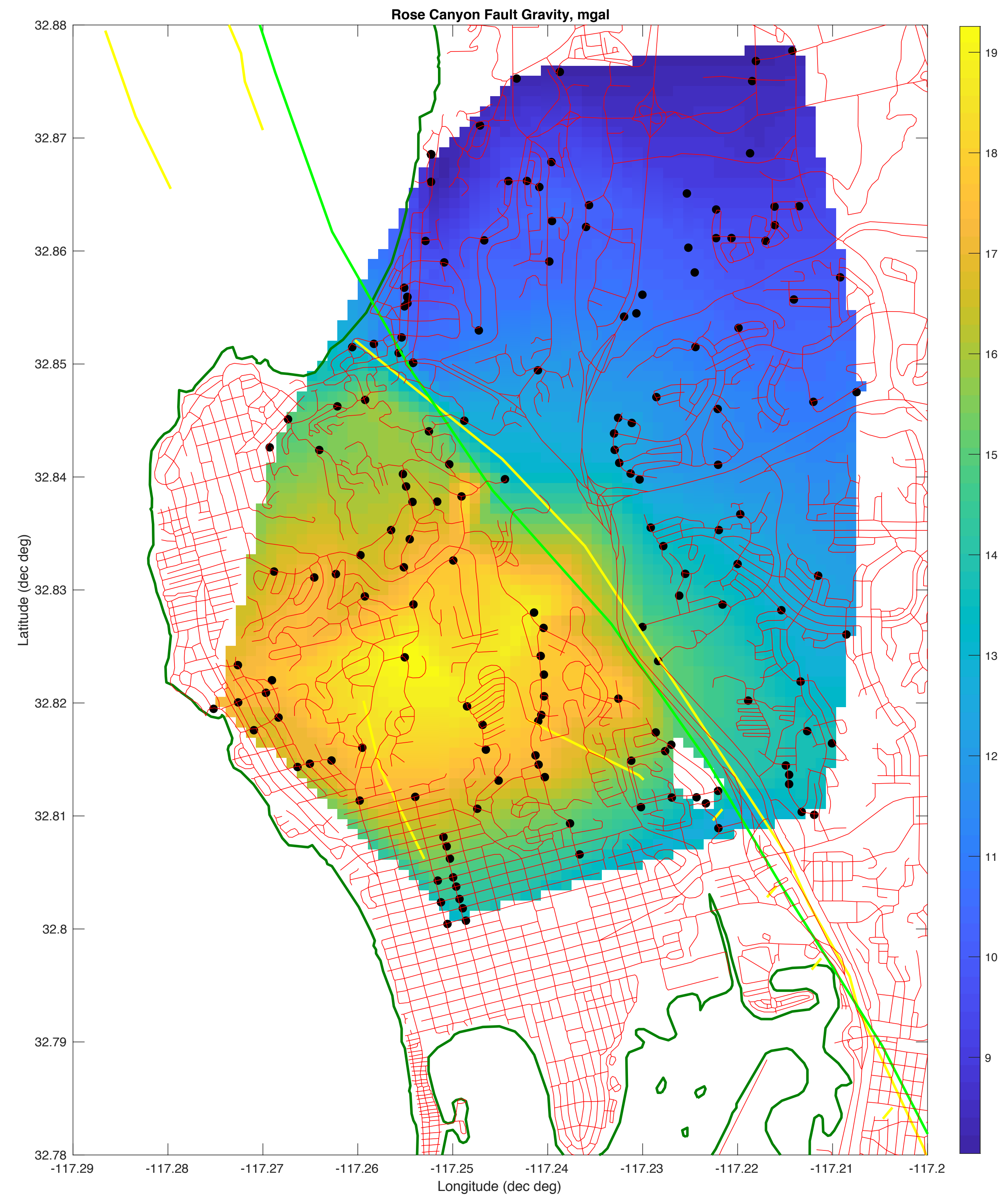

3 2 0 7 6
5


Level Reset
Long Level
Microscope Eyepiece
Level Reset
Cross Level
Cross Level Adjust-
12X
Long Level Adjustment
Reading & Level Light Switch
Nulling Dial
Re-range Access (Model D only)
Counter
Arrestment Knob

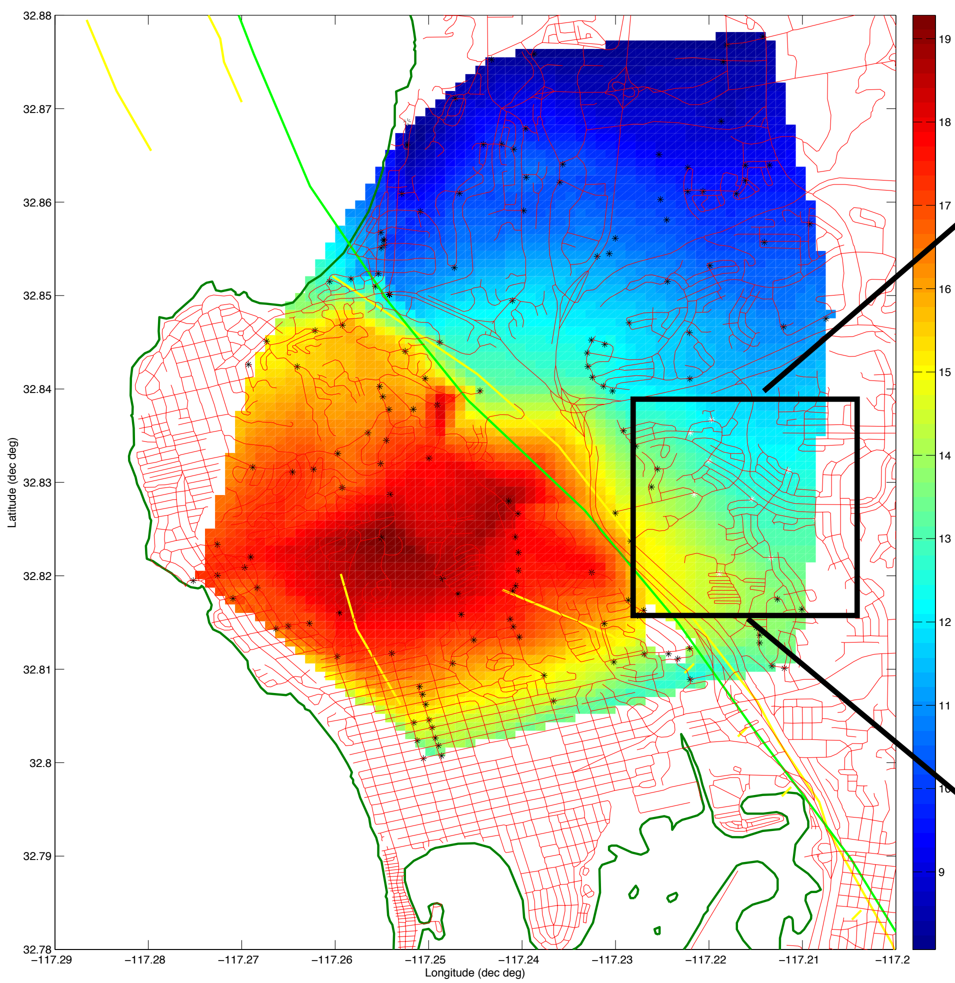
AutoGrav CG-5

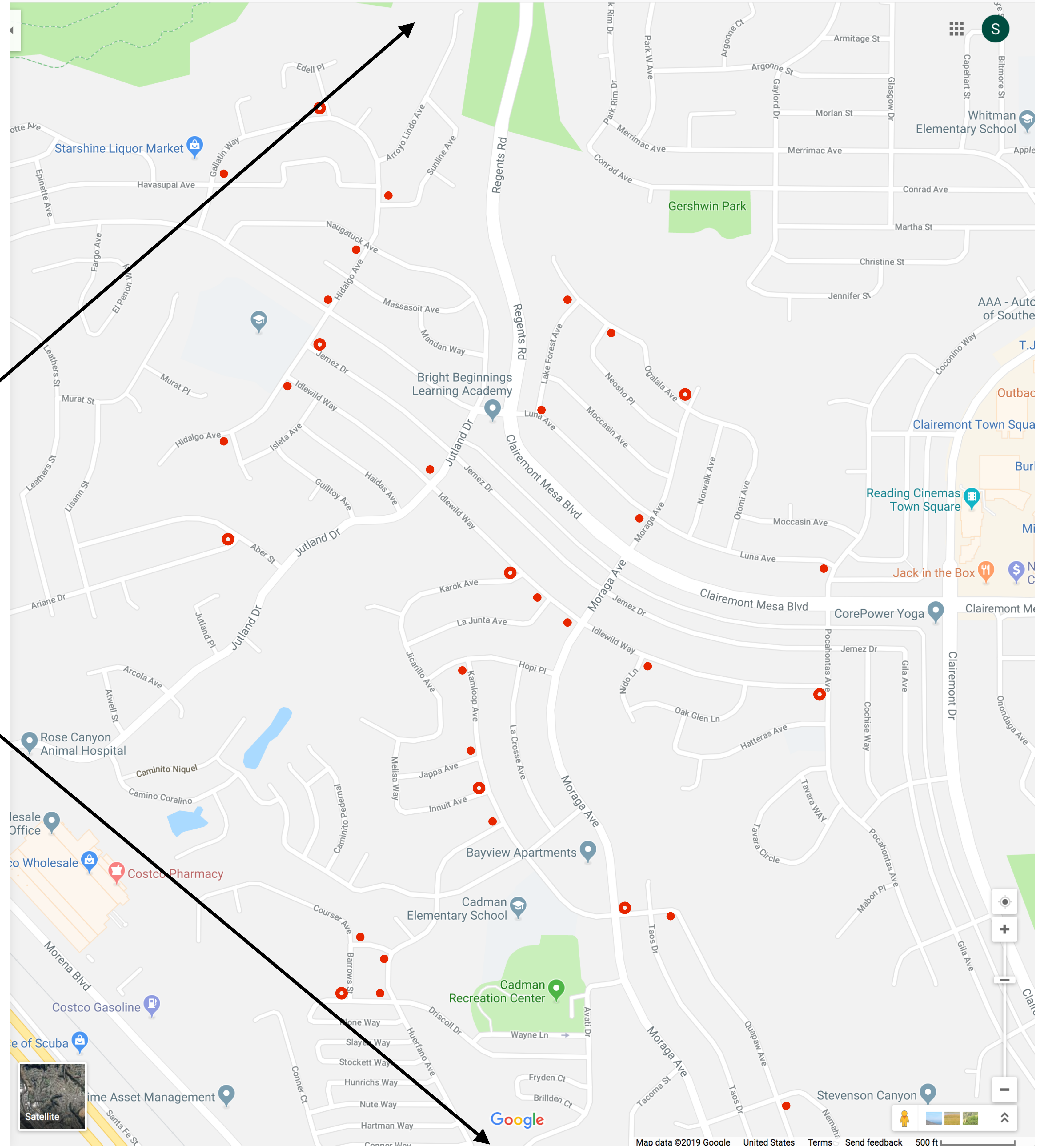
Mount Soledad gravity:





2019 data collection





Base station: Mark Zumberge's laboratory

```
% 2019 Survey  Gravimeter: G349, Date: 10 April 2019
%  ID         lat        lon       height(ft) N/E (100')     Time  Reading      Raw       Station
190   -3    32.86855 -117.25228  154.000    NaN   NaN    14 12  3216.750       0    % Zumberge lab (base) by Steve
192  2789   32.82021 -117.21889  298.177   2392  17025   14 23  3209.295      NaN   % Barrows and Driscoll by Eric
193  10725  32.82190 -117.21337  328.429   2398  17042   14 58  3206.395      NaN   % Kamloop and Moraga by Joseph
194  10000  32.82606 -117.20854  336.659   2413  17057   15 11  3205.670      NaN   % Idlewild and Pocahontas by Ben
195  9996   32.82821 -117.21539  328.822   2421  17036   15 19  3206.665      NaN   % Karok and Idlewild by Alysse
196  2093   32.82871 -117.22159  291.825   2423  17017   15 34  3209.810      NaN   % Ariane and Aber by Sakumaru
197  13467  32.83126 -117.21152  341.792   2432  17048   15 46  3205.645      NaN   % Morega and Ogalala by Kendall
198  9583   32.83230 -117.22000  343.826   2436  17022   16 05  3206.125      NaN   % Jemez and Hidalgo by Shiyue
199  8399   32.83670 -117.21972  344.065   2452  17023   16 18  3205.805      NaN   % Edwin and Gallatin by Memo
200  8400   32.83530 -117.22198  353.004   2447  17016   16 29  3205.645      NaN   % Havasupai and Gallatin by Ben
173   -3    32.86855 -117.25228  154.000    NaN   NaN    16 50  3216.825       0    % Zumberge lab (base) by Zhen
```

MILLIGAL VALUES FOR LACOSTE & ROMBERG, INC. MODEL G GRAVITY METER #G- 349

COUNTER READING*	VALUE IN MILLIGAL	FACTOR FOR INTERVAL	COUNTER READING*	VALUE IN MILLIGAL	FACTOR FOR INTERVAL
000	000.00	1.06141			
100	106.14	1.06135	3600	3822.01	1.06255
200	212.28	1.06129	3700	3928.26	1.06255
300	318.41	1.06124	3800	4034.52	1.06255
400	424.53	1.06118	3900	4140.77	1.06253
500	530.65	1.06114	4000	4247.02	1.06255
600	636.76	1.06110	4100	4353.28	1.06246
700	742.87	1.06109	4200	4459.53	1.06240
800	848.98	1.06107	4300	4565.77	1.06234
900	955.09	1.06108	4400	4672.00	1.06227
1000	1061.20	1.06112	4500	4778.23	1.06218
1100	1167.31	1.06116	4600	4884.44	1.06210
1200	1273.42	1.06120	4700	4990.65	1.06200
1300	1379.54	1.06125	4800	5096.85	1.06188
1400	1485.67	1.06130	4900	5203.04	1.06175
1500	1591.80	1.06135	5000	5309.22	1.06160
1600	1697.93	1.06140	5100	5415.38	1.06144
1700	1804.07	1.06145	5200	5521.52	1.06125
1800	1910.22	1.06151	5300	5627.65	1.06105
1900	2016.37	1.06158	5400	5733.75	1.06085
2000	2122.53	1.06165	5500	5839.84	1.06061
2100	2228.69	1.06171	5600	5945.90	1.06035
2200	2334.86	1.06180	5700	6051.93	1.06007
2300	2441.04	1.06188	5800	6157.94	1.05977
2400	2547.23	1.06196	5900	6263.92	1.05945
2500	2653.43	1.06205	6000	6369.86	1.05913
2600	2759.63	1.06212	6100	6475.77	1.05877
2700	2865.84	1.06220	6200	6581.65	1.05840
2800	2972.06	1.06226	6300	6687.49	1.05804
2900	3078.29	1.06233	6400	6793.30	1.05765
3000	3184.52	1.06238	6500	6899.06	1.05728
3100	3290.76	1.06243	6600	7004.79	1.05685
3200	3397.00	1.06246	6700	7110.47	1.05641
3300	3503.25	1.06250	6800	7216.11	1.05590
3400	3609.50	1.06252	6900	7321.70	1.05550
3500	3715.75	1.06254	7000	7427.25	

* Note: Right-hand wheel on counter indicates approximately 0.1 milligal.

12-13-73

MILLIGAL VALUES FOR LACOSTE & ROMBERG, INC. MODEL G GRAVITY METER #G- 349

COUNTER READING*	VALUE IN MILLIGAL	FACTOR FOR INTERVAL
000	000.00	1.06141
100	106.14	1.06135
200	212.28	1.06129
300	318.41	1.06124
400	424.53	1.06118
500	530.65	1.06114
600	636.76	1.06110
700	742.87	1.06109
800	848.98	1.06107
900	955.09	1.06108
1000	1061.20	1.06112
1100	1167.31	1.06116
1200	1273.42	1.06120
1300	1379.54	1.06125
1400	1485.67	1.06130
1500	1591.80	1.06135
1600	1697.93	1.06140
1700	1804.07	1.06145
1800	1910.22	1.06151
1900	2016.37	1.06158
2000	2122.53	1.06165
2100	2228.69	1.06171
2200	2334.86	1.06180
2300	2441.04	1.06188
2400	2547.23	1.06196
2500	2653.43	1.06205
2600	2759.63	1.06212
2700	2865.84	1.06220
2800	2972.06	1.06226
2900	3078.29	1.06233
3000	3184.52	1.06238
3100	3290.76	1.06243
3200	3397.00	1.06246
3300	3503.25	1.06250
3400	3609.50	1.06252
3500	3715.75	1.06254

COUNTER READING*	VALUE IN MILLIGAL	FACTOR FOR INTERVAL
3600	3822.01	1.06255
3700	3928.26	1.06255
3800	4034.52	1.06255
3900	4140.77	1.06253
4000	4247.02	1.06255
4100	4353.28	1.06246
4200	4459.53	1.06240
4300	4565.77	1.06234
4400	4672.00	1.06227
4500	4778.23	1.06218
4600	4884.44	1.06210
4700	4990.65	1.06200
4800	5096.85	1.06188
4900	5203.04	1.06175
5000	5309.22	1.06160
5100	5415.38	1.06144
5200	5521.52	1.06125
5300	5627.65	1.06105
5400	5733.75	1.06085
5500	5839.84	1.06061
5600	5945.90	1.06035
5700	6051.93	1.06007
5800	6157.94	1.05977
5900	6263.92	1.05945
6000	6369.86	1.05913
6100	6475.77	1.05877
6200	6581.65	1.05840
6300	6687.49	1.05804
6400	6793.30	1.05765
6500	6899.06	1.05728
6600	7004.79	1.05685
6700	7110.47	1.05641
6800	7216.11	1.05590
6900	7321.70	1.05550
7000	7427.25	

3205.805 mu = 3397.00 + 1.06246 x 5.805

* Note: Right-h nd wheel on counter indicates approximately 0.1 milligal.

12-13-73