New Gravity Anomalies Mapped from Old Data

Newly applied ways of processing gravity data by computer are revealing unsuspected features deep within the earth's crust

Geophysicists have been poring over seemingly abstract, mottled gravity maps for years, with mixed success. Using the faint variations in the force of gravity displayed there, they have been able to look below the surface of the earth and to reconstruct how geological forces have shaped some parts of the crust and upper mantle. On such maps, the mid-continent gravity high, for example, is an obvious feature that wriggles from the tip of Lake Superior down to Kansas; it almost certainly results from the slightly stronger pull of gravity of the denser rock that oozed into a rift in the crust more than half a billion years ago. But more subtle variations in the pull of gravity have resisted interpretation or even detection, in large part because of the jumbling together of gravity anomalies of different strengths originating at different depths.

Within the past year, researches have begun using computers to help sort out some of this complexity. Computer processing is providing a rapid means to archive and manipulate the hundreds of thousands of data points that have been in hand for years. Interpretations of the new gravity maps are still rather speculative, but geophysicists and geologists are excited by the potential of these maps. A 1000-kilometer-long strip of anomalously low gravity, stretching from Nebraska through Missouri, seems to mark a geologic structure that influences everything from earthquakes to the formation of caves. A major rift, running from Georgia to New York, may lie hidden beneath the Appalachians. A section of central New England seems to be a bit of exotic rock patched onto the continent. And perhaps most speculative of all, a group of researchers has suggested that a gravity map of Canada and the northern United States reveals traces of a 2700-kilometer-wide meteorite crater basin.

The first attempt at producing new gravity maps by computers was made by an informal group of U.S. Geological Survey (USGS) researchers.* Their initial interest was in earthquakes and hazards to nuclear power plants. They started with about 475,000 individual measurements of gravity, most of them from the files of the U.S. Defense Mapping Agency. That agency is not as interested in the structure of the earth's crust as in targeting ballistic missiles. The added mass of a mountain or variations in the thickness of the earth's crust can produce complex variations in the gravity field. Although these variations amount to only some hundreds of parts per million, they can throw a missile off course.

The USGS group, being more concerned with subsurface geology, first used standard processing procedures to bring out gravity anomalies originating in the crust that were free as possible of distortions from certain known sources. After putting the gravity measurements in a form convenient for processing, they adjusted each value to account for the variable elevations—and thus distances from the center of the earth's mass—at which the measurements were made. They then eliminated the effect of the mass of rock between the gravimeter and sea level, which is the corrected elevation for all measurements. These two corrections allow for the necessity of making measurements at elevations above sea level and produce a Bouguer gravity map. This form of gravity map has been until now the most refined data format available for the study of subsurface geology.

The USGS group went a step farther by removing the effects of broad variations in the gravity field that complicate some types of interpretation. By passing the data through a Fourier transform filter, they suppressed gravity anomalies having wavelengths greater than 250 kilometers. These originate for the most part in variations in the density of rock near the boundary between the crust and the mantle at depths of about 40 kilometers or more. Gradual changes in density near the surface, such as gradually thinning wedges of sediment, also produce broad anomalies that are suppressed by such processing. What remains are the more subtle gravity anomalies (having ranges of a few tens of parts per million of gravity) that can be linked to geological features within the crust. "We're looking at old data sets in new ways," says Robert Simpson of the USGS group. "It seems that every time we make a new map something jumps out at you. You go back to the original [unprocessed] map, and it's usually there." The problem had been sorting out the anomalous patterns by eye.

A new feature receiving considerable attention at the moment is the faint band of anomalously low gravity that cuts diagonally across Missouri, extending 1000 kilometers from near the southern Appalachians to southeast Nebraska. Few researchers are willing to give its source a more specific label than "geologic structure" at this point. It might be a rift that failed to open farther, a suture between two pieces of crust that collided, or a fault that allowed two sections of the crust to slide past each other.

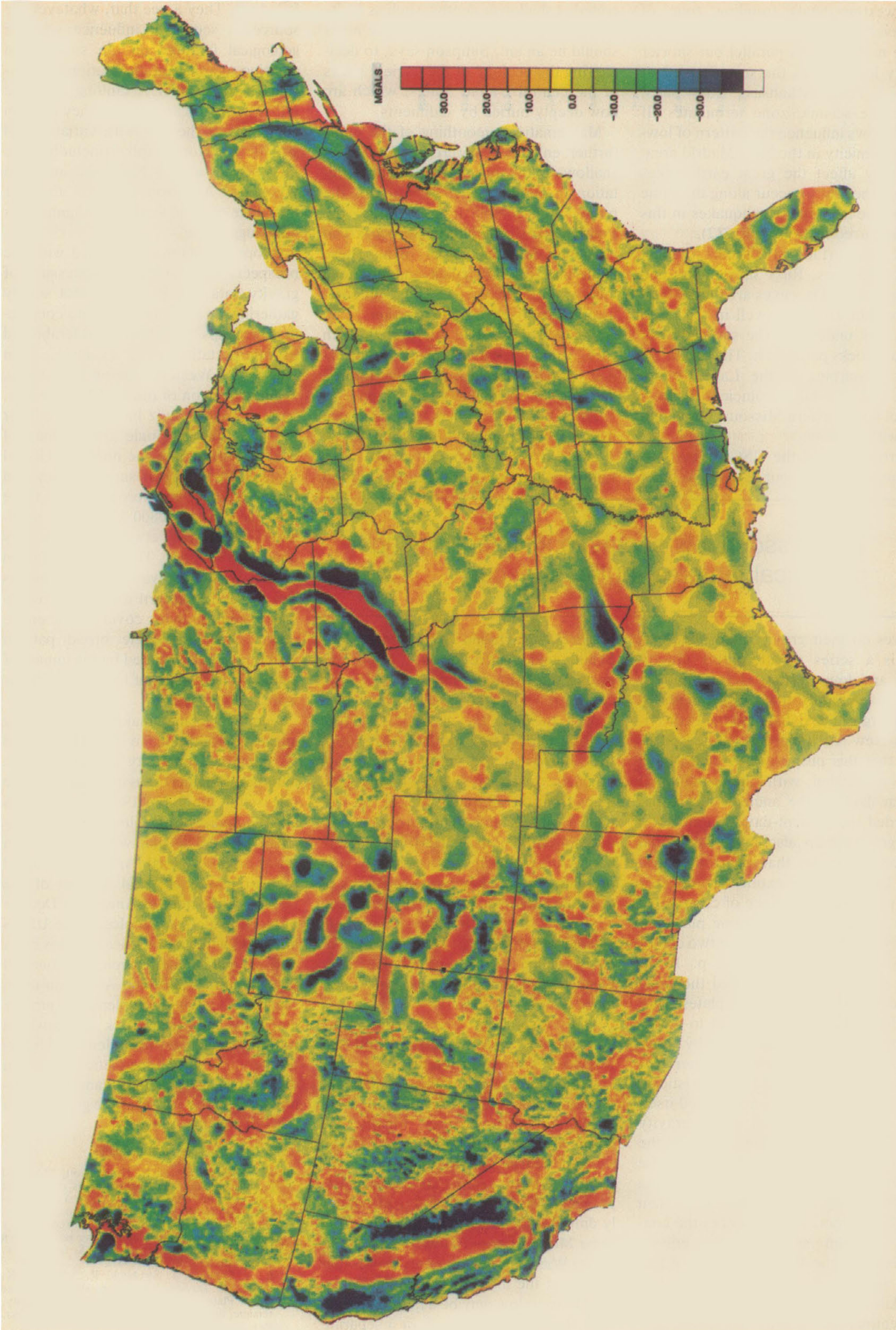
Whatever the deep geologic source of the Missouri gravity low, it appears to influence much of the crust above it. David Russ of the USGS in Denver notes that this low cuts across the New Madrid, Missouri, area precisely where a

Filtered gravity map of the United States

Computer processing of a standard Bouguer gravity map by researchers at the U.S. Geological Survey removed broad-scale gravity features having wavelengths greater than 250 kilometers. Most of the sources of the remaining features are within the crust (upper 20 to 30 kilometers) because wavelengths less than 250 kilometers generated by sources at greater depths are strongly damped. A prominent feature of the map is the mid-continent gravity high extending from Lake Superior to Oklahoma, which is probably caused by an ancient rift system. A series of alternating highs and lows extending from the California coast to the Nevada-Utah border is possibly related to the subducted Pacific plate. Using this map, one may be able to divide the crust into distinctive domains on the basis of consistent trends of anomalies, the map's originators say. (One milligal, or 1 mgal, is 1/980,000 of the acceleration of gravity.) This map and one similarly processed having a 1000-kilometer cutoff will shortly be available as U.S. Geological Survey Geophysical Investigations Map, GP-953 (A), scale 1:7.5 million. A discussion of significant features of these maps is now available as U.S. Geological Survey Open-File Report 82-284.

*Richard Godson, Thomas Hildenbrand, and Martin Kane at Denver, Colorado, and Robert Simpson at Menlo Park, California.

0036-8075/82/0305-1220$01.00/0


MGALS
30.0
20.0
10.0
0.0
−10.0
−20.0
−30.0

southwest-northeast trending zone of low-level seismicity makes an abrupt jog to the northwest. A parallel but shorter gravity low crosses the seismic zone at Marked Tree, Arkansas, Russ says, where the seismic zone terminates. If gravity lows influence the pattern of low-level seismicity in the New Madrid area, they may affect the great earthquakes that are thought to occur along the same trends (the last great earthquakes in this area occurred in 1811 and 1812).

The Missouri low also seems to affect surface features, Russ says: faults and streams parallel it, caves are more abundant within it, and a swell in the basement rock underlying the surficial sedimentary rocks parallels it. The recent 10-meter upwarping of the Lake County uplift and the larger, ancient Pascola arch of southeastern Missouri both coincide with the low.

Martin Kane of the USGS group has suggested possible sources for two other features on their gravity map. One feature is a series of alternating gravity highs and lows, arranged in a pattern suggestive of a rift, that runs from northern Georgia and Alabama to the Pennsylvania–New York border. Kane speculates that this proposed rift could have been associated with the continental margin flanking the ancient ocean that preceded the present-day Atlantic. The new gravity map also lends additional support to the idea that a part of central New England is an exotic terrane; that is, it was a separate piece of crust, such as an island arc, that became plastered onto North America when the two collided (*Science*, 7 March 1980, p. 1059). Kane independently identified the same boundary between the two plates (running from central Connecticut to northwestern Maine) as was found by other researchers using a variety of other geophysical and geological characteristics.

The USGS group has not limited itself to a single manipulation of the gravity data. In another map, they removed the broad gravity low that dominates the western United States by eliminating features having wavelengths greater than 1000 kilometers. That enhances the contrast between smaller scale gravity anomalies in the West. Removal of features having wavelengths greater than 125 kilometers produces another map that emphasizes gravity anomalies generated at shallower depths, such as faults and sutures between plates. These maps should be an aid, Simpson says, to deciphering the geology of the ancient rocks of the central United States, which are now deeply buried by sediments.

Mathematical smoothing of the maps further enhances features generated at shallow depths, but it also aids interpretation in another way. Along with the removal of complicating features, the Fourier transform filtering process can introduce features of its own. These flank the real anomalies and create a false grain in the map. "Thus," a commentary to a set of maps cautions, "all anomalies must be interpreted with care." Smoothed maps (maps of the second vertical derivative of the filtered data) do not introduce a false grain.

The USGS researchers have not been the only ones manipulating gravity data. A group at Washington University in St. Louis, including Edward Guinness, John Strebeck, Raymond Arvidson, Klaus Schulz, and Geoffrey Davies, has drawn on the same gravity data, but they processed it with a space-age twist. In a project to study the geologic structure and ore deposits of southeast Missouri, they borrowed the computer program originally used to make topographic maps from the altimeter data of the Pioneer Venus orbiter. This program produces a continuous image from discrete data points, filtering out or greatly suppressing features having wavelengths of about 20 kilometers or less. The data can be filtered further by wavelength, enhanced with the use of techniques previously applied to images of the planets, or blended with topographic data in a color map.

The Washington University group's first gravity map, covering southeast Missouri, showed an interesting gravity low, but it went off the edge of the map. A map of the entire state did not reveal an end to the low either. Finally, the group prepared a national map, which showed the true 1000-kilometer extent of the low. Both groups of researchers, pursuing different goals and using slightly different methods, had uncovered the same Missouri gravity low.

The Washington University group suggests that the most plausible source for the Missouri low may be a fault emerging from the mid-continent rift or a separate failed rift. They agree that, whatever the source, it seems to influence younger geological features on the surface. In addition to apparent correlations in Missouri with seismicity, faulting, and the intrusion of volcanic rocks, they note an alignment of the low with variations in gravity and topography (including the Platt River) across Nebraska and into Wyoming. Arvidson cautions that, at this stage of their work, the alignment is only suggestive.

The Missouri low seems to influence younger geological features on the surface.

Geophysicists are impressed with the prospects for computer processing of gravity data, but it appears that simply gathering the available data into comprehensive maps could be a considerable aid to interpretation. For example, John Klasner of Western Illinois University, William Cannon of the USGS in Reston, Virginia, and Schulz have compiled, for the first time, a single gravity map of central Canada and the northern United States. Much to their surprise, they had pieced together a pattern of at least three concentric zones 2800 kilometers in diameter centered between Hudson Bay and Lake Superior. The visual confusion created by shorter wavelength anomalies had made the pattern difficult to recognize except on maps covering the entire region, they say. The broad pattern might have been created by the impact of a meteoroid the size of the state of Delaware, they speculate.

Geophysical map making is continuing apace. In addition to the USGS and Washington University filtered maps, a national Bouguer gravity map will be released in the fall of 1982 by the USGS and the Society of Exploration Geophysicists (SEG). This map will form part of a gravity map of North America expected to be released by 1984 as part of the Geological Society of America's Decade of North American Geology. The USGS and SEG will also be releasing this fall a U.S. map of magnetic anomalies that will become part of a North American map. Magnetic maps complement gravity maps by indicating rock composition rather than changes in its density. Unfortunately, not all the magnetic data are in digital form yet, so they cannot be manipulated in the way that the gravity data are.—RICHARD A. KERR

Additional Readings

1. R. W. Simpson and R. H. Godson, "Colored gravity anomaly and terrain maps of the east central United States," *U.S. Geol. Surv. Open-File Rep. 81-846* (1981); R. W. Simpson, W. A. Bothner, R. H. Godson, "Colored gravity anomaly and terrain maps of the northeastern U.S. and adjacent Canada," *U.S. Geol. Surv. Open-File Rep. 81-560* (1981).
2. E. A. Guiness, J. Strebeck, R. Arvidson, K. Schulz, G. Davies, "Basement structure of the Ozark Plateau, Missouri—topography, gravity, seismic, and remote sensing data," *J. Geophys. Res.*, in press.