

## GEOPHYSICS

# Seafloor secrets revealed

## Satellite data reveal formerly unknown tectonic structures

By **Cheinway Hwang<sup>1</sup>** and  
**Emmy T. Y. Chang<sup>2</sup>**

**T**he trenches and ridges on Earth's seafloor are shaped by tectonic processes such as seafloor spreading and plate subduction. Detailed knowledge of seafloor tectonics is lacking in many areas. The most comprehensive data come from satellite altimeters, which use the strength and waveform of the radar signal returned from the sea surface to determine the tectonic properties of the underlying seafloor. On page 65 of this issue, Sandwell *et al.* (1) present the latest global marine gravity and depth data from altimeter missions CryoSat-2 and Jason-1. The data reveal buried tectonic structures, for example, in the Gulf of Mexico and the South Atlantic Ocean, that help to elucidate past tectonic processes.

The small-scale underwater tectonic structures seen in the gravity field of Sandwell *et al.* are particularly pronounced. This is because the gravity signal is strengthened by decreasing distance and these structures originate largely from shallow layers. Because of a major improvement in accuracy, this new gravity field will lead to more discoveries of tectonic features, especially in regions with thick sediments where sediment-induced gravity signals obscure tectonic structure-induced gravity signatures.

The vertical gravity gradient—that is, the change in gravity in the vertical direction from the surface—further enhances short-wavelength features and can be used to detect edges of geological transitions such as the continent-ocean boundary, where the properties of the rocks change from those of a continent to those of an ocean basin. Existing magnetic and seismic data cannot always resolve these features and have, for example, not been able to delineate fully the continent-ocean boundary in the northern South China Sea (2). A clear trace of this boundary, as well as features of an extinct spreading

center in the South China Sea, can be seen in Sandwell *et al.*'s data (see the figure).

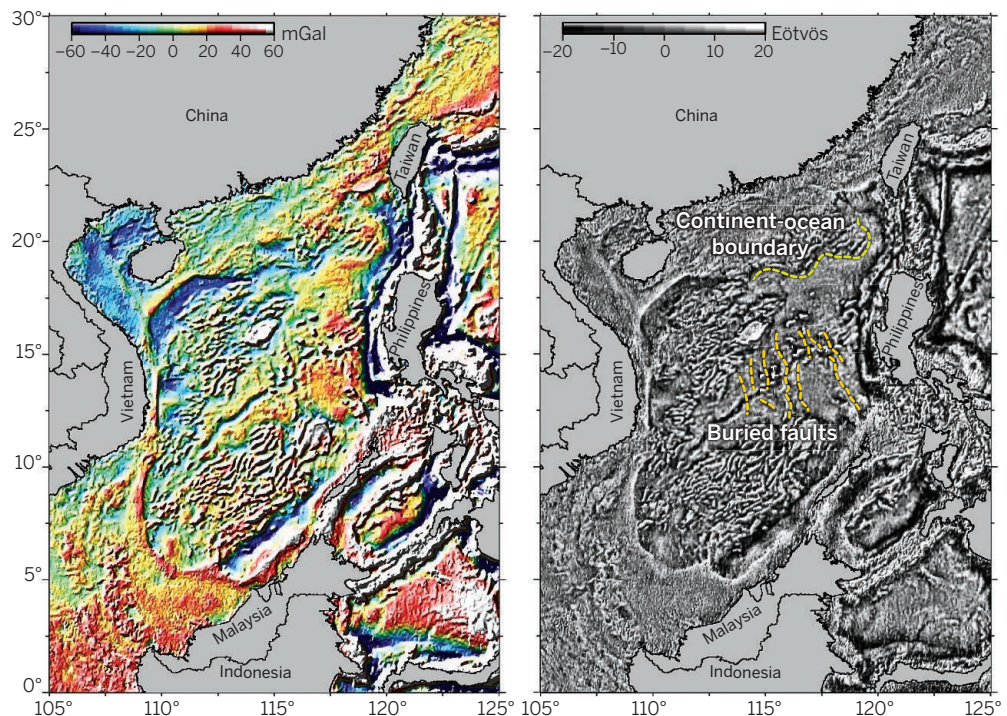
A method called waveform retracking is used to refine the radar return time and thereby improve altimeter ranging accuracy. The retracking techniques used by Sandwell *et al.* are designed to improve the accuracy of sea surface slopes determined from altimetry data (1, 3). Accurate and efficient methods are also needed to improve the accuracy of absolute sea surface heights (SSHs) from altimetry data; such data will improve identifications of oceanic signatures at medium to long wavelengths, such as mesoscale oceanic eddies and superswells (4, 5). The DTU global gravity grids (6) are based on retracking aimed at improving absolute SSHs. Neither retracking method may be able to fully decouple the contributing sources to radar measurements (range, wind, and wave height); further improvements may come from advanced techniques called knowledge-based iterative retracking and batch-jobbed multiple-waveform retracking that are under development.

To achieve optimal accuracy, it is important to combine satellite missions of varying

orbit inclinations to obtain a nearly equal accuracy for the north and east components of sea surface slope for gravity derivation (1, 7, 8). Currently, there are four high-resolution altimeter data sets to serve this need: Geosat, ERS-1, Jason-1, and CryoSat-2, with inclinations ranging from 66° to 108°. However, one must be careful in assigning appropriate weightings to each data set by considering their spatial resolutions and accuracies. This can be accomplished through iterative estimation of relative covariance factors between data sets.

The 1- to 2-mGal gravity accuracies achieved by Sandwell *et al.* (1, 7) are based on worldwide comparisons between altimeter gravity and high-quality ship gravity at wavelengths between 12 and 40 km. A gravity measurement accuracy of 1 mGal requires 1-mm accuracy in SSH measurements over 1 km along satellite ground tracks. This accuracy is a very challenging goal for measurement technology and data processing alike, especially in coastal areas and large inland water bodies such as the Caspian Sea, the Black Sea, and the Great Lakes.

The challenge in shallow-water regions arises from two factors: The waveform of the altimeter is distorted (“contaminated”) by land mass, biasing the radar arrival time, and poor measurement corrections obscure the gravity signal (4, 6). For example, altimeter corrections in shallow waters for the effects of ocean tide, wet tropospheric delay, and



**Hidden features of the seafloor.** The marine gravity anomaly (left) and vertical gravity gradient (VGG) maps from satellite altimetry in the China Seas and the seas around southeast Asia reported by Sandwell *et al.* (1) show a wealth of tectonic features. The VGG image provides evidence for the continent-ocean boundary and the buried faults across the extinct spreading center.

<sup>1</sup>Department of Civil Engineering, National Chiao Tung University, Hsinchu, Taiwan. <sup>2</sup>Institute of Oceanography, National Taiwan University, Taipei, Taiwan. E-mail: cheinway@mail.nctu.edu.tw; etychang@ntu.edu.tw

wave height have large uncertainties relative to such measurements made in the open ocean. Furthermore, SSH or slope cannot be converted to gravity at a coastal point unless land gravity is also known. Efficient extraction of tectonic features from the increasing data volume of altimetry will require novel data-processing strategies and gravity recovery methods (9, 10).

In addition to geophysical studies, altimeter gravity is increasingly important for coastal terrain mapping on land and at sea with technologies such as GPS, LIDAR (light detection and ranging), and satellite imaging. These applications require a highly accurate model of Earth's level surface (geoid) from gravity measurements. A dedicated, small ship-based coastal gravity survey can deliver 1-mGal accuracy at 500-m spatial resolution (11), but the cost is high. If 1-mGal altimeter gravity accuracy can be achieved at this spatial resolution, coastal nations, especially at lower latitudes, will no longer need shipborne or airborne gravity measuring campaigns for purposes such as resource exploration and coastline topography determination.

Sandwell *et al.*'s results are a breakthrough in space-based marine gravity observation. The key factors driving this success are advances in altimeter technology (10, 12), an improved processing technique (3, 7), and a dedicated algorithm for deriving gravity and depth from altimetry (1, 8). As CryoSat-2 continues to increase the coverage of satellite ground tracks to densify spatial coverage and several innovative altimeters are planned for launch (10), we will soon be able to detect even finer-scale gravity signatures that can benefit studies ranging from marine resource exploration to tectonic evolution. ■

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**The hunt is on.** Cheetahs reach famously high speeds during hunting, but Scantlebury *et al.* show that it is the search for prey rather than the chase itself that is energetically more costly.

#### ECOLOGY

## How large predators manage the cost of hunting

For pumas and cheetahs, seeking prey is more energetically costly than the subsequent chase

By John W. Laundré

**B**eing a large carnivore is not easy. First, there is the food, the energy they need to survive, which by definition consists mainly of other animals. This means that meeting daily energetic needs is not as easy as just going out and gathering plants that are waiting around to be found and eaten. Large carnivores often prey on animals that are bigger than themselves and that try to avoid being killed. Foraging by carnivores becomes a two-player game of stealth and fear (1), making it more difficult and thus energetically costly for carnivores to catch enough to stay alive. Large carnivores must balance the energy spent seeking and subduing prey with the energy they get back when they catch something—which does not happen as often as one might think (2–4). Two reports in this issue, by Scantlebury *et al.* (5) on page 79 and by Williams *et al.* (6) on page 81, look at how two carnivores, cheetahs (*Acinonyx jubatus*; see the first photo)

and pumas (*Puma concolor*; see the second photo), tread the fine line of energy losses and gains in order to survive.

The carnivores investigated in the two studies seek prey in very different ways. Pumas are sit-and-wait hunters, whereas cheetahs typically chase their prey at high speeds. The results of the studies should thus help to elucidate the effect of energetic demand on hunting style.

There have been ample studies of the energetics of carnivores. However, most attempts to calculate the energetics of large carnivores have not explicitly determined the specific energy necessary for seeking and subduing prey. Most have relied on estimates of metabolic rates under laboratory conditions (7, 8) or velocities and distances traveled over 24 hours based on telemetry or Global Positioning System data gathered from wild animals

University of California at Riverside, James San Jacinto Mountains Natural Reserve, Post Office Box 1775, Idyllwild, CA 92549, USA. E-mail: john.laundre@ucr.edu



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Cheinway Hwang and Emmy T. Y. Chang  
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