drug, if metabolized as it is in humans, should have been eliminated within several hours. Does this mean that hamsters retain much of the large dose of triazolam, or that the clock mechanism has resettable periodicity as well as resettable phase?

The experiment also raises questions about the unforseen circadian side-effects of medications containing psychotropic compounds. David Earnest and Turek recently demonstrated (*Proc. natn. Acad. Sci. U.S.A.* **82**, 4277; 1985) that cholinergic neurotransmission centrally mediates the effect of light on the circadian clock of the hamster. This might lead one to wonder about over-the-counter 'sleeping pills' that contain belladonna and scopolamine: do they also have an impact on circadian coordination? □

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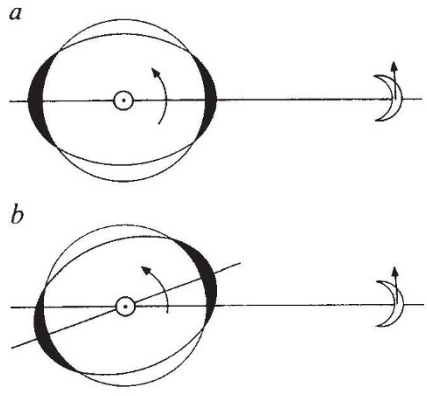
Geophysics

Is there coherence between Earth tides and earthquakes?

from Paul W. Burton

Do tides in the Earth cause earthquakes? Are some types of earthquakes or regions of the Earth more susceptible to earthquakes triggered by tides than others? And is this relevant to the prediction of earthquakes? There has not yet been much success in answering these questions, although the thorough studies of T.H. Heaton[1,2] did demonstrate that some types of shallow earthquakes that have magnitudes greater than 3 are more easily triggered than are smaller events. But his later, more rigorous approach did not confirm his earlier hypothesis — much seems to be ambiguous or inextricably tangled in this subject. A. Palumbo is now trying to provide answers to some of the questions[3]. He finds that earthquakes most likely to be triggered by tides are those with magnitudes higher than 5 and that shallow earthquakes and their foreshocks in the Appennine Mountains are significantly more frequent when stretching in the crust caused by tides in the Earth is at a maximum.

Under consideration are stresses or tides in the solid Earth caused by the action of the Sun or the Moon on the deformable Earth. (Tides in the ocean and in the atmosphere are caused by the same actions but in more mobile and fluid media.) Stress and strain changes in the Earth caused by the varying proximity of the Sun and the Moon are accompanied by variations in the acceleration caused by gravity, g, at the surface of the Earth. Thus, g is not constant at 9.81 m s^{-2} but fluctuates both daily and over longer periods. This may be visualized simply (see figure) as deformation of the Earth's surface, and can amount to a semi-diurnal movement of the ground of as much as 0.1 m up or down. These motions are damped by friction in the Earth and so maximum strain lags behind the response expected in a totally elastic Earth; some parts of the Earth being stretched while others are compressed. Compression is maximum with the Moon or Sun on the horizon (morning earthquakes?), and some earthquake fault systems may be susceptible to compressional perturbations. Tensional regimes across fault zones may be susceptible when the Moon or Sun are overhead (midday earthquakes?).



Earth tides caused by lunar action. *a*, Without friction, Earth strain would cause an upward motion of the ground along a line joining the centres of the Earth and the Moon. With the Moon on the horizon the strain would cause a downward and inward motion of the ground. *b*, With friction, the tidal bulge in the Earth is carried forward by rotation of the Earth causing a phase delay with respect to the action of the Moon on the Earth. These small periodic strains may perturb strain energy stored in the Earth and trigger release of that energy as an earthquake. (Adapted from ref. 6.)

When the Earth acts gravitationally on the Moon (a larger body acting on a smaller body), it is an acceptable interpretation that tidal effects trigger moonquakes. The reverse situation, when the Moon acts gravitationally on the Earth, is riddled with complexity and ambiguity: for example, the perturbations to strain are not so large; the Earth has mobile oceans and an atmosphere which varies the surface loading; and earthquake catalogues are rarely homogeneous and complete. When many globally distributed earthquakes are considered no significant effect is discernible — presumably any effect is blurred by a multiplicity of unidentified fault orientations and stress regimes. Palumbo has deliberately isolated a relatively small region of the Earth, in Italy, and, largely rejecting Fourier spectral analysis, used the Chapman–Miller method to detect lunar daily variations (for an up-to-date account of the method with minimum mathematics, see ref. 4). Palumbo's results are clearer than his discussion and analysis: no tidal term is discernible in the Alpine or southern Calabrian areas but there is a lunar tidal term for major earthquakes and related foreshocks in the Appennines. He suggests that the tidal terms in the frequency of earthquakes are linked with extensional tidal stresses in the east–west direction.

Although hardly being on the level of prognostication associated with a 'Jupiter' effect, this suggestion is fascinating in relation to Appennine earthquakes. It will be interesting to see if the resolution of coherency achieved by Palumbo will improve when seismic moment tensor solutions (giving a full description of seismic fault orientations and slip vectors) for earthquakes in the Appennines can be combined with local tidal strain tensors.

Palumbo certainly seems to have identified one geographical region where tidal variations in the frequency of earthquakes are discernible despite the inevitable problems obscuring potential coherency between Earth tides and earthquakes. The relevance to earthquake prediction is another matter. Although much is known about Earth tides[5] and global and local seismicity, coherency between the two is usually within the noise of any analysis; certainly earthquake disasters do not show the sort of semi-diurnal or diurnal variation which would prompt an actuary to take cover at dawn or dusk.

The problem remains largely unresolved and confused from a statistical viewpoint. But instruments used to measure Earth tides and strain changes will also be sensitive to the volume increases that are thought to accompany changes in rocks before brittle failure. Here there may be a practical link between the two sciences; otherwise coherency between tides and earthquakes appears highly localized, where it merits further study, but elsewhere, given the present state of knowledge and the resolution of this coherency, these studies appear to be rather an esoteric pursuit. □

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