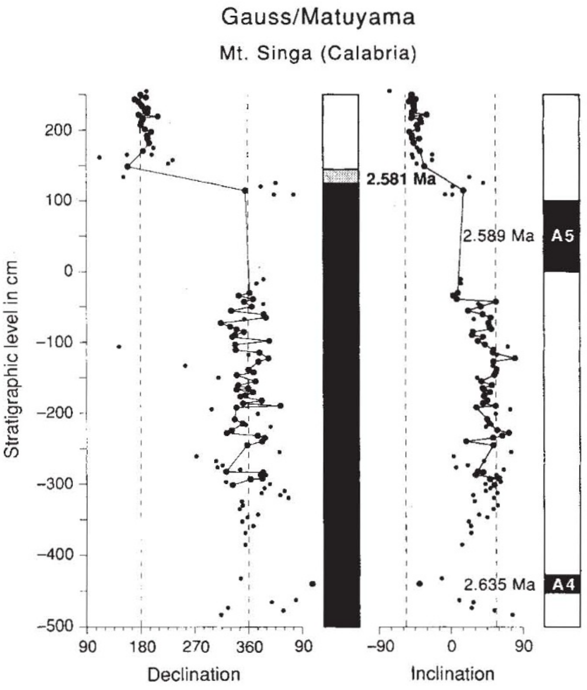
Steadying the rates

SIR — Wilson[1] used high-precision plate-rotation solutions for five plate pairs to test the astronomically calibrated timescale[2,3] over the past 5.32 million years. Wilson based his analysis on the determination of total rotation poles and provided a confidence interval for spreading distance with the significance level better than 95%. He found that the use of the astronomical ages rather than those from the standard polarity timescale[4] resulted in very small and physically realistic spreading rate variations. As a result, plate-motion rates of the NUVEL-1 global model[5] need to be revised downwards by 4.5%, leaving a marginally significant difference of 1.5% with geodetic plate-tectonic rates averaged over years[6]. Wilson concluded that the errors in the astronomical calibration are no greater than 20,000 years and that the spreading rate can remain constant for several million years.

In four of the five plate pairs only the Gauss–Matuyama (GM) boundary shows a (reduced) distance that — within its confidence interval — significantly differs from the assumption of constant spreading. Wilson inferred minor refinements to the astronomical timescale and suggests that the age of 2.60 million years (Myr) ago[2] for the GM boundary appears too old by 10,000–20,000 years. Similarly, he suggested that the base of the Nunivak (4.62 Myr ago[3]) may be slightly too young, although uncertainties are larger. Here we provide a refined age of the GM boundary which confirms Wilson's suggestion.

The astronomical ages reported by F.J.H.[3] are based on earlier magnetostratigraphic studies[7,8] of Pliocene–Pleistocene land sections in the central Mediterranean. All these reversals have subsequently been sampled and studied in detail (ref. 9, and our unpublished data), thereby providing their exact positions and hence more accurate ages. The detailed record of the lower Nunivak[10] now provides a best age estimate of 4.618 Myr ago, the same as the earlier estimate of 4.62 Myr age[3]. For the GM boundary, Wilson used the age of 2.60 Myr ago (from ref. 2), whereas F.J.H.[3] gives two ages: the older age of 2.62 Myr ago is probably caused by delayed NRM acquisition[10]; the younger age of 2.59 Myr ago was based on the magnetostratigraphy of the Mounte Singa section[7].

We have resampled the GM boundary in detail in this latter section. We applied progressive stepwise thermal demagnetization to all samples; the palaeomagnetic characteristics are very similar to those from the earlier magnetostratigraphic study[7]. The results (see figure) show that the GM boundary is at level 135 cm, above the top of sapropel A5 which has a midpoint (at 50 cm) with an age of 2.589 Myr ago[3]; the lower sapropel A4 has a midpoint (at −440 cm) with an age of 2.635 Myr ago[3]. The resulting average sedimentation rate of 10.7 cm per 1,000 years has been used to extrapolate an age of 2.581 Myr ago for the GM boundary. This new age shows that Wilson's analysis gives an accurate test of astronomical ages, and that his suggestion of a younger GM boundary is correct. Indeed, refinement of orbital dates steadies the rates[6].



The GM reversal record sampled in detail in the Mounte Singa section[7] in southern Calabria. Characteristic remanent magnetization directions (declination and inclination) are derived from progressive stepwise thermal demagnetization; large (small) dots are reliable (less reliable, low intensity) directions. The polarity column (left) shows normal (black) and reversed (white) polarity; the shaded part denotes the GM transition interval. The lithological column denotes marine clays (white) and the sapropelitic layers[7] (black). The midpoints of sapropels A4 and A5 have astronomically calibrated (4,000 year lagged) ages of 2.635 and 2.589 Myr ago, according to ref. 3. The average sedimentation rate of 10.7 cm per 1,000 years between the sapropels has been used to extrapolate an age of 2.581 Myr ago for the GM boundary at the 135-cm level.

The slightly older astronomical age of 2.60 Myr ago of Shackleton *et al.*[2] is derived from correlation of the $\delta^{18}O$ record of the Ocean Drilling Program Site 677 to that from the Deep Sea Drilling Project (DSDP) Site 607, where the GM boundary falls within oxygen isotope stage 104 (ref. 11). The boundary appears to fall at slightly younger levels, however, in DSDP sites 609 and 552A, that is, in stage 103 (ref. 11). Evidently, this latter position is consistent with the boundary in the Mounte Singa section. The younger age is preferred, because sedimentary remanence mechanisms can make the reversal appear older, but not younger.

C. G. Langereis
A. A. M van Hoof
F. J. Hilgen
Institute of Earth Sciences,
Utrecht University, 3584 CD Utrecht,
The Netherlands

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Sea-level rise

SIR — Sahagian *et al.*[1] have assessed the contributions to global sea-level rise of groundwater withdrawal, surface-water diversion and land-use changes. One of their key conclusions is that these direct anthropogenic contributions account for 30% of the total observed sea-level rise this century. But their data actually account for only a 7% rise.

Sahagian *et al.* calculate that human activities are at the present time causing a sea-level rise of 0.54 mm per yr, and have caused a total sea-level rise since 1900 of 11.8 mm. For the average observed rise since 1900, they take a value of 1.75 mm per yr from the literature. It is indeed true that if one assumes a constant sea-level rise since 1900, which is open to question, a value of around 30% (0.54/1.75=0.31) for direct anthropogenic contributions to actual sea-level rise is obtained. But Sahagian *et al.* state that this value is valid for total sea-level rise during the twentieth century, which is incorrect. It should be 7% (11.8/(94×1.75))=0.07. In any event, sea-level changes integrated over longer periods, for example over 1900–94, are more interesting than calculating the current rate of rise.