Can we calculate palaeogravity?

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Abstract

Palaeogravity, the strength of the Earth's surface gravity in the past, is widely believed to have been constant for hundreds of millions of years. A simple scientific method is outlined to check if this belief is correct. The results indicate that, far from being the constant assumed, palaeogravity was lower in the past and has slowly increased towards our present-day surface gravity.

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Palaeogravity, the strength of the Earth's surface gravity in the past, is widely believed to have been constant for a vast amount of geological time. Indeed, palaeogravity is commonly imagined to have been the same as today's surface gravity for hundreds of millions of years. This raises an interesting question. Is there any scientific method to measure palaeogravity?

At first it might seem that we would need a time machine to measure palaeogravity, but let's explore the possibility further. Measuring the Earth's surface gravity today is a simple scientific procedure. Only two measurements are required: weight and mass. We can measure the weight of a known mass and then use these values to calculate the Earth's surface gravity. On Earth the gravitational acceleration is about 9.81 m/s^2, commonly denoted as 1g, but it can vary slightly. Surface gravity is measured at about 0.5% more at the poles than at the equator, because the weight of our mass has increased. The variation is even more extreme on another planetary body - on Mars surface gravity measures approximately one third of the Earth's surface gravity. The Moon's surface gravity is only one sixth.

If we *did* have a time machine we could simply take our mass back to some point in the past and use this weight-mass method to calculate palaeogravity. In the absence of a time machine we could also calculate palaeogravity if we could calculate the weight of a mass that we know existed in the past.

An animal can be used to calculate gravity using the weight-mass method and naturally produces a surface gravity of 9.81 m/s^2 (1g) for present day life on Earth. The same weight-mass method could be used to calculate palaeogravity when a particular prehistoric ground-based animal was alive, if we could calculate the animal's weight and mass.

- For weight: Anderson *et al.* (1985) studied the bones of a range of present-day animals and produced a formula to calculate the weight of an animal based on the dimensions of its leg bones. This formula can predict the weight of land-based animals alive today, as well as the weight of prehistoric land-based animals.

- For mass: Palaeontologists have produced accurate reconstructions of a large number of prehistoric animals from just their skeletons. These reconstructions allow the mass of the same land-based animal to be calculated from its body volume and tissue density.

Palaeogravity can therefore be calculated from:

$$g_a = w_a \ / \ m$$

where g_a is palaeogravity at some predefined age, w_a is the weight at that age and m is the mass. Since mass never varies it does not need a subscript to denote its age.

Because fossils of land-based life are known from hundreds of millions of years ago the weight-mass method can be used to quantify reasonably accurate estimates of palaeogravity at these remote periods in the past.

The application of this technique to four specimens of *Tyrannosaurus rex*, representing some of the most complete theropod dinosaur skeletons known, should provide us with reasonably accurate values of palaeogravity when they lived. For the four *Tyrannosaurus rex* specimens: "Carnegie" CMNH 9380, "Wankel rex" MOR 555, "Stan" BHI 3033 and "Sue" FMNH PR 2081, the results indicate that palaeogravities of 0.67g, 0.66g, 0.61g and 0.64g respectively are reliable estimates for 67 million years ago.

Obviously, these results are so extreme that we must wonder why they have not been noted previously. In practice they have. In the paper by Günther *et al.* (2002), *Gravitational tolerance and size of Brachiosaurus brancai*, the authors recognised there remained "an unsolved contradiction between the theoretical assumptions" of gravity and the largest fully terrestrial animal. They noted that the previous mass estimate for *Brachiosaurus brancai* by Gunga *et al.* (1996) was too large to exist in a 1g environment. Recognising this general problem for theropod dinosaurs in particular, some palaeontologists have advised abandoning the use of the weight formula based on leg bones entirely, since they seemed to give absurd results. The differences between weight and mass were so great for large bipeds in particular that Hutchinson *et al.* (2007) concluded that: "...it is almost certain that these scaling equations greatly underestimate dinosaur body masses... Hence, we recommend abandonment of their usage for large dinosaurs."

However, these problems with weight estimates are obviously based on a fundamental belief in an unchanging palaeogravity.

Let's accept that both the weight and mass estimates are correct. Using the weight-mass technique we can push the palaeogravity calculation further back in time by looking at some of the very first dinosaurs.

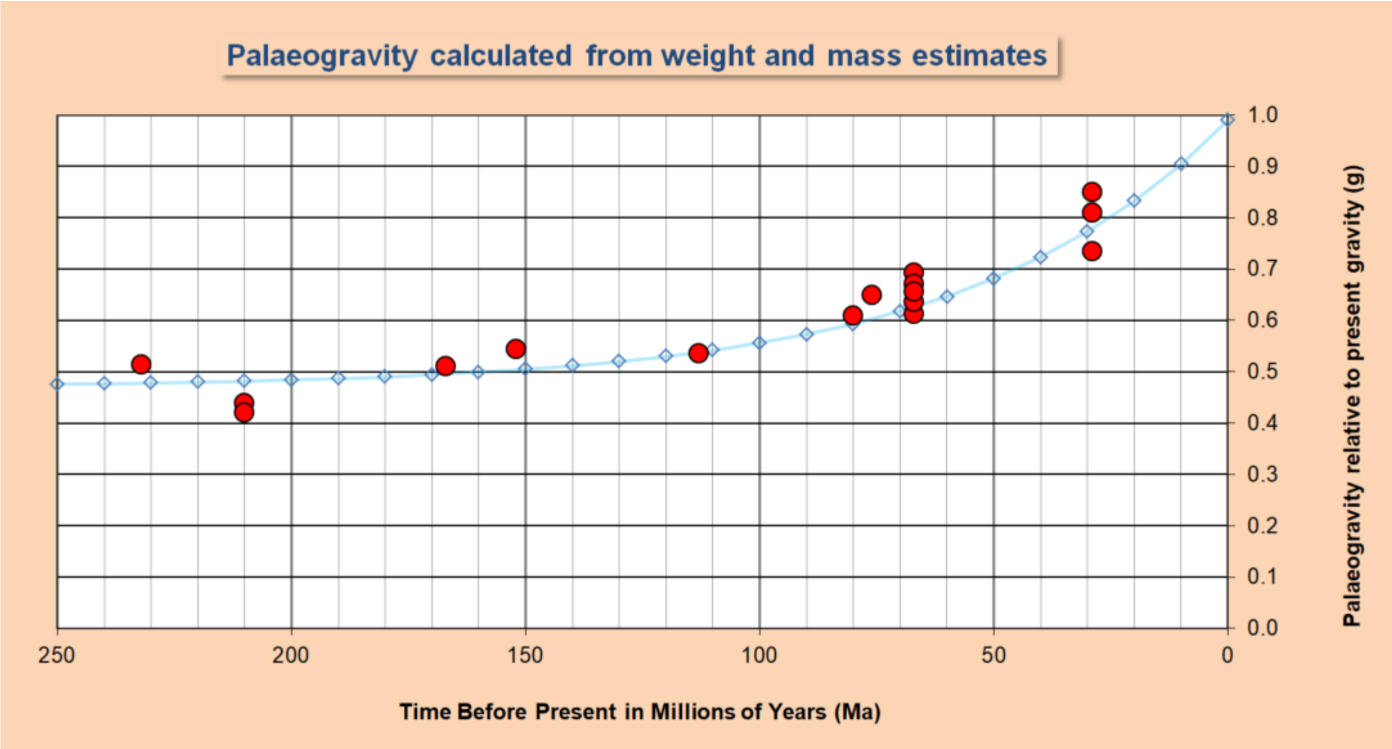

Figure 1. Graph showing slowly increasing palaeogravity over time, based on weight and mass estimates of prehistoric life. *Herrerasaurus:* 0.51g, *Coelophysis*: 0.42g and 0.44g at 210 Ma, *Megalosaurus*: 0.51g at 167 Ma, *Giraffatitan*: 0.54g at 152 Ma, *Acrocanthosaurus*: 0.54g at 113 Ma, *Gigantoraptor:* 0.61g at 80 Ma, *Euoplocephalus:* 0.65g at 76 Ma, *Tyrannosaurus rex:* 0.67g, 0.66g, 0.61g, and 0.64g at 67 Ma, *Ankylosaurus:* 0.69g at 67Ma and *Paraceratherium*: 0.73g, 0.81g and 0.85g at 29 Ma. A tentative fit line is also shown.

Herrerasaurus predicts a palaeogravity of approximately 0.51g at 232 million years ago (Ma). Two specimens of *Coelophysis* allows us to predict palaeogravities of approximately 0.42g and 0.44g at 210 Ma. Other animals produce a range of palaeogravity estimates: *Megalosaurus* predicts 0.51g at 167 Ma, *Giraffatitan* predicts 0.54g at 152 Ma, *Acrocanthosaurus* predicts 0.54g at 113 Ma, *Gigantoraptor* predicts 0.61g at 80 Ma, *Euoplocephalus* predicts 0.65g at 76 Ma, *Ankylosaurus* predicts 0.69g at 67Ma and *Paraceratherium* predicts 0.73g, 0.81g and 0.85g at 29 Ma. Plotting all these results, as shown in Figure 1, indicates that palaeogravity has been slowly increasing towards our present-day surface gravity.

A tentative fit line has been added to this preliminary data. The formula for the calculation of the relative palaeogravity predicted by this line is:

$$g_a = 0.52.e^{-0.018.a} + 0.47$$

Where a is the time before present in millions of years. This formula gives the relative palaeogravity taking the present gravity as 1. If palaeogravity is required in m/s^2 then g_a should be multiplied by 9.81.

Scientific authorities may well give a thousand reasons why we should ignore these results but I only ask you to consider my reasoning. Have we all been blinded by what we think we know? Could it be possible that both the weight and mass estimates are correct and it is our belief in an unchanging palaeogravity that is the mistake?

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