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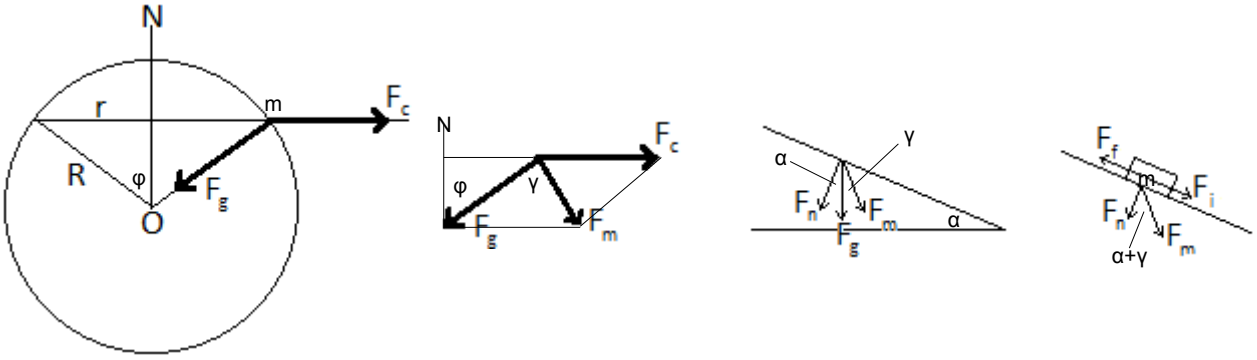
Stonehenge Problem B: How the Stones got to Stonehenge?

Given a smooth, flat, slightly inclined ice surface at a specified latitude (Wales), determine if a megalith of mass *m* on the ice surface moves acted on only by natural forces.

Preliminary Analysis:



Earth's radius: $R = 6{,}378km$

Angle from North at latitude 52 degrees: $\varphi = 38^0$

Gravity constant: $g = 9.81 \left(\frac{m}{s^2}\right)$

mass of megalith: $m = 3000kg$

latitude radius to the Earth's axis: $r = R\sin\varphi \ (km) = 1000R\sin\varphi = 3926688.8896270594 \ (m)$

speed of rotation at given latitude:

$$v = \frac{2\pi R\sin\varphi}{24} = \frac{\pi}{12}R\sin\varphi\left(\frac{km}{hr}\right)\cdot\frac{1000m}{km}\cdot\frac{hr}{3600s}$$
$$= \frac{\pi}{43.2}\cdot R\sin\varphi\left(\frac{m}{s}\right)$$
$$= 285.5568742738 \ (m/s)$$

centrifugal acceleration at given latitude:

$$a_c = \frac{v^2}{r} = \frac{\left(\frac{\pi}{43.2}\cdot R\sin\varphi\right)^2}{1000R\sin\varphi} = \frac{\pi^2}{1{,}866{,}240}\cdot R\sin\varphi \quad \left(\frac{m}{s^2}\right)$$
$$= 0.02076628190734949057 \ (m/s^2)$$

force due to gravity: $F_g = mg = 29430 \ (Newtons)$

centrifugal force: $F_c = ma_c = \frac{\pi^2}{1{,}866{,}240}\cdot mR\sin\varphi = 62.2988457220 \ (Newts)$

mass force F_m due to gravity and rotation: $F_m^2 = F_g^2 + F_c^2 - 2F_gF_c\cos\left(90^0 - \varphi\right)$

$F_m = 29380.9328746897 \ (Newtons)$

angle γ of F_m from Earth's radius R : $\sin\gamma = \frac{F_c}{F_m}\cos\varphi = 0.0016708850115686$

$\gamma = 0.0957347038^0$

Consider next an angle of inclination α . Let the 'coefficient of friction' be given by μ and the force due to friction be F_f . Let F_n be the 'normal force' and F_i be the 'incident force' to the surface exerted by the mass m . Then the angle between F_n and F_m will be $\alpha + \gamma$. Notice that the centrifugal force F_c acts as an inclined plane of angle γ . We have,

normal force to the ice surface: $F_n = F_m \cos(\alpha + \gamma)$

incident force along the ice surface: $F_i = F_m \sin(\alpha + \gamma)$

force F_f due to friction: $F_f = \mu F_n = \mu F_m \cos(\alpha + \gamma)$

net force F acting on mass m : $F = F_u + F_i - F_f$ where F_u may be due to 'wind' or 'water'.

$= F_u + F_m \cdot (\sin(\alpha + \gamma) - \mu \cos(\alpha + \gamma))$

In order to have movement we'll need a net positive force F. Thus,

$$F = F_u + F_m \cdot (\sin(\alpha + \gamma) - \mu \cos(\alpha + \gamma)) > 0$$

and so, $$\tan(\alpha + \gamma) + \frac{F_u}{F_m} \cdot \sec(\alpha + \gamma) > \mu$$

or, $$F_u > F_m \cdot (\mu \cos(\alpha + \gamma) - \sin(\alpha + \gamma))$$

Rational Plausibility: At Wales the γ due to Earth's rotation for a mass of 3000 *kg* equals 0.0957347038^o . For a megalith of mass 3000 *kg* on a smooth flat ice surface with no inclination (α =0) and with kinetic coefficient of friction* $\mu = 0.02$ and a force $F_u > 540$ Newtons (due to wind)** the resulting net force F acting on the megalith will be greater than 0 and thus producing movement. Perhaps intermittently over many years. The direction of movement would be generally from NW to SE in agreement with the direction from Preseli to Stonehenge.

Conclusion: It is possible for a 3 ton megalith to be moved on a flat ice surface from Wales to Stonehenge through 'natural agency' alone.

* *Babcock, David D. The Coefficient of Kinetic Friction for Curling Ice. 8 April 1996.*
(http://hypertextbook.com/facts/2004/GennaAbleman.shtml)

** *A wind velocity of about 60 mph will exert on an object a force of about 660 N per square meter.*
(http://www.knmi.nl/samenw/hydra/faq/press.html)