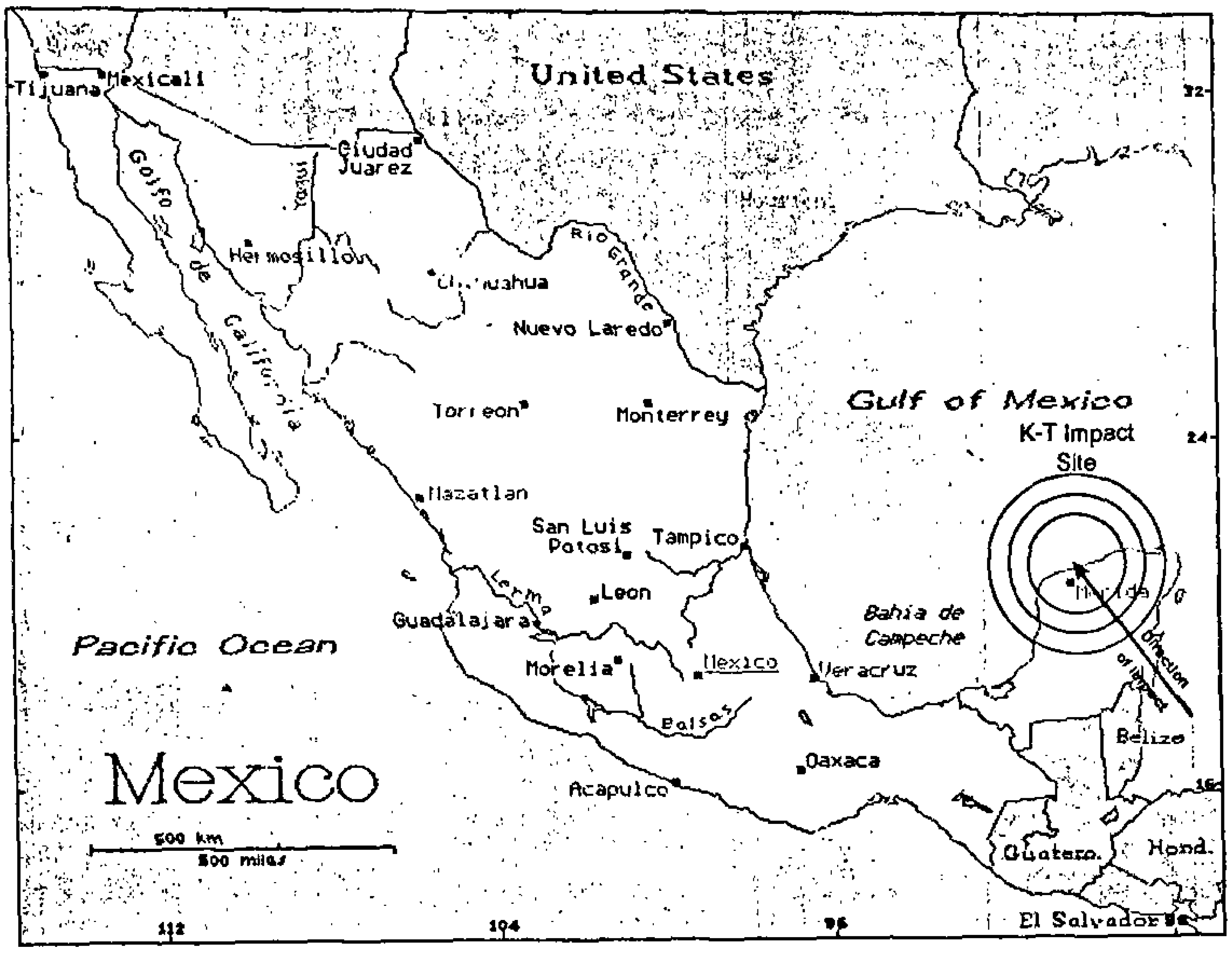

Figure 1. The K–T meteorite impact site (Chixulub Crater) in Yucatan Peninsula, Mexico.

infer were part of this K–T meteorite. One of them[1], Benjamin Schuraytz and colleagues at the NASA's Johnson Space Center, Houston, isolated from the Chixulub crater, the impact site, nuggets of nearly pure iridium enclosed inside a silicate. Apart from this, they also found iridium enriched (13.5 ppb) particles from the impact-generated melt-rock and melt-breccia and the enrichment values happened to be far above those typical of Earth's crust. They suppose that these abnormal amounts of iridium are due to admixture of meteoritic material (chondritic) into the impact melt[1], and they have estimated that at least 3% of chondritic material must have been incorporated.

The second find by Frank Kyte of the University of California, Los Angeles, has come from mid-Pacific, about 9,000 km due west of Yucatan impact site, from drill-core samples retrieved by a team drilling the ocean bed. The meteorite relic they found was a 5 mm long inclusion in a core of dark-brown clay lying at the bottom of K–T boundary layer. This inclusion contained a 2.5 mm long pebble having high amounts of Cr, Fe and Ir, in quantities characteristic of meteorites. They infer that the most reasonable source of this material, undoubtedly deposited within the K–T layers, must belong to the K–T projectile itself. This view is strengthened by the fact that this mid-Pacific site lies exactly in the path of debris that must have been thrown in a northwesterly direction when the meteorite hit Yucatan from the southeast. The impact is believed to have been made at a low angle of 20° to 30° which is considered most destructive.

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A planet rotating inside Earth's womb

Seismological and computer simulation studies about the internal structure and composition of Earth, in an effort to understand the temporal variation of its magnetic field and reversal of its poles, have brought out one of its most interesting aspect – an independent spinning of the inner core, a region about the size of the moon deep in the womb of Earth.

The structure of earth into lithosphere, asthenosphere, transition zone, lower mantle and core has been largely inferred through seismic wave studies. These waves (chiefly the P and S waves, so designated on the basis of their vibration modes) travel through the Earth with different velocities, and they are affected by the density and elastic constants of the materials through which they pass. Thus, they get deflected at surfaces of discontinuity and as a result distinct subzones have been recognized within the mantle and core regions; for example, the core is made up of an outer zone about 2270 kms thick, of molten iron mixed with lighter elements and an inner one of solid iron with a radius of 1220 kms.

According to Walter Elasser and Edward Bullard, Earth's core is a self-exciting dynamo, generating its own magnetic field[1]. Here the fluid iron is 'stirred into convective motion by heat generated from residual radioactivity in the core' and in the presence of small, stray magnetic field, this motion would produce electric currents (which in turn will create its own magnetic field) just as in a dynamo where a conductor (copper wire or disc) moving through a magnetic field of a bar magnet generates electric currents. Now this phenomenon has triggered two geophysicists, Gary Glatzmaier of Los Alamos National Laboratory in New Mexico and Paul Roberts of the University of California, Los Angeles[2–4], to predict on the basis of computer simulations studies, that

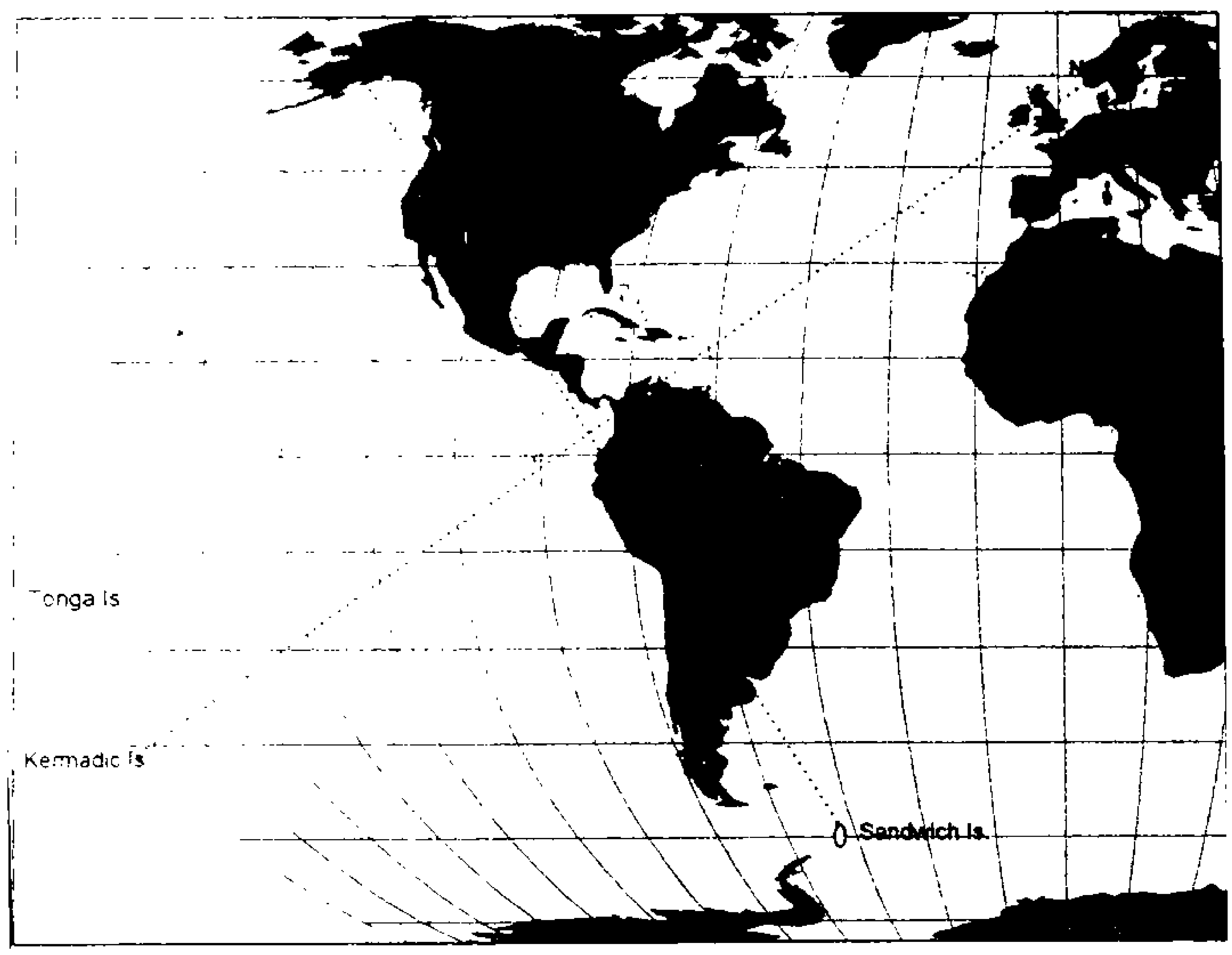

Figure 1. Earthquake focus sites and receiving stations.

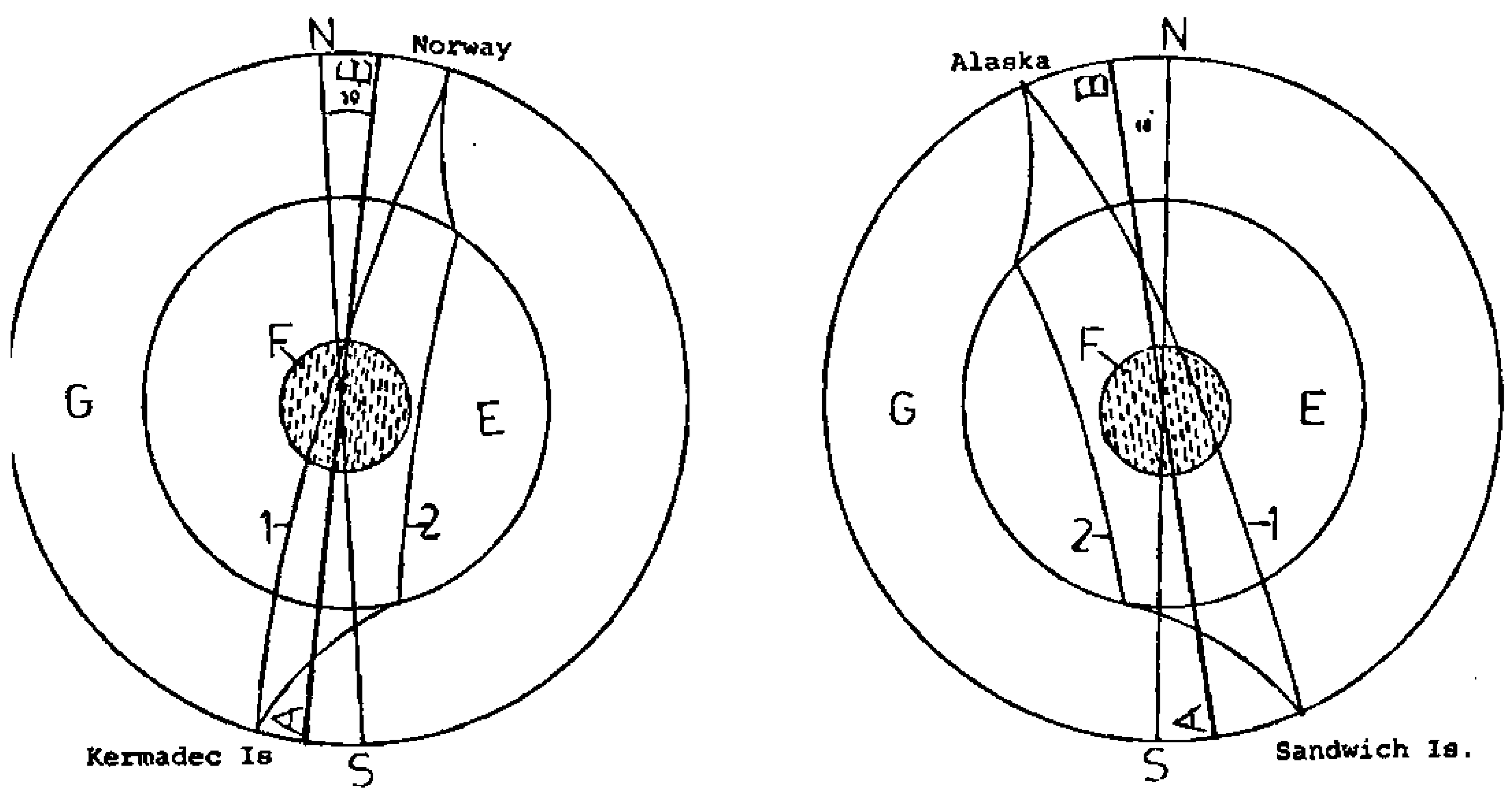

Figure 2. Idealized diagram showing drift of axis of anisotropy due to rotation of the inner core and the passage of seismic waves from earthquake foci at Kermadec and Sandwich Islands in the Southern hemisphere and arriving at the receiving stations in Norway and Alaska in the Northern hemisphere: (*left*) the position of the axis of anisotropy in 1967 and (*right*) its position in 1995. A–B, Axis of anisotropy (fast axis); N–S, North–South axis of Earth; E, outer core; F, inner core; G, mantle; (1) P-wave travelling through both the inner and outer cores, (2) P-wave travelling through the outer core only.

this dynamo action of the inner core of the Earth can induce it to spin freely. They argue that the magnitude of electric currents generated across the boundary with the solid inner core is quite huge (of the order of a billion amperes) and in the presence of magnetic field, this will exert a pulling force on the inner core. Since the outer core is viscous, they calculated that this tug will result in imparting a motion or spin to the inner core by about one or two degrees in an eastward direction.

However, according to another model developed by Arnou, Brito and Olson of Johns Hopkins University, Baltimore, this tug is caused by the powerful electromagnetic field created by stormy vortices of thermal currents raging along a north–south oriented cylindrical zone of relatively hotter outer core fluid, immediately adjoining the inner core[14].

Their predictions about the differential spin of the inner core have now been proved to be true by latest seismic studies by Xiadong Song and Paul Richards of Lamont-Doherty Earth Observatory[5]. Their observations were based on an unique behaviour of the P-wave travelling through the inner core. These waves are known to travel faster inside the inner core in the direction close to the N–S axis but slower along the equatorial plane[6,7]. This is attributed to the preferred N–S orientation exhibited by the high pressure hexagonal polymorph of iron crystals (according to one view[8], the inner core is thought to be one giant single crystal) that make up the solid inner core[9,10]. This direction, better known as the 'fast axis' or the 'axis of anisotropy', is tilted by about 10° to Earth's N–S axis of rotation[11].

Song and Richards examined all the earlier seismic data of earthquakes arising from almost the same site for several years and evaluated the time P-waves took to reach receiving stations located at the opposite sides (antipodes) of Earth (Figure 1) after travelling through (a) both the inner and outer cores (Ray 1, Figure 2) and (b) outer core only (Ray 2, Figure 2). Their examination of these earlier data pertained to the travel times of such pairs of P-waves from (i) 38 earthquakes (> 5.5 magnitude) originating from Sandwich islands (located between Cape Horn and Antartica) in the southern hemisphere and arriving at the receiving station, College, in Alaska (ii) quakes from Tonga island (mid-Pacific), and reaching Graefenberg in Germany, stations lying close to the equatorial plane and (iii) Kermadec island N.E of New Zealand, and arriving in Norway, stations lying close to the N–S axis of anisotropy. They found that while the travel times of the P-waves taking the Tonga–Germany route close to the equatorial plane, remained the same over the years, the ones that took the Sandwich–Alaska route arrived at the receiving stations 0.3 seconds sooner in 1995 than they did in 1967.

Song and Richards argue that since the paths of the P-waves through Earth are essentially fixed, their shorter travel time between Sandwich and Alaska progressively over the 28-year period can take place only if the angle between the paths of P-wave and the fast axis of anisotropy gets gradually reduced. This reduction in the angle is possible only if the inner core rotates, a feature predicted by Glatzmaier and Roberts earlier. The inferences deduced by Song and Richards from past seismic recordings were further strengthened when they noticed that the travel time between Kermadec and Norway, stations which were initially close the fast axis of anisotropy, showed an increase with the passage of time, a clear indication that these two stations are no longer close to this fast axis (Figure 2). Their calculations indicate that the 'inner core rotates about the N–S axis like the rest of the planet, but at a rate that is 1.1° faster', eastwards.

However, subsequent work by Wei-Jia Su and his colleagues from Harvard and University of California, Berkeley, evaluating a 29-year data from International Seismological Centre (1964–1992) has revealed that the inner core rotates about 3° per year faster[12].

The differential spin of the inner core was, in fact, envisaged as early as 1986 and 1989 by the Indian scientist J. J. Rawal, Nehru Planetarium[13], Bombay, as an outcome of the progressive slowing down of the spin of the Earth, a view endorsed later by Raymond Jeanloz, University of California, Berkeley. They felt that this slowing down is due to friction caused by lunar and solar tides and that this deceleration is not fully transmitted to the inner core owing to the existence of a fluid zone of outer core separating it from the rest of the planet. According to Jeanloz, the inner core is rotating presently at a rate Earth's surface was doing some 60,000 to 100,000 years ago.

These findings about the inner core rotation can have great bearing on our understanding of the physics and chemistry of the core, particularly about the outer core viscosity, its temperature and melting conditions, heat flux across the core–mantle boundary, about the dynamo action, geomagnetic reversals and the precession of equinoxes.

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SCIENTIFIC CORRESPONDENCE

Does steam cause a more severe burn than boiling water?

May be not necessarily. This question is making rounds of our high schools and examinations and has even entered the popular science literature. Often it is posed in such a way that we are not asked to choose whether it is right or wrong but to explain why it is so. The *expected* answer, we know, is that steam causes a more severe burn due to the high latent heat of evaporation.

The question whether steam causes a more severe burn than boiling water is vague and ill-posed and strictly speaking cannot be answered. But what is being done here is to see how far can we rationalize this question and push analysis to understand the related issues. This exercise should also warn us while posing similar *clever* questions.

Steam and boiling water can exist at varying temperatures but it is only correct to assume here that both are at the same temperature. But this aspect is not as simple as it appears. We may have them at the same temperature at the source, but that does not necessarily mean that they will be at the same temperature when they contact the skin to cause a burn. This problem will be discussed later.

Water indeed has an impressively high latent heat of evaporation $H = 2.257 \times 10^6$ J/kg at 100°C and this aspect must have led some science teacher to coin this question. It is quite possible that the question has been

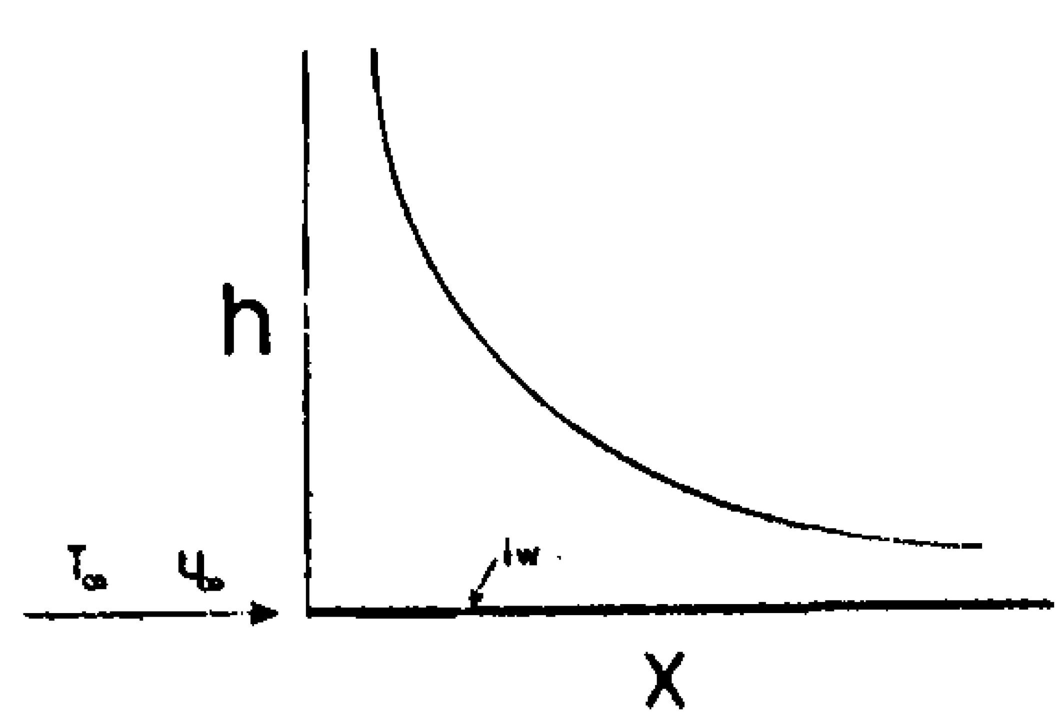

Figure 1. Heat transfer coefficient *h* due to flow along a flat plate.