PACIFIC GEOMAGNETISM

On January 17th 1779, Captain James Cook sailed into Kealakekua Bay on the Big Island of Hawai'i. The first westerner thought to discover these tropical islands, found himself greeted by ten thousand curious Polynesian natives. Yet, less than one month after their arrival in paradise, the crew of the *Endevour* had taken too many liberties and were no longer welcome. Cook was a bad swimmer, and one night in February, rather than swim the short distance to an awaiting ship, he chose to stay on land and encounter an angry mob who beat him to death. Thankfully, his other naval skills were better perfected. Cook, like many other Captains of that era, ensured that meticulous records were kept of the varying conditions at sea, the weather and stellar observations (Figure 1). Little did he realize though, that the modern day scholar of geomagnetism would make great use of one particular aspect of his logs; namely the direct measurements of the Earth's magnetic field.

The magnetic field of the Earth was first noticed around AD 1000 by the Chinese. They documented that an iron-rich ore called lodestone consistently aligned itself with the South Pole when allowed to float freely in water. Despite this early recognition, the underlying physics of geomagnetism has only started to be understood within the past 50 years. Centuries earlier, people didn't know either what caused or affected the magnetic field, to the extent that some helmsmen were told not to eat garlic because it was believed that the pungent fumes had an adverse affect on it. Despite this lack of knowledge, the magnetic field was still utilized as an important navigational tool along with the constellations of the stars. Since Columbus set sail in the 15th century, the volume of marine traffic steadily increased as new lands were discovered and colonized and the trading of slaves and produce began. Early measurements were dominated by declination, the angle between the geographic north, as defined by the stars, and the magnetic north the compass pointed to (Figure 2). As interest in the subject grew, measurements of inclination, the deviation from horizontal in a vertical plane, and intensity were also made. Unfortunately, a common problem of taking magnetic measurements at sea was constraining the precise position of the ship at that time. Prior to the mid-1700s, when new equipment and tools were invented, such as better clocks, longitude was very hard to determine accurately. Usual practice involved guessing the drift rate from the ship's speed and the weather conditions, then making corrections when known coastlines were sighted. The first logs with reliable longitude were from Cook's circumnavigation in 1768-1780.

Magnetic observatories began operating in the late 1830's, making continuous measurements at the same location. However, observatories are limited to being on dry land, the majority being concentrated in the northern hemisphere in western Europe or within the colonies of the British Empire, and therefore a decent coverage over the Earth's surface was not possible. Jackson et al. (2000) trawled through the magnetic data found in the log books made by navigators criss-crossing the world's oceans and combined it with data from observatories and recent satellites. Knowing three of the components (inclination, declination and intensity) the whole magnetic vector could be deduced (Figure 2) and a comprehensive account of the global change in the morphology and intensity of the magnetic field over the past 400 years could be made - this is the geomagnetic secular variation.

Historical records, whilst useful, do not help us to properly understand the behavior of the geomagnetic field on geological timescales. To this end the 137 volcanic islands that make up Hawai'i are an ideal natural laboratory for the study of geomagnetism and paleomagnetism. Kilauea volcano (meaning spewing and much spreading) is the most active volcano in the world having been in it's current eruptive episode for over 2 decades. When molten lava cools and solidifies, it locks into it's memory the magnetic field at that time. The historic lava flows are well mapped and easily accessible, resulting in Hawai'i being densely sampled in both inclination and declination since James Cook's arrival. For example, the vast 1960 flow covering the eastern tip of the Big Island, provides the opportunity to collect lots of fresh samples to work on. The Hawai'ian magnetic observatory recorded the actual field in 1960 meaning that field and laboratory techniques can be robustly tested and the results compared to the known 'answer'. All the data collected from Hawai'i complement the global database of Jackson et al. (2000) since the Pacific side of the globe is otherwise limited in accurate or repeated measurements.

To investigate the behavior of the ancient field, paleomagnetic techniques are used to study the magnetic properties of samples cut from cores drilled through several flows spanning thousands of years. However, the discontinuous and sporadic eruptive nature of volcanoes means that independent radiogenic dating of the rocks is also required, a process which can have significant associated errors, especially with older samples. In laboratories, the aim is to reverse the natural geological process, indirectly obtaining information about the ambient magnetic field at the time the lava initially cooled. Regardless of the technique used (for example Thellier and Thellier, 1959; Hill and Shaw, 1999), an unexpected trend of the Hawai'ian data is the inclination being systematically 3^o shallower than expected (Hagstrum and Champion, 1995). There are many explanations for the possible cause: Baag et al. (1995) suggest the underlying terrain of previous flows as a controlling factor, the associated magnetic field strength having a demagnetizing effect on the new flow subsequently covering it. Other ideas involve the movement of flows after they have solidified, i.e., cliff slumping, or varying cooling rates. An alternative theory currently under investigation, is that it could be caused by the large-scale magnetization of the seamount; the name given to the conical shaped submarine peak before it breaches the sea surface to become a volcanic island.

Consolidating all the published results from several independent global surveys produces some interesting results. The historic secular variation in the Pacific seems to be low, lacking the magnitude and rapidity of the variations in the Atlantic hemisphere (Figure 3). The interesting question is whether this has always been the case, or whether, when the constraining time window is extended further back by the addition of paleomagnetic data, we may discover that this is in fact a recent phenomenon or alternatively, if it has occurred periodically at different times in the Earth's life. The key is Hawai'ian data and the extension and improvement of the existing set of results; looking at existing, unpublished data and new core data collected from specified lava flows that fill in the critical age gaps. The fine detail seen with the historic data needs to be matched within the paleomagnetic record as well. When looking specifically at the geomagnetism in the Pacific, the data from Hawai'i are invaluable because of their location. Hawai'i lies close to the center of the large Pacific plate so that it's magnetism is predominantly influenced by the core-mantle boundary within the active 'ring of fire'. A larger data set over a longer time frame should enable a better understanding of the magnetic story from Hawai'i and the Pacific.

Over the years we have learnt that the magnetic field is generated and maintained in the liquid iron outer core and on a basic level can be modeled by bar magnet aligned with the rotation axis of the Earth. Looking more closely we find that the main field is internal to the Earth, but that there is also a fast varying external component originating from solar activity. New observations are needed to test the current theories about the dynamics of the core and the way fluid flow there modifies the field we observe at the surface. The Earth's magnetic field has always had an impact on life whether it is being used for navigational purposes or protecting us from solar radiation. It is vital that future generations of scientists continue the quest to understand this fundamental component of our environment.

References

Baag, C., Helsley, C. E., Xu, S., and Lienert, B. R. Deflection of paleomagnetic directions due to magnetization of the underlying terrain. *J. Geophys. Res.*, 100 (B7), 10013–10027, 1995.

Hagstrum, J. T. and Champion, D. E. Late Quaternary geomagnetic secular variation from historical and ^{14}C-dated lava flows on Hawaii. *J. Geophys. Res.*, 100(B2), 24393–24403, 1995.

Hill, M. J. and Shaw, J. Palaeointensity results for historic lavas from Mt Etna using microwave demagnetisation/remagnetisation in a modified Thellier-type experiment. *Geophys. J. Int.*, 139, 583–590, 1999.

Jackson, A., Jonkers, A. R. T., and Walker, M. R. Four centuries of geomagnetic secular variation from historical records. *Phil. Trans. R. Soc. Lond. A*, 358, 957–990, 2000.

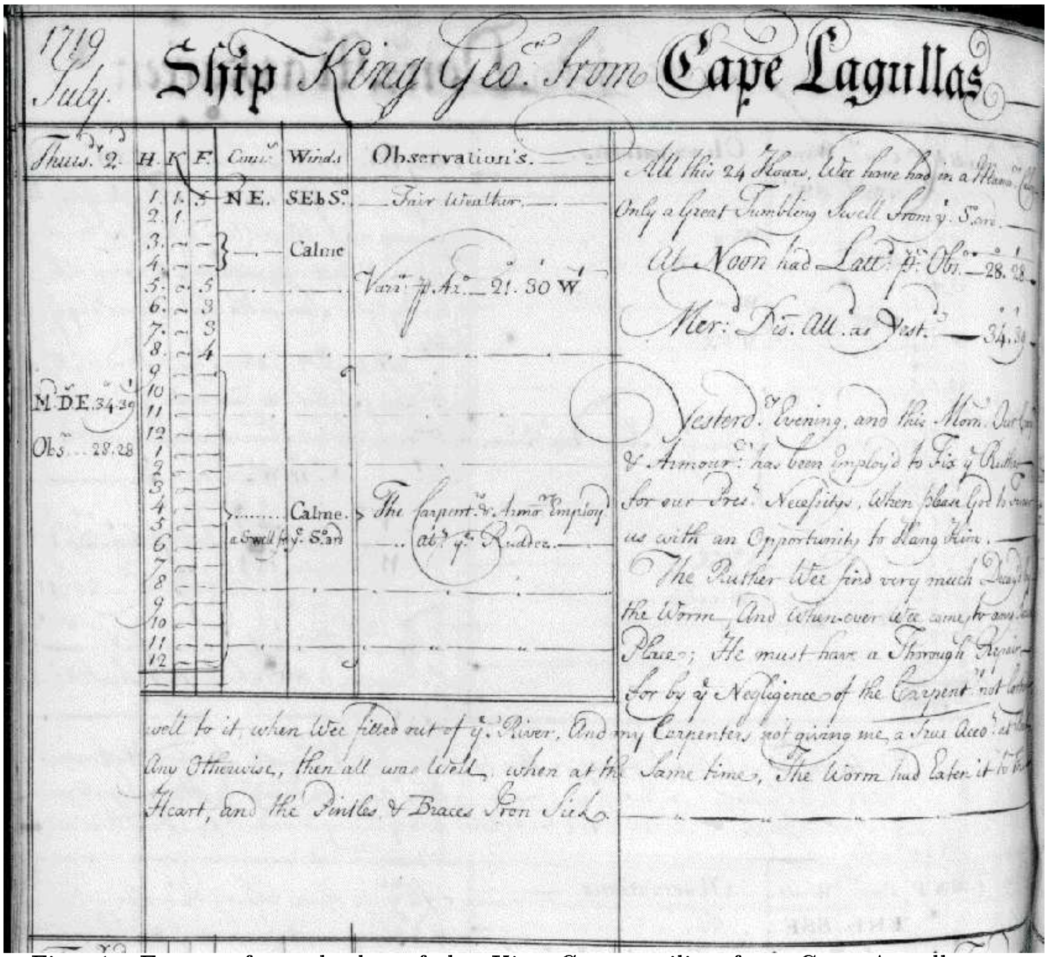
Thellier, E. and Thellier, O. Sur l'intensite des champ magnetique terrestre dans le passe historique et geologique. *Ann. Geo.*, 15, 285–376, 1959.

Figure Captions

- **Figure 1.** Excerpt from the log of the *King George* sailing from Cape Angulhas to Mauritius on July 2nd, 1719. The declination measurement is abbreviated Var. per Azimuth in the table (variation observed with azimuthal compass). By permission of The British Library (L/MAR/B 402 B).

- **Figure 2.** Schematic representation of how the x, y and z components of the magnetic field vector, F relate to the declination, D, and inclination, I. Taken from the website of The World Center for Geomagnetism, Kyoto (http://swdcwww.kugi.kyoto-u.ac.jp/element/eleexp.html).

- **Figure 3.** Comparison of secular variation for a location on Kilauea volcano, Hawai'i (solid line) and a point on the same latitude in the Atlantic hemisphere (dashed). (a)Declination. (b)Inclination.



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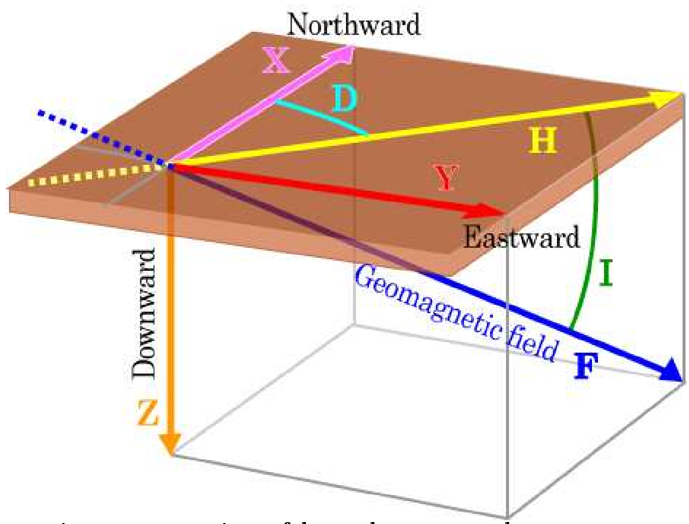

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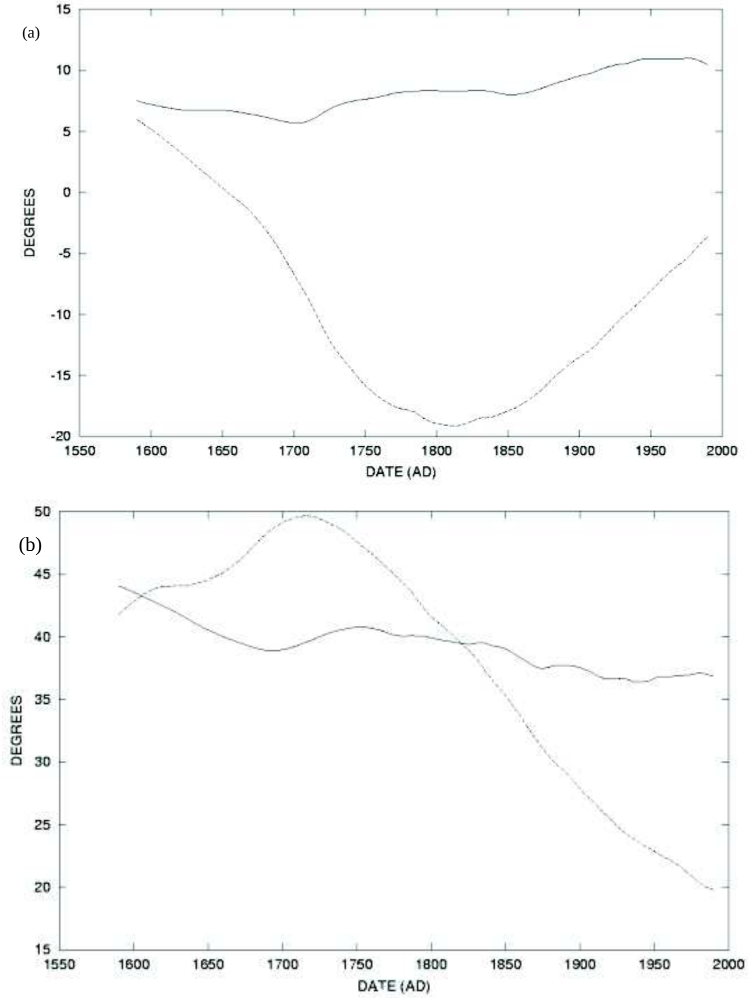

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