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The Incompleteness of the Geological Record One of the basic ideas central to geology has been that geological processes, although extremely slow have had enough time to mould the Earth's surface to its present form; the estimated 4.5 billion years of the Earth's history have been assumed to provide an appropriate time to account for the events recorded in the stratigraphical record. However, recent studies seem to indicate that the observed rates of geological building processes are often orders of magnitude faster than was once believed. If these rates are typical, then it becomes clear that the time of 4.5 billion years is far longer than needed to account for the observed geological record. In Wyoming for instance, a sequence of early Cretaceous sandstones and shales closely resembles the coastal sediments of the Gulf of Mexico. Applying the present measured rates of deposition indicates that a mere 100,000 years would be needed to produce the entire sequence, although the stratigraphical interval encompassed by the series is known to be about 6 million years. Many other examples exist where a sequence apparently only requires 1% to 10% of the available time to account for its formation, based on the measured deposition rates.

This interesting observation has recently been examined in depth by P. M. Saddler (*J Geology 89* 569 1981; discussed by T. H. van Andel in *Nature 294* 397 1981). His detailed analysis of the data available indicates that the geological record does indeed appear to be very incomplete, and that the incompleteness is greater the shorter the time span at which we look. There had been some previous evidence for a degree of incompleteness in the record; thus the sediments in the undisturbed deep ocean which might be expected to be complete, were shown by the *Glomar Challenger* drillings to contain less than half the history of the past 125 Myr. However, the level of incompleteness since revealed is very much greater than might reasonably have been expected.

This inferred severe incompleteness of the record has a number of consequences for the history of the Earth. It will make it unlikely that the stratigraphical boundaries between rock layers will have been preserved in many cases, particularly for beds spanning relatively brief periods. Many gaps in the record can be clearly seen, but it seems that many other breaks must go unnoticed. We are apparently left with a picture where brief periods of activity are separated by long periods where nothing happens, or during which traces of brief events are not recorded, eg periods of erosion or non-deposition. There is clearly a vastly increased need for more accurate stratigraphical and chronological studies to explain this apparent incompleteness. This picture of periodic activity followed by relative quiet has a parallel in a current view of the evolutionary process, namely that it takes place in a series of jumps interspersed by longer periods of relative inactivity. If these evolutionary jumps occur in periods when geological activity is minimal, then there would be every chance that they would never be recorded as fossils in the geological record.

Volcanoes A recent book entitled *Volcanoes of the World* (by Simkin, Siebert, McClelland, Bridge, Newhall and Latter, Academic Press, 1981) provides a very comprehensive regional directory, gazetteer and chronology of Earth's volcanism in the past 10,000 years, dealing with 1343 volcanoes and 5564 known eruptions in this period.

A vast compendium of facts is presented. Thus 96 island forming eruptions have been recorded in this period. The various extremes are catalogued, eg the highest active volcano (Llullaillaco at 6723m in the Chilean Andes) and the briefest major eruption (the draining of a $20km^3$ lava lake in Zaire in less than one hour). The size of eruptions can be measured in a number of different ways, but there has in the past been no equivalent of the Richter scale used for earthquake classification by which eruptions can be measured. The authors have included values of a volcanic explosivity index (VEI) put forward by 2 other geologists which combines 8 different measures including volume of ejecta, eruption column height, duration and degree of stratospheric injection. A scale ranging from 0 (non-explosive) to 8 (more explosive than any eruption in the past 10,000 years) results—the Mount St Helens eruption of May 1980 is just rated 5 on this scale ('very large'). Many recent and historic eruptions have been considerably larger. The 1815 explosion of Tambora is the only event to have received an index of 7.

One problem the authors point out is the haphazard reporting of volcanic activity; they believe that many significant eruptions have gone unrecorded and that supposed alterations in activity over time may just reflect historical trends in reporting. This point of view has however been rejected by those who believe that they can detect significant correlation between volcanic activity and other world-wide phenomena, eg climate and glacier variations (as discussed in last year's Notes, *AJ 87* 228). However, although the record may be somewhat garbled, the authors still believe that the behaviour of volcanoes is not random. Thus the eruptions of Souffriere and Mont Pelée (VEI 4) were within one day of each other in 1902, the mountains being 165km apart. These events were followed in 5 months by the larger eruption (VEI 6) of Santa Maria in Guatemala 3260km to the W. These are the 3 most explosive eruptions to have occurred in the same year, and all were on the edge of the same crustal plate suggesting that stresses transmitted across a plate may trigger relatively simultaneous volcanic activity over a large region.

The book ends on an ominous note. The longer a volcano remains dormant, the more lethal is its next eruption likely to be. Eruptions of VEI 0 to 2 had quiet intervals preceding them of 1 to 10 years. Most eruptions of VEI 6 had been preceded by a quiet period of 1000 years. The period of deceptive quiet is probably even greater for the rare events which dwarf anything in the record of the last 10,000 years. Seven hundred thousand years ago, for instance, the Long Valley Caldera in California is estimated to have spewed out $600km^3$ of ash over an area of $1200km^2$. This compares with the $1km^3$ of ash from Mount St Helens.

The Antarctic Ice Sheet Substantial advances have been made in recent years in our knowledge of the Antarctic ice sheet, and the rocks which lie beneath it. Much of this has resulted from the development in the early 1960s of the first airborne system for radio echo sounding (RES) of the ice sheet, work which was carried out at Cambridge University. The method is similar in principle to marine echo sounding, and uses a downward looking very high frequency pulsed radar system to probe the ice. Choice of optimum wavelengths in the band 0.3m to 10m results in pulses which penetrate the ice surface and which are ultimately reflected from the ice/rock interface, the echo being finally detected at the point of transmission. The time of return of the echo allows the calculation of the thickness of the sheet and subsidiary pre-echoes indicate internal reflecting layers within the ice, due to small density changes (resulting from seasonal variations) and acid impurities (the aftermath of past volcanic activity). A remarkable result of RES studies has been the detection of what are apparently lakes below the ice surface. These occupy hollows in the land surface beneath the ice, where the ice thickness is such that the pressure induces melting. The largest appears to be some $8000km^2$ in area.

To allow construction of a contour map of the ice sheet, the RES measurements which covered 50% of the continent were supplemented by 3 types of surface elevation determination. The surface of the ice sheet can now be depicted in much more detail than hitherto and features such as ice drainage basins and ice flowlines identified. Surprisingly, the thickest ice is only 400km from the coast in Terre Adelie where a huge subglacial trench is filled with 4776m of ice. Some of the thinnest ice is at the centre of the continent where a subglacial mountain chain rises to some 3500m. This new work has enabled more accurate estimates of the amount of ice in Antarctica to be made. The mean ice thickness appears to be 2160m and its volume about $3 \times 10^7 km^3$, the bulk being contained in the enormous East Antarctic Ice Sheet. Altogether, the Antarctic contains 99% of the world's ice and 90% of global fresh water.

The 2.7×10^{13} tonnes mass of ice has a severe loading effect on the crust beneath it, and calculations of the depression produced have been made based on the data obtained. The greatest depression is in central East Antarctica, estimated as 950m. This corrected rock surface is the one which should be used in any comparison of the fit of former fragments of the 'supercontinent' Gondwana of which Antarctica formed a part. The RES measurements have also been combined with another type of aerial measurement, namely surveys of rock magnetism. An analysis seems to indicate that Antarctica comprises 5 separate lithospheric plates, the large ancient East Antarctica shield and 4 smaller geologically more recent components which make up West Antarctica. (See D. J. Drewry, *New Scientist* 22 July 1982, p246.)

Earthquake Prediction Observation of seismic gaps or faults and determination of earthquake recurrence frequencies provides some possibility of determining the long-term risk of earthquakes. On the other hand, it has been more difficult to evaluate short-term earthquake risk. However, recent work (*Nature 299* 12 1982; W. Thatcher) suggests that close study of the pattern of stress build-up between successive earthquakes may give some clue to the imminence of the next major shock. It seems probable that there is not a steady increase in stress between large seismic events. A model which involves a steady post-seismic decline in rate followed by random occurrence of short periods of greater than average stress increase seems more likely. These transient events become more frequent until one finally triggers off the next earthquake. Such episodic changes have been detected in closely monitored seismic faults in southern California and Japan. Specific examples of triggering by such events have been observed in regions where the stress changes result from sub-surface magma movements, leading to large tectonic earthquakes. Shocks induced by the filling of reservoirs provide a further example consistent with the triggering mechanism sketched above. Swarm activity, ie large numbers of closely spaced seismic events, appeared to precede all the well documented large artificially produced shocks. A possible mechanism here seems to be a relatively steady build-up of stress that was occurring in the absence of the reservoir being suddenly accelerated as a result of the small triggering action of the pore pressure due to the water. A substantial shock is thus produced much more quickly than might have been the case, although the actual incremental pressure of the water is extremely small compared to the total stress needed to initiate the earthquake.

It thus seems necessary to evaluate very carefully the precise changes occurring across a fault to give a clearer picture of the state of the stress versus time curve. Where a deformation is followed by a marked increase in micro-seismicity, it seems likely that the risk of a large shock within a short time is large. Once anomalous movements are detected, further detailed studies can begin immediately and provide risk assessments that can be continuously up-dated. A number of intraplate faults exist in Japan which appear from earthquake frequency data to be current points of risk, and these seem promising areas to mount detailed studies to test further these ideas of earthquake triggering.