# Peeling the Chinese onion

**Jared M. Diamond**

**There are many explanations for the technological decline of China at the end of the mediaeval period, and the coincident technological rise of Europe. One, in a word, is geography.**

In mediaeval times, the region that led the world in technological innovation was China. By contrast, Europe north and west of the Alps was a backwater that had invented nothing of significance except for improved watermills. How did China lose its enormous lead in science and technology to Europe? Two papers by Graeme Lang[1,2], rich with broad implications, address this paradox in terms of structural or ultimate causation.

China's contrast with Europe has been the subject of much discussion[3–6]. The commonest interpretation — that Confucianism's conservative influence stifled science and technology in China — dissolves under scrutiny. For nearly 2,000 years under Confucianism, China reigned technologically supreme, with a long list of innovations ranging from canal lock-gates, gunpowder and magnetic compasses to paper, printing and sternpost rudders. Mediaeval Christian Europe was ideologically more hostile to scientific inquiry and innovation than was Confucian China. Attribution of China's eventual lag to its lack of Europe's Greek heritage or capitalistic outlook proves equally unconvincing. All such cultural interpretations, even if they were valid as proximate explanatory factors, would still beg the question of ultimate cause. As Lang remarks[1], "But even if culture was a factor, we are left with the problem of explaining why the cultures of these two regions were so different".

Lang begins by pointing out that the rise of scientific inquiry in Europe developed within a peculiarly European institution: autonomous universities where critical inquiry was relatively uninhibited by governmental or religious authority. Between AD 1450 and 1650, 90% of Europeans now considered to be contributors to science received university educations, and half of them held career posts at universities[7]. There was no comparable institution in China. Why not?

Historical causation is like an onion, whose concentric layers must be peeled back in sequence to reveal the ultimate causes at the centre. Lang sees the autonomous universities on the onion's outer skin as springing from an underlying layer of European political fragmentation. Mediaeval Europe was still divided into a thousand independent statelets, whereas China was already unified in 221 BC. So it proved impossible to suppress critical thinking for long in Europe: a thinker persecuted in one statelet could (and often did) merely walk into the next. To take just one example, the astronomer Johann Kepler was always able to keep one step ahead of the authorities by moving between Tübingen, Graz, Prague, Linz and Silesia.

Technological innovations were as hard to suppress in Europe as was scientific inquiry: when some princes tried to suppress firearms, printing or ocean-going ships, inventors found support from another prince. Competition between statelets provided a positive incentive for them to adopt innovations that might yield military or economic advantages over their rivals. (One such beneficiary was Christopher Columbus, whose schemes for ocean exploration were rebuffed in five states before he received backing from the sixth, Spain.) In contrast, China's unity meant that the decision of a single emperor could block an innovation over the whole of China — the demise of China's clocks, ocean-going fleets and water-powered spinning machines being only the most flagrant instances.

Thus, at the onion's core rests this question of ultimate causation: why was political unification easy in China but impossible in Europe? After China's initial unification in 221 BC, that unity disintegrated several times but was always restored, whereas not even the determined efforts of Augustus and Charlemagne (and later Napoleon and Hitler) could ever unify Europe. In partial explanation, Lang cites a contribution from Wittfogel's[8] much-debated 'hydraulic hypothesis'. The potential for increasing agricultural productivity in the major river valleys of climatically dry north and central China by large-scale hydraulic engineering projects favoured the rise of centralized states there, whereas purely local control sufficed for maximal productivity of Europe's rainfall-based agriculture.

But the ultimate reason for Europe's political fragmentation emerges from a glance at a map of Europe (see Fig. 1). Seas, a highly indented coastline, high mountains and dense forests divide Europe into many peninsulas, islands and geographical regions, each of which developed political, linguistic, ethnic and cultural autonomy. Each such region became one more natural experiment in the evolution of technology and scientific inquiry, competing against other regions. Conversely, China has a much less indented coastline, no islands large enough to achieve autonomy, and less formidable internal mountain barriers. (Even China's two largest islands, Hainan and Taiwan, each has less than half the area of Ireland; neither was a major independent power until Taiwan's emergence in recent decades; and, until recently, Japan's geographical isolation kept it much more remote politically from the Asian mainland than Britain has been from mainland Europe.) China was linked from east to west by two parallel, long and navigable rivers, and was eventually linked from north to south by canals between those rivers. So once a unified Chinese state was founded, geogra-

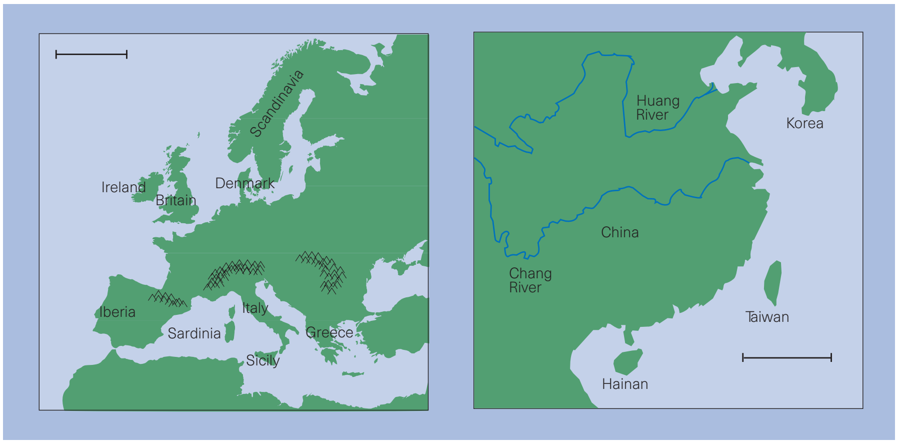


Figure 1 **Sketch maps of Europe and China. Europe's coastline is much more indented and includes more peninsulas; the continent also has internal mountain chains, such as the Pyrenees, Alps and Carpathians, and two large islands. Graeme Lang argues[1,2] that it is this comparative geographical fragmentation in Europe that resulted in the persistence of many independent states, as compared with the long-standing political unity of China. Competition between states, he proposes, permitted and fuelled the wave of scientific and technological innovation that began in Europe from the mid-fifteenth century AD. Scale bars are 500 miles.**


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phy prevented any other state from gaining lasting autonomy in any part of China.

Lang's analysis obviously has broader implications, of which four may be mentioned briefly. First, China's Great Proletarian Cultural Revolution of 1966–76 illustrates Santayana's famous dictum, "Those who cannot remember the past are condemned to repeat it". Just as China's unity permitted a disastrous decision by one emperor to abolish ocean shipping throughout China after AD 1433, a disastrous decision by Chairman Mao Zedong shut down the entire educational system for one billion of the world's people.

Second, the advance of technology may be hindered not only by excessive unity but also by excessive geographical fragmentation (take, for instance, New Guinea, and possibly India). Some intermediate degree of fragmentation, with moderate connectedness between the fragments, may be optimal for science and technology[6]. The problem of devising that optimal intermediate fragmentation is acute in Europe today. Current attempts to unify Europe appear to run counter to thousands of years of European history and to the source of Europe's strength. How can Europe now achieve an optimal balance between unity, easy communication, local diversity and local autonomy? If disunity has been good for Europe, might Britain equally profit from fragmentation into England, Scotland and Wales? In the business world, is organization into semi-autonomous but intercommunicating units the key to success of large corporations?

Third, political unity and also technological innovativeness fluctuate with time within the same geographical region. An analysis of Middle Eastern, Indian and Chinese history by Cosandey[9] suggests that these two types of variation may be correlated in time as they are in space: for example, that ups and downs in China's technological progress arose from temporal fluctuations in China's political unity.

Finally, Lang's broadest message is that historians need to think more in terms of ultimate causes, and less in terms of culture as an arbitrary independent variable whose local idiosyncracies defy understanding. In his words[2]: "One of the advantages of this kind of account is that it escapes the circularity which often creeps into explanations which do not go deeper than social or cultural differences between Europe and China. Such explanations can always be challenged with a further question: Why were Europe and China different with regard to those social or cultural factors? Explanations rooted ultimately in geography and ecology, however, have reached bedrock." □

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**Remote sensing**

# Appreciate the gravity

**Thomas A. Herring**

Two satellites will soon be launched that can measure annual variations in the Earth's gravity due to mass changes equivalent to 1 cm of water over 250,000 km$^2$ — an area smaller than the Caspian Sea. This is gravity measurement of unprecedented accuracy. It will affect nearly all areas of study of the Earth, with the greatest advances expected in the study of ocean dynamics, continental water-table variations, sea-level rise, glaciology, and postglacial rebound. These possible applications were discussed at a meeting last month* and have been addressed in a National Research Council (NRC) report[1].

The first mission, CHAMP, is being developed in Germany with cooperation from the United States and France, and should be launched in 1999. CHAMP is a low-Earth orbiter whose main purpose is to study the Earth's magnetic field. However, it will be equipped with three global-positioning-system (GPS) receivers looking fore, aft and up. These receivers will be used to measure atmospheric refractivity (as GPS satellites go behind the Earth) and to refine our picture of the large-scale gravity field.

But the second mission, the Gravity Recovery and Climate Experiment (GRACE), to be launched by the US space agency NASA in 2001, is expected to provide the more detailed view of the changes in the Earth's gravity field. GRACE will be a pair of satellites, separated by a few hundred kilometres, and orbiting at an altitude of about 600 km for 3–5 years. These satellites will accurately measure changes in their separation, produced as they orbit the Earth following the bumps in its gravity field (Fig. 1). If the predicted measurement accuracy is realized, these satellites will give us a remarkably precise view of the Earth's gravity field and its fluctuation.

The gravity field provides a record of the Earth's mass distribution, and so can be used to understand the structure and dynamics needed to maintain that distribution. For the more fluid portions of the Earth, gravity measurements can be used to sense motions of mass. Calculating the mass distribution and dynamics from the gravity field is not a straightforward problem, but, through a combination of spatial and temporal analyses, insight can be gained into the processes that control these dynamics. For example, the distribution of mass in the mantle can be used to measure the vigour of mantle convection. The reliability of these inferences depends on the accuracy, spatial resolution, temporal resolution and duration of the gravity measurements.

The size of the mass changes GRACE can see depends on a number of factors. Perhaps counter-intuitively, it will be most sensitive to spread-out changes: the larger the area over which the mass change occurs, the larger the perturbations to the satellites' orbits. Also, the longer a mass change exists the more accurately it can be measured, because of the increased averaging time.

The NRC report[1] details the sensitivity of an imagined mission similar to GRACE by expressing mass changes as equivalent thicknesses of water over regions of different sizes, and over timescales of 90 days and up. For example, the groundwater level of the High

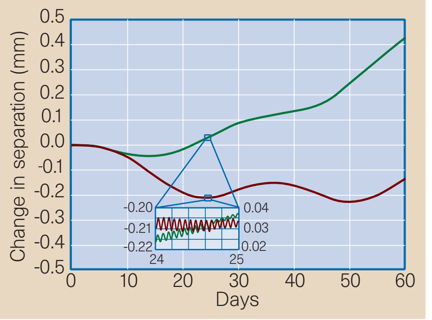


Figure 1 **Sinuous grace: a simulation of the changes in separation between the two GRACE satellites, for two different mass changes on the Earth's surface. The satellites are assumed to be 400 km up in near-polar orbits, and at day zero, 1 cm of water is added over 250,000 km$^2$ at the Equator (red curve) and at 30° latitude (green). The deflections produced are much more than the expected measurement accuracy of 0.001 mm; the real problem will be subtracting the signal produced by the steady part of Earth's gravity field, a separation change of about 1 km with a periodic pattern like that in the insert.**

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