# On the Methods of Long Distance Control: Vessels, Navigation, and the Portuguese Route to India

## John Law

### Abstract

It is argued that long-distance control depends upon the creation of a network of passive agents (both human and non-human) which makes it possible for emissaries to circulate from the centre to the periphery in a way that maintains their durability, forcefulness and fidelity. The argument is exemplified by the empirical case of the fifteenth and sixteenth century Portuguese expansion and the reconstruction of the navigational context undertaken by the Portuguese in order to secure the global mobility and durability of their vessels. It is also suggested that three classes of emissaries - documents, devices and drilled people - have, together and separately, been particularly important for long distance control, and that the dominance of the West since the sixteenth century may be partly explained in terms of crucial innovations in the methods by which passive agents of these three types are produced and interrelated.

## (1) The problem

Columbus's discovery of the New World in 1492, when taken with the arrival of heavily armed Portuguese vessels in the Indian Ocean in 1498, clearly marks an important turning point in the balance of power between Europe and the rest of the world. From that moment onwards until the very recent past the rest of the world has been under European control and domination.

Given the importance of these episodes, it is unsurprising that historians have written extensively about the Iberian expansion. Thus historians of Portuguese imperialism have written in great detail about the political and military strategies adopted by commanders in the field and in Lisbon (Diffie and Winius 1977, Boxer 1969) and about the vital techniques of buying, selling and the raising of capital (Magalhaes-Godinho 1969). Such accounts are necessarily a central resource for any student of the Portuguese expansion. However, much of the serious work on ships, on methods of navigation and on the development of cannon has been left to specialists in maritime history (Cotter 1968; Landstrom 1978; Taylor 1956; Waters 1958). This work often displays a high degree of sensitivity to economic and social considerations (e.g. Lane 1934). However, the number of historians who have seriously attempted to integrate what might be called the technology of Portuguese expansion into more general accounts of the latter is relatively limited - Chaunu (1979) being, perhaps, the most notable exception.[1]

In this paper I want to argue that it is not possible to understand this expansion unless the technological, the economic, the political, the social, and the natural are all seen as being interrelated. My argument is that the Portuguese effort involved the mobilisation and combination of elements from each of these categories. Of course kings and merchants appear in the story. But so too do sailors and astronomers, navigators and soldiers of fortune, astrolabes and astronomical tables, vessels and ports of call, and last but not least, the winds and currents that lay between Lisbon and Calicut.

Thus the problem for the Portuguese was not just one of social control, though this was important. It was rather, or in addition, one of how to manage long distance control *in all its aspects*. It was how to arrange matters so that a small number of people in Lisbon might influence events half-way round the world, and thereby reap a fabulous reward. And it is also my argument that if these attempts at long-distance control are to be understood then it is not only necessary to develop a form of analysis capable of handling the social, the technological, the natural and the rest with equal facility, though this is essential. It is also necessary that the approach should be capable of making sense of the way in which these are fitted together.

This, then, is the first purpose of the present paper: to make a contribution to a general analysis of long-distance social control. There is a small body of recent work in which an attempt has been made to develop a systematic vocabulary that would make this possible[2] and this paper is therefore intended as a contribution to that literature. It is also, however, intended as a contribution towards the sociological treatment of technology. As I have implied above, the idea that artefacts may be treated in isolation from, or at best as a function of, social factors seems to me to be fundamentally mistaken. The second purpose of this paper is thus to argue that though artefacts form an important part of systems of long-distance control they do not, so to speak, stand apart as means or tools to be directed by social interests. Rather they should be seen as forming an integral part of such systems, interwoven with the social, the economic and the rest, and their form is thus a function of the way in which they absorb within themselves aspects their seemingly non-technological environments.

My third aim is to make some kind of a contribution towards an understanding of the means of long-distance control involved in the growth of imperialism. How was it, in other words, that Christian Europe, at the turn of the fifteenth century, hemmed in in the East by predatory Muslim powers, succeeded so dramatically in turning in tables? I cannot, of course, answer this question, but I am certain that that when an answer comes it will not be reducible to the economic, the political, the social or the technological alone. Hence this paper is also intended, if somewhat indirectly, as a tribute to the *Annales* school of interdisciplinary history and in particular to the work of Fernand Braudel.[3]

**(2) On Portuguese vessels and imperial power**

How, then, were the Portuguese able to bombard the Samorin of Calicut, to fight and win a naval victory against a powerful combined Gujerati and Egyptian fleet at Diu in 1509 (Parry 1963: 143) and obtain a stranglehold on the vital Indian Ocean spice trade that had previously been monopolised by Muslim sailors? In short, how were they able to exercise long distance control? A full answer would require the description of a structure composed of all the people and elements mentioned in the Introduction. However, for reasons of space I concentrate here on the vessels of the Portuguese and suggest two things. The first is that, when seen in the context of the *Carreira de India*, these display certain properties that are crucial to all systems of long-distance control. The second is that their shape and form as technological objects cannot be understood unless they are seen as forming part of that system. My argument is thus that, if their structure is to be understood, they must not be reified simply because they can be seen as physical artefacts.

The mediaeval European sailing vessel was unable to operate with any degree of safety or certainty beyond European waters. Its range and endurance were limited, its carrying capacity small, its ability to handle adverse weather conditions was restricted and its ability to find its way out of sight of land or soundings was doubtful. This is not to say that it functioned badly in the context of the short journeys, the small volumes of goods, and the seasonal nature of mediaeval trade. Within this social, economic and geographical 'envelope' the single-masted sailing vessel was a relatively satisfactory means of transport, permitting (for example) Hanseatic long-distance control of all Baltic trade. However, the scope of the envelope within which its mobility and integrity was ensured was limited to a European scale. To control the Indian Ocean spice trade a structure with a larger envelope of mobility and integrity was essential. For unless vessels could travel safely from the Tagus to Goa there was obviously no possibility of controlling events in the latter. And to do this it was in turn necessary to control, direct, and maintain the integrity of the - vessels sent out from Lisbon. Mobility and (which amounts to the same thing) the creation of an environment within which vessels might operate with integrity - these we're the first requirements for imperial control.

In their explorations the Portuguese used a range of vessels. However, for reasons of space I here consider only the mainstay of *the Carreira*, the carrack. This has been described as the 'perfected transport ship' (Chaunu, 1979:242). The hull was broad, heavily built and powerful, made in the carvel manner (Chaunu 1979:242; Parry 1963:64). There were large castles, both fore and aft, which formed an integral part of the structure of the hull. The forecastle was topped off by a large pointed platform which projected forward of the bows (Parry 1963:64-5; Chaunu 1979:242) and was used for raising and lowering anchors.[4] The castles, which in certain large ships - for instance the early sixteenth century Portuguese *Santa Catarina de Monte Sinai*, (Landstrom 1978:94) - became very high and towering, were used for defence and cabin accommodation. Most depictions of these craft show thefts as stepping three or sometimes four masts - a small foremast, often with a square sail, a main mast with a large square sail, sometimes topped by a top mast with a further small square sail, and a mizzen mast usually with the traditional lateen sail. If there was a fourth mast this would be a bonaventure mizzen. Sometimes vessels also carried a small spritsail beneath the bow (Chaunu 1979:242; Landstrom 1978:93-9).

These bulky ships were able to carry a great deal of cargo. They were, accordingly, used from the early fifteenth century onwards to transport bulky and heavy goods on well established trading routes. By the sixteenth century the carrack was not the latest word in naval architecture. More manoeuvrable vessels were available for a variety of purposes. Nevertheless, it embodied a range of elements which, when placed in the context of the *Carreira*, rendered it both mobile and able to act with relative impunity in the face of normal circumstances. Let me, then, note some of the features of these vessels that, when taken in context with other aspects of the Portuguese system, generated an envelope of mobility and durability appropriate to the Eastern trade.

1. First, they were virtually impregnable to attack by boarding from small craft. This was one of the normal hazards of the Eastern trade (Parry: 1963:118). In the face of such attack commanders battened down the hatches, and subjected boarders to lethal cross-fire from the castles. Here, then, size and the otherwise antiquated castles counted as a positive advantage. These, together with an appropriately disciplined crew and their small-arms, ensured that this peculiarly Eastern military environment did not destroy the mobility and durability of the carrack. Another way of putting this would be to say that the castles incorporated that environment in a way that was favourable to the Portuguese and therefore extended the envelope of mobility and durability available to the vessels.

2. As I indicated above, by the standards of the age the carracks carried a great deal of cargo. This not only meant that profitable trade was possible, although this is true. It also meant that they did not have to make frequent stops *en route* and could steer the most efficient course, one which routinely took them thousands of miles from land. Once again, then, they were relatively independent of their surroundings. One might say that their architecture incorporated and appropriately handled the paucity of appropriate ports of call. It also, however, incorporated the trader's need for a relatively speedy passage between Goa and Lisbon. Here again the envelope of mobility and durability in the face of a range of environments

was extended by a combination of technological artefact and human resources.

3. The combination of square and (triangular) lateen sails characteristic of the carrack and other contemporary vessels marks a successful attempt to obtain versatility in the face of a range of different wind conditions.[5] Large square sails provided the main propulsive force, but might rapidly be reduced in area in case of storm. The smaller sails at bow and stern rendered the craft more manoeuvrable than would otherwise have been the case and the lateen sails, in combination with the bowline attached to the weather leech of the main squaresail, made it possible for the vessel to steer a course across the wind. In this way it might sail before the North East Trades from Lisbon to Madeira on the outward journey, before crossing the area of variable winds to reach across the South East Trades into the giant circle to the Cape. Thus, by means of appropriate rigging, pilotage and manpower, the Portuguese incorporated these trade winds within the *Carreira* on their own terms and thereby increased the size of the envelope within which the vessel might move and maintain its integrity.

4. The carrack was more independent of its environment than earlier types of vessel in yet another way. This arose from the fact that the handling of large lateen sails is both difficult and labour-intensive (see, e.g., Gille 1970:196.[6] Since the lateen sails of the carrack were relatively small the size of the crew was correspondingly reduced. This increased the envelope of mobility and durability of the vessels in a variety of ways. They could be sailed with relatively small crews, something that was particularly important given the high degree of mortality on the long voyages of the *Carreira da India* (Rego 1964:45). In addition, it was possible to reduce the number of stops along the way, or even to eliminate these altogether.[7] Again, then, the scope of independent action for these vessels was increased by incorporating features of their environment within their design and pilotage on terms favourable to the Portuguese.

The Portuguese vessels were not only part of a structure of heterogeneous elements that provided them with an appropriate envelope within which they might maintain their mobility and durability. They were also, and this is in some respects another way of saying the same thing, in an enhanced position *to control or exert force upon other, non-artefactual, elements of that structure.* This capacity of extract compliance from the environment is most vividly exemplified for the case of naval battles or bombardments where unfortunate Muslims or Hindus found themselves at the wrong end of the superior Portuguese cannon-fire (see, e.g., Diffie and Winius 1977:240ff). In this instance European methods of cannon-founding contributed very directly to long distance control (Cipolla 1965:102; Parry 1963:118). But so, too did the innovations in shipbuilding mentioned above. Without these there would have been no possibility of sending such floating gun-platforms half way across the globe.

However, the Portuguese not only exerted force on their sworn enemies in order to bring them into line. Their whole effort depended, from top to bottom, on the capacity to extract compliance. Seamen, merchants, masters, envoys, it was necessary to keep all of these in line and to make use of their efforts if the *Carreira da India* was to work and the vessels were to sail reliably with their loads of spices for the European markets. And such compliance was not only required from the human components of the system. It was also expected from its inanimate parts - from the hulls and sails that made up the vessels and the environments in which those vessels sailed. Thus, the improvements in methods of rigging described above can be seen as novel ways of borrowing the power of the wind, converting it, and using it to exert force upon the sea. As I have suggested, they made it possible to use the winds in ways that had not earlier been possible by transforming those that might previously have been dangerous, or simply adverse, into forces that contributed to the projects of the Portuguese by driving their vessels towards their destinations.[8] Currents were likewise transformed, this time by geographical knowledge and navigational competence, into forces that speeded rather than hindered the voyage. The metaphor, that of struggle with, attempts to extract compliance from, and making use of, potentially hostile elements, is one that works equally well for the human and the inanimate.

Finally, and partly as a function of their mobility, durability and capacity to exert force, Portuguese vessels also had the *capacity to return* to their point of origin. They were able to set sail from the Tagus and return months or even years later from Goa or Calicut in a relatively predictable manner. This was, of course, a *sine qua non* if the spice trade was to be monopolised. It was also vital if other types of control were to be maintained at the periphery, if the periphery was to belong, in any sense at all, to the centre.[9] The ability to return depended on seaworthy vessels such as the carracks mentioned above. It also depended on trained seamen and masters, the capacity to carry the necessary provisions and a host of other factors. At least as important as any of these, however, was an ability to find their way about the ocean and arrive at the desired destination. For, as I have indicated, the course followed by the *Carreira da India* did not hug the African shoreline. This would have been impossible for vessels as large as the carrack. In addition, with adverse winds and currents it would have taken far too long. Instead the Portuguese charted out a path that in places took them thousands of miles from land and required novel methods of navigation.

In the next sections I consider the late fifteenth century Portuguese development of astronomical navigation. However, before doing so I want to suggest that the features that I have described above in the context of the development of Portuguese imperialism may be seen as general characteristics of long distance control. Mobility, durability, capacity to exert force, ability to return - these seem to be indispensable if remote control is to be attempted. Indeed, they may be seen as specifications of a yet more general requirement: that there be no degeneration in communication between centre and periphery. No noise must be introduced into the circuit. Periphery must respond, as it were mechanically, to the behest of centre. Envoys must not be distorted by their passage, and interaction must be arranged such that they are able to exert influence without in turn being influenced. Finally, they must have the capacity to return, again unscathed, in order to report to centre.[10] If we except the case of the Chinese, then it was the Portuguese and the Spanish who, for the first time in history, developed the technical capacity for relatively undistorted communication at a global level.

## (3) Mediaeval navigation and the Portuguese problem

In the middle ages there were two worlds of European navigation, one in the Mediterranean and the other in north-west Europe. The approaches adopted by navigators in these two worlds, though they shared certain features - for instance the magnetic compass and the pilot book or rutter - were very different. The Mediterranean navigator used his[11] rutter in combination with a *portolan* or plain (plane) chart to determine an appropriate magnetic compass course.[12] This was made possible by the fact that the chart was laid out around wind roses and rhumb lines of constant magnetic bearing. The navigator thus determined the bearing of his course by looking for an appropriate rhumb line coming from a convenient wind-rose. If no wind-rose was suitably located, he used a ruler and dividers to relate the line of his desired course to a nearby rhumb line (Taylor 1956: 111). He determined the distance to be run by measuring this off the chart and/or by consulting his pilot book (Waters 1958:62). He then used the magnetic compass to steer the determined bearing, and dead reckoning, plus landmarks mentioned in his pilot-book, to calculate distance run. If tacking was necessary, then progress was measured by means of a set of *marteloio* tables (Taylor 1956:112; 117-20; Diffie and Winius 1977:130). *Portolan* charts, usually drawn on a single sheepskin with the neck to the west, covered the Mediterranean, the Black Sea and by the end of the thirteenth century, the Atlantic some way south down the coast of what is now Morocco and north to the English Channel, the Wash and Flanders (Taylor 1965:113; Waters 1958:62). Even so, they were intimately linked with the Mediterranean world of navigation and only extended as far as the Venetian and Genoese trade routes.

The north-west European mediaeval school of navigation developed very differently and depended hardly at all upon charts but instead made use of the magnetic compass and the rutter together with the lead and line. This was popular for a number of reasons. First, the rise and fall of the tide (which was, of course, unknown in the Mediterranean) made it essential for the seaman to know how much water lay under his keel (Waters 1958:18). Second, again in contrast with the Mediterranean, the waters of the north Atlantic were opaque and direct observation of the sea-bottom was not usually possible. Third, (think again of the Mediterranean) the seaman of the Atlantic frequently had to contend with adverse visibility. He could not be certain that he would be able to observe landmarks from any great distance. This was no impediment to the use of the lead and line as these were not dependent on good visibility. And finally, unlike the steeply shelving Mediterranean, much of the north-west Atlantic was less than 100 fathoms deep (Waters 1958:18). For all these reasons, not only was the lead and line an aid to Atlantic navigation. It was one of the fundamental tools around which navigational practice was organised.

That this was the case is witnessed by the surviving rutters. The earliest known example in English which is dated 1408 (Waters 1958: 11) and which gives directions for the circumnavigation of the British Isles, gives names of landmarks and the magnetic compass bearings between them, has data on the direction of tidal flows, a section on the establishment of ports[13] and much information (consisting of about a third of the whole) on soundings and the nature of the sea bed. Thus even in very poor visibility the master of a vessel was able to move his way from point to point with some degree of success by using his compass, his rutter and by taking periodic soundings which also allowed him to determine the nature of the sea bed.

These systems of navigation served their purpose very well. The limitations detected in them by later commentators (which related particularly to an ignorance of, or an inability to cope with, the magnetic variation) were scarcely relevant to the practice of seafarers in the middle ages. So long as the established trading routes were followed few difficulties arose and regular communication was possible. This is witnessed both by the regular trading activities of the Venetians and Genoese who sailed from the Black Sea and the Holy Land at one end of Christendom to England and Flanders at its other and those of the Hanseatic masters and their British, French and Basque counterparts who navigated from the Baltic to Palestine. However, the Mediterranean system and that of the North-West Europeans had one feature in common: they were only effective over certain (though admittedly quite extensive and important) geographical areas. The vessel that strayed out of these areas, or indeed, off the charted routes within them, was liable to lose its way and risk disaster.

What was the case for the carrack is true again here. The vessels were physically mobile, forceful and durable only while they stayed *within* the envelope generated by rutters and charts. Or, to put it somewhat differently, they were undisturbed by their external environment only so long as they were able to transfer that environment inside themselves in the form of charts, rutters and the rest. But this transferred context imposed some fairly strict limits, at least for certain purposes. For an independent check on distance and direction run, navigation was dependent upon observable geographical features. For, with the influence of winds, tides and currents, and the difficulties involved in attempting to measure the speed of the vessel in the water, no master was happy to depend exclusively upon dead-reckoning and his compass course in order to determine location. The pilot books offered sometimes erroneous but nevertheless independent data that made it possible to check position under most conditions.[14] But the features noted in the rutters had two important and related characteristics. First, in order to act as the kind of check needed they had to be observable. Shorelines were visible from a distance of a few leagues, at least under favourable circumstances. Depths might be sounded and the characteristics of the sea-bed determined in waters of up to 100 fathoms. And second, their description varied in nature or quality as a function of position. It was this very characteristic that made them useful as independent checks of position. Where shorelines were not visible or depths were too great (or where, of course, neither had been observed) these methods of navigation were of no assistance. The mariner had travelled outside the envelope described by his rutter into the unknown, and at once the durability, the mobility, the strength and the capacity of his vessel to return were all were put at risk.

This, then, was the Portuguese problem. In the fifteenth century their explorations were beginning to take them beyond the charts and rutters of their time. And it was not simply that no-one had been there to observe and report back before (though this was true). It was also, and more fundamentally, that their journeys to Madeira and the Azores took them deep into the north Atlantic, far from the coastline and the limits of sounding. Compass courses and dead reckoning were useful allies in the Mediterranean where it was impossible to get very far from shore and they might be checked against written descriptions of important landmarks en route. But they no longer contributed their quantum of force when the destination was a small and isolated island which might easily be missed by a few leagues. Under such circumstances, description of (the rare) landmarks, though necessary, did not provide a context appropriate to environmental independence and the vessel no longer contained, within itself, the environment necessary to ensure such independence.

To summarise: vessels may move to and fro with relative freedom. Like faithful servants they may thus be seen as candidate means for those who wish to exercise long-distance control. However, before they can be so used, they have themselves to be controlled. They have to be able to retain their integrity under a range of circumstances. Their structure, but also their means of navigation - these are two of the features that define the envelope within which they come and go like faithful servants. In this section I have suggested that independence with respect to a *particular* context may be achieved, but that this depends upon embodying features of that context in a system of heterogeneous elements that describes an appropriate envelope of physical durability. Seen in this light then, the Portuguese problem was to build a new navigational context for their vessels that was less dependent upon European geography, one, that would render their vessels independent of a broader geographical environment, and hence make possible an undistorted system of global communication and control.[15] It was to this that they turned their minds.

**(4) The Portuguese solution**

Every year, from the turn of the sixteenth century, the great carracks left the Tagus in March or at the latest early April. They needed to pass the Cape of Good Hope in July in order to catch the south-east monsoon, and could expect to be in Goa by the end of August or the beginning of September. To catch the monsoon for the return journey it was best to leave India in December though January would do. Then, depending on the passage, vessels could expect to be back in Lisbon again between mid June and mid September (MagalhaesGodinho 1969:665-8; Rego 1964: 39-40). Despite losses due to the sea and, towards the end to Dutch and English privateering, the *Carreira da India* functioned, as Magalhaes-Godinho notes 'avec des resultats tres satisfaisants pendant plus de quatre-vingts ans' (1969:670).

The Portuguese solved many of the navigational problems involved in this journey between the 1460s and the 1480s. During this period, they continued the exploration of the African coast started under the direction of Henry 'the Navigator' in the 1430s. As the Mediterranean method of navigation with plain chart, compass, rutter and distance run became steadily more inadequate, they sought additional navigational aids. Perhaps as early as the 1460s they started to make systematic observations of the angular altitude of the Pole Star, *Stella Maris,* above the northern horizon.[16] By the later 1480s their mariners were using not only the Pole Star (which could be used only in the northern hemisphere) but also measuring the *altura* of the Sun and the Southern Cross as an aid to navigation. These methods, and the instruments and tables of data used in their practice, though not novel in scientific terms, nevertheless mark a major breakthrough in methods of navigation and the construction of a system within which global mobility and communication might be ensured.

Mediaeval astronomers were committed to the Ptolemaic conception of the Universe. As is well known, this considered the Universe to consist of a set of concentric spheres, with the earth at its centre. The approach, and the careful observations of the heavens that it sustained, offered well-developed explanations for the behaviour of celestial objects as observed from the earth. Furthermore, these theories had predictive value. Tables of Ephemerides which predicted the times of astronomical events of particular importance were calculated and circulated. Thus not only was there a theoretical explanation for the daily variation in the declination of the sun but the value of the latter was also routinely predicted. That there was a relationship between the observed location of heavenly bodies in the celestial sphere and the position of the observer on earth was also well understood. Ptolemy's *Geography* (which became available in Latin translation in 1409 (Taylor 1956: 151)) showed how every point on the surface of the sphere of the earth might be described by a unique latitude and longitude. Accordingly, explanations for the altitude and bearing of astronomical objects were posed in terms of terrestrial latitude and longitude, while the idea that the latter might be determined by observing the former was also generally accepted.

Mediaeval astronomers and astrologers not only had a cosmological theory. They also had a range of instruments available to them. The most important for our purposes were the planispheric astrolabe and the quadrant. The former, which has been described as a 'compendium of instruments' (Cotter 1968:60, citing Gunther), might, in combination with the Ephemerides, be used in a wide variety of ways. Most of these were concerned with depicting positions of heavenly bodies at a given moment in time. Thus, given a time, it was possible to display the positions of the sun and selected stars. This was important, for instance, in casting horoscopes. Contrariwise, given a star or sun sight, it was possible to tell the time. The same was also true for the quadrant, another specialist instrument of astronomers and astrologers, that had many of the same qualities. However, in addition to their properties as analogue computers, they were also built to allow measurements of the altitude of astronomical (or other) objects. In the case of the astrolabe, which was shaped in the form of a disc, this was suspended by a ring. A swivelling sight called the alidade was then turned until the object being sighted was simultaneously visible through two pin-holes. Its altitude was then determined by looking at the point where the alidade crossed a scale inscribed around its circumference. This was graduated from 0° (horizontal) to 90° (vertical). The quadrant, which was shaped like a quarter circle, was suspended from its corner and swivelled about this until one of the radii was in line with the object to be sighted. The altitude of the latter was measured by a plumb-line which fell from its corner to cross a scale marked along its circumference.

It was widely believed in the early modern period that the earth was, indeed, a sphere, and mariners, who were used to telling the time by observing the Pole Star and its surrounding stars, were well aware that the latter sank towards the horizon in the northern sky as they sailed south. However, Ptolemaic astronomy and the instruments associated with its practice, were opaque to the layman (Taylor 1956:158). Thus, though it is possible in retrospect to see how mediaeval astronomy might have been adapted to solve the problem of global navigation, we should beware of assuming that such a transfer was either easy, obvious, or an excessively long time in coming. There is controversy about the exact moment when this took place[17] but since this does not directly affect the argument that I am trying to make, I will pass over the disputed period of the 1460s and 1470s and instead discuss the progress that most historians concede occurred in the 1480s.

In 1484 King John II convened a small commission and charged it with the task of finding a method for navigating outside European waters. The commission appears to have had at least four members. There was the Royal Physician, Master Rodrigo. There was Diego Ortiz. who had been Professor of Astrology at the University of Salamanca before being forced to flee abroad, and who subsequently became, in succession, the Bishop of Tangier, Ceuta and Viseu. It is known that he liked to mix science with politics and had good connections with astronomers (Beaujouan 1966:74-6). There was Martin Behaim. a geographer, originally from Nuremberg, who was to use up-to-date Portuguese cartographic data for the magnificent globe which was made in 1492 and which bears his name (Bagrow and Skelton 1964:106-7; and Tooley and Bricker 1976:152-3). [18] And perhaps most important there was Jose Vizinho, a Jewish doctor, who had been a disciple of the astronomer Abraham Zacuto of Salamanca (Chaunu 1979:257). These four men, and probably in particular

Vizinho, were responsible for one of the earliest successful practical applications of scientific knowledge to practice: the *Regimento do Astrolabio et do Quadrante.* A printed copy, dated 1509, exists and Taylor suggests not only that there was an earlier 1495 printed edition, but that handwritten copies would have been prepared in the 1480s for selected pilots (Taylor 1956:162).[19] Whatever the exact date, its importance is beyond question for it not only fulfilled the expectations of the king but it also laid the foundations of modern astronomical navigation.

The new navigation proposed by the commission hinged around the determination of the latitude by means of solar or stellar observation,[20] a method particularly appropriate for journeys that were mainly in a northerly or southerly direction, such as those undertaken by the Portuguese; in the Atlantic and, to some extent, the Indian Ocean. This was because it depended upon sailing north or south until the vessel reached the same latitude as its destination. Then the master could steer east or west as appropriate, in the certain knowledge that he would make an appropriate landfall.

The success of the commission in putting this method into practice rested on three elements. First, it made available greatly simplified versions of the astrolabe and the quadrant. All the machinery for calculating the relationship between time and astronomical position was swept away. In the case of the astrolabe what had previously been on its back - the alidade and the scale for reading off the altitude (or zenith) - was all that was left (Waters 1976:42).[21] The quadrant was similarly reduced to its altitude-measuring essentials. Second, it made available a range of astronomical and geographical data that were essential if crude measurements of the altitude of the sun were to be converted into data about the latitude. As background reading, so to speak, it included a Portuguese translation of Sacrobosco's *Sphaera Mundi*, an elementary text written in about 1250 (Cotter 1968:21) on the spherical nature of the earth. However, the most important directly relevant data concerned the sun's declination on different days of the (leap) year. As I have indicated, these had been regularly calculated by astronomers, but the significance of the work of the commission was to make them available in a form which, like that of the astrolabe and quadrant, might be used with some hope of success by the literate but relatively untutored mariner.[22] In addition to the tables of declination, and a calendar, there were also geographical data necessary for navigational decision making. Thus the earliest known version of the *Regimento* includes observations of the *altura* for significant points on the coast from Lisbon southwards to the equator (Taylor: 1956:163), a list that was further extended in subsequent years. Such data was obviously important in providing a context for the latitudes discovered by the navigator on board ship.

Third, and perhaps most important, were three sets of rules telling the mariner how he should use the instruments and data provided to determine the latitude.[23] First there was a Regiment of the North, which told how to measure the altitude of the Pole Star and then convert this into the latitude. Second, there was a Rule for Raising the Pole, which told the navigator how far he had to sail on any course in order to raise one degree, and how far east or west he had sailed in doing so. This rule was the product of what we would now call elementary trigonometry. And third there was the Regiment of the Sun, which tackled the difficult problem of guiding the navigator through a solar fix to a determination of the latitude. This was complicated, or at least it was more complicated than the analogous Regiment of the North, because of the daily variation of the declination of the sun and the consequent necessity to consult tables in order to determine the latter.

These rules were, as I have indicated above, written on the reasonable assumption that most navigators had little grasp of the principles of astronomy. They were, accordingly, rather literal in nature. Consider, for instance, the Regiment of the Sun. This starts by telling the observer to find the height of the sun 'and this must be at -midday when the Sun is at its greatest elevation' (Taylor 1956:165). After writing this down (probably on a slate) he is instructed to enter the table for the month and the day.

> Take out the declination, and if the Sun is in a northern Sign, and if the shadow is falling to your north, then subtract the altitude that you found from ninety, and add the declination. The sum will be the number of degrees you are north of the equinoctial. (Taylor 1956:165)

This, however, is only one of the cases, and the rules proceed to describe the other possible combinations of declination and direction of fall of shadow, and conclude by considering those instances where the resultant calculation ends up with a figure of 90°. Given the anticipated competence of the mariner, the authors of the rule had to be sure that they covered all possible cases. Taylor makes the point in this way:

> To teach the rule of the Sun to the novice must have been a matter of great difficulty for an astronomer. The would-be pilot must learn how to 'enter' the calendar and pick out the figures, he must memorize the dates of the equinoxes and know which are the northern and which are the southern Signs. For according as the Sun's shadow falls north or south, and according as it is in the same or the opposite hemisphere to himself, the figures are to be manipulated differently. In fact he has eight rules to learn, apart from the special case when his ship is on the 'line' precisely at one of the equinoxes. (1956:165)

In fact, the new navigation did not depend upon the mariner being able to 'pick it up' by himself. The simple rules, the simple data and the simple instruments were supplemented by systematic training, at least from the turn of the sixteenth century. The Portuguese set up the Casa de Guinea e India at Lisbon which, writes Waters:

> included an organization equivalent to a modern hydrographic office at whose head was a cosmographer-in-chief. He was assisted by cosmographers whose business it was to draw and correct charts and to compile books of sailing directions and, no doubt, as in the similar Spanish organization of the sixteenth century, to assist in the instruction of pilots. (1958:62).

This training was thorough, at least in the early years of the sixteenth century. Though it later became somewhat lax (Rego (1964:40)) goes so far as to say that this was the root cause of later marine decadence of the Portuguese) there is no doubt that the method and the training on which this depended made an indispensable contribution to the long-lived Portuguese mastery of the Indian ocean.

We started by saying that long-distance social control depended upon creating a structure of elements, both human and natural, capable of generating an envelope of durable mobility for vessels. We then noted that those vessels embodied a part of that structure in their form and were, in turn, both able to exert force upon other parts of that structure and then return to base. We then suggested that some such kind of relatively undistorted communication was a necessary adjunct to long-distance control. However, since no vessel was an island unto itself, if it was to be relatively mobile on a global scale then it was necessary to create and incorporate within itself a different, astronomical, context: one that would extend the envelope of its mobility and durability. In this section we have seen how the Portuguese faced this problem in an acute form as they pushed further south in the course of the fifteenth century, and have briefly considered the solution to which they came. Of course, they did not do without rutters and charts. These continued to be vital components of their navigational context, essential allies in routefinding. But through the activities of the commission they rebuilt that context to include the very heavens, heavens that stayed with the navigator wherever he might go. And this borrowing from the heavens was achieved by means of a judicious juxtaposition of data, instruments and rules for the guidance of mariners which in turn, had the individual and collective property that they were relatively mobile, durable and forceful.[24]

### (5) The materials of long-distance control

If the Portuguese were successful in their efforts to build a navigational envelope for their vessels that made mobility and undistorted communication between Lisbon and India possible, is there any more general lesson to be learned about the way in which this success was achieved? To answer this question we need to look again at the *types* of elements that they brought together in their system.

Consider first, then, the *Regimento* itself. The Rule of the North Star, the Regiment of the Sun, the Rule for Raising the Pole, the tables of solar declination, the latitude of possible points of destination, all of these took the form of *written or printed inscriptions.* Within the envelope of the vessel (of which, in a more general sense, they formed a part) these were mobile, durable, yet also capable of exerting force upon that environment. In other words, they were endowed with the same set of properties as the carracks discussed above. But whence came that force? Part of the answer is that it came from the way in which they were juxtaposed with the right kinds of people and instruments. It came, in other words, from a specially constructed and relatively stable structure.

However, it also came in part from their contents, from the very inscriptions that made them up.

Consider one case, that of the table of solar declination. This represented the distillation, as it were, of many years of astronomical expertise, of thousands and thousands of calculations, of correspondence, of argument and of innovation. When it created a table the commission was therefore creating a kind of surrogate astronomer. It was not necessary to take along Jose Vizinho or Abraham Zacuto in person. Their force, and the work of their predecessors, was being borrowed, converted into a highly transportable and indefinitely reproducible form, and being put to work on every ship. The production of tables of solar declination for the purpose of navigation may thus be seen as a way of reducing the relevant aspects of a weighty astronomical tradition to a form that, in the context of the vessel, was more mobile and durable than the original. It seems, if I may mix metaphors, to have been a way of capitalising on generations of astronomical work by converting this into a nicely simplified black box that might be carried anywhere within the Portuguese system of long distance control and which would contribute to this when posed the right questions.

But the *Regimento* was not sufficient by itself. Navigation also demanded astrolabes or quadrants. In short, it demanded instruments. Like the *Regimento* itself, these were transportable and relatively durable on board ship. Indeed, much of the effort of the commission and those who followed it was devoted to devising instruments that were more mobile and versatile. When the Portuguese first started using astrolabes these appear to have been enormous wooden instruments which were taken ashore and set up, presumably on a tripod. They were quite unsuitable for observations from on board ship. Even the brass disc of the classical planispheric astrolabe offered so much wind resistance that observation was very difficult. In the course of the sixteenth century the nautical astrolabe took on a different form. It became a small, open, brass ring which, while still difficult to use from the deck of a vessel, was at least an improvement on its predecessors.

However, if the astrolabe was relatively durable within its structured envelope then it was also potentially forceful with respect to that structure. As with the *Regimento*, this force came from two sources. First, it was borrowed from the navigational context that had been specially constructed by the commission. But second, it also represented the relevant distillation of generations of work in astronomy and instrument-making. This may be a little less obvious than it was for the case of tables of declination. Perhaps this is because we tend to assume that devices have a natural solidity which is absent in the case of inscriptions. Nevertheless, the argument made there is equally applicable here. Work and discussion went into the many generations of the astrolabe, into decisions about what to fit and how to fit it together. Indeed, I mentioned a little of that work earlier: the commission, or its close Portuguese predecessors, decided that most of the components of the astronomical astrolabe were simply irrelevant to the problems of navigation and swept them away. Just as with the tables, the final mariner's astrolabe may be seen as a physical manifestation of previous work, a kind of nicely simplified black box which, if placed within the appropriate envelope of other elements, was capable of generating the kind of answers that were needed to sustain that structure.

But documents and devices were not all. There were also the navigators themselves. In short, there were people. These are, as we all know, relatively mobile and somewhat durable. Properly clothed, sheltered, and given a means of transport, they become yet more mobile and durable. Thus the Portuguese sailors were passing through places and arriving at destinations undreamed of by previous generations. And they were also forceful, forceful for the same two reasons: first because of the structured envelope in which they were placed, and second because they themselves embodied a great deal of previous effort. The structure of which they formed a part was, of course, all-important. The Portuguese mariner, on a vessel with a cannon, was indeed powerful. The same mariner, shipwrecked on a beach, was pathetically weak. This is why the commission spent so much time designing an appropriate context for its fledgling navigators. The latter could not afford to be mystified by a stereographic projection of the heavens. This was removed from the astrolabe. They could not afford to be confused about how to sight the Pole Star. So they were told to aim at it like crossbowmen. They could not afford to misunderstand the tables of declination and draw their data from the wrong section. So they were given a recipe which dealt with all the possible combinations of season and hemisphere. They could not afford to get their arithmetic wrong. So they were given worked examples to follow. They could not be left to do trigonometry by themselves. So they were given the Rule for Raising the Pole. The care with which the commission attended to the context of the navigator is notable, for they knew that it was only in this way that he would not go astray, that he would successfully borrow the forces that lay in the tables and the instruments. Even so, the navigator was only able to do this because of his past. He could read, he could count, he knew how to hold an astrolabe. He was, in other words, the embodiment of previous effort, both that of other people and his own. And in order to function as a navigator he had to be persuaded to select and borrow from that work. From the standpoint of successful navigation he too, then, was a black box. Placed in the right circumstances, and fed the right inputs, he produced a simple latitude.

Documents, devices and drilled people: I want to argue that it was this combination that was the key to the success of the commission. For documents, devices and people have in common that, placed in the right structure, they are potentially mobile, durable and able (though this may sound odd to those brought up in the traditions of interpretive sociology or theoretical humanism) to act upon that structure. Of course, they do not retain these characteristics under all circumstances. They may lose their force and their capacity to move if things go wrong. Nevertheless, when the commission scratched its head and considered what *kinds* of elements it could hope to put on a vessel which would subsequently retain their shape and power, the answer, though it would not have been posed in these terms, must have been obvious. It was documents, devices and drilled people. They would hold their form. They would act as they should at a distance so long as they were properly chosen and placed at the right location within an appropriately designed structure. For they could not be chosen randomly and thrown together. The right documents, the right devices, the right people properly drilled - put together they would create a structured envelope for one another that, ensured their durability and fidelity.

## (6) Conclusion

I have argued that the Portuguese made good use of documents, devices and drilled people and that these were obvious resources to be used by anyone who wanted to exercise long-distance control. Other work, for instance on the way in which laboratory scientists succeed in influencing their fellows, their research directors, the agencies that give them their grants and the process of industrial manufacture, also points in the same direction (Callon 1985a; Callon, Law and Rip 1985b; Latour 1984b; Law 1985a). Texts of all sorts, machines or other physical objects, and people, sometimes separately but more frequently in combination, these seem to be the obvious raw materials for the actor who seeks to control others at a distance. Of course this remains an hypothesis of an empirically testable kind. Are these the means that are generally used by those who wish to exert power at a distance, or are there others? Are there particular combinations of the three that characterise different major institutions? These are questions that take us beyond the scope of the present essay. However, I want to conclude by making a few comments that relate to the problem which I originally posed about the sources of western long-distance control.

To what extent, then, are major disparities in the creation of envelopes of undistorted communication and long-distance control explicable in terms of revolutions in methods for the creation of durable and mobile documents, devices and people? To what extent, in other words, may the hegemony of the west be explained in terms of a few basic innovations in the production of the means of control? These are questions to which it is possible to give only speculative answers. Nevertheless, there is a range of recent sociological, anthropological and historical work that bears upon them. The argument is clearest for the case of documents and texts. Goody, in rejecting the notion that there is a difference between the mind of the savage and that of his domesticated neighbour, argues that literacy and in particular the act of making lists should be seen as potent methods of domestication (Goody 1977). This argument has been extended by Latour (1985a) who cites Eisenstein's (1979) monumental study of the importance of the printing press for western social change. Thus Latour, who argues that power is a function of the capacity to muster a large number of allies at one spot, suggests that inscription, and in particular its printed reproduction, makes possible the concentration of a far wider range of allies than had previously been possible. On the one hand, then, my argument about the force of the tables of declination is consistent with and indeed follows Latour's line of reasoning. The tables can be seen as ways of allying generations of astronomical observations with a new structural envelope that rendered these durable, mobile and forceful on a global scale. On the other hand, the significance of Latour's analysis of the role of the printing press is that its invention may be seen as a revolutionary improvement in the textual means of long-distance control, one that goes some way to explaining both the hegemony of the west and the 'great divide' between primitive and modern.

Similar arguments may be made about people. In this case the primary problem for long distance control may not necessarily have to do with mobility, nor even forcefulness. It may rather be concerned with a special aspect of durability, that of fidelity. This is because it is no good sending out agents who promptly become double-agents, fail to exert the proper force, and do not report back. As we have seen for the case of Portuguese navigational methods, fidelity may be increased if the agent is placed in a well designed structural envelope. It may also be increased if he or she is properly prepared, primed, as it were, with the appropriate range of allies, before being sent out. The question then, is whether the west has been able to exert particularly effective long-distance control via people as a result of an innovation analogous to that of the printing press. Has it, in other words, found a special way of keeping people faithful? The answer to these questions would appear to be yes. It is only recently that the implications of the invention and diffusion of military drill have come under scrutiny. Nevertheless, arguments by Foucault (1979) and McNeill (1982) suggest that its importance for social control both on and off the battlefield has been immense. Drilled armies were able to march faster and in better order than their predecessors and militarily they were much more effective. Furthermore, individual soldiers fought more reliably in battle. This was because drill broke actions down and then reassembled them into a prescribed, regular and observable structure. Previously unreliable. actions were converted into ranks of dependable, gestures. As is well known, the argument has been deployed by Foucault on a much broader front. The 'model' worker was one who had been drilled, who was a reliable automaton, and who accordingly offered a more convenient way of exercising power.

The argument may also be made with respect to devices and machines. It is a commonplace that the technological history of western Europe reveals the way in which devices displayed an increasing capacity to harness natural forces. Methods of milling. of agricultural work, of military technology and of ocean navigation, all of these (to name but four) developed in such a way that wind, water, animal and to a lesser extent human power were more fully harnessed, and harnessed in a more flexible manner. The result was increasing forcefulness, increasing durability and, in the case of the means of transport, increasing mobility. With respect to overseas imperialist domination, a good case can be made that the 'nautical revolution' of the fifteenth century with its invention of the three-masted, mixed rigged, seagoing sailing vessel played a crucial role. However, if there is a single innovation which had an impact with respect to devices and machines comparable with that of drill and the invention of printing on people and texts, it must surely be the development of manufacture. This, as is well known, brought together an unprecedented range of natural and human forces by taking processes that had previously been geographically dispersed and relatively undifferentiated, and breaking them down into separate but physically adjacent components. With the harnessing of steam-power the process of social control has been the subject of extensive analysis in the Marxist tradition. However, it is important to underline the way in which this occurred, not only in the workplace and to those who worked there, but also to those who never saw a factory in their lives. For it was not simply that goods of a standard quality became common. It was also that reliable machines and devices became widely available to those who wished to enhance their ability to act at a distance. These might be sent into mines (Lankton. 1983), into homes (Hughes 1979; Pinch and Bijker 1984; Schwartz-Cowan 1984), into vessels and power stations (Constant 1978) and into military arsenals (MacKenzie 1984). Indeed, novel devices have been integrated with new contexts to such an extent that the moon itself is no longer the limit. It is possible to sit in a control-room in Houston and influence events at the other end of the solar system.

The empirical analysis of revolutionary development in the means of long-distance control remains, in most cases, work to be done. Equally I would not like to leave the reader with the idea that the document/device/drilled person trinity is necessarily sacrosanct. There may well be other ways of creating the structured envelope/hardened envoy duo that is so crucial to long-distance control. However, I believe the theoretical claim - that the undistorted communication necessary for long-distance control depends upon the generation of a structure of heterogeneous elements containing envoys which are mobile, durable, forceful and able to return - to be well founded. This, as I have shown above. has profound implications for the conduct of a sociology of artefacts and devices. In addition i hope that, notwithstanding the deeply held sociological prejudice in favour of privileging the status of human beings, the present essay will have demonstrated that if one wishes to understand the nature of long-distance control, then it is not only possible but also desirable to talk of people, texts and devices in the same analytical terms.

## Notes

[1] Cipolla (1975) is a *tour de force* on vessels, firepower and imperialism in general. Parry (1963) and Penrose (1952) are also honourable exceptions, particularly Parry whose account nevertheless falls into two parts: first the social and technological means, and second the process of expansion itself. See also Lane (1950).
[2] See, in particular, Callon 1985a; 1985b; Callon and Latour 1981; Callon, Law and Rip 1985b; Latour 1983; 1984a; 1984b; 1985b; Law 1984; 1985a; 1985b.
[3] Even if I had the ability and the inclination (and I have neither), in an essay of this length there would be no space to create the kind of global historical panoramas favoured by Braudel (1975; 1979) or Wallerstein (1974).
[4] Each ship was equipped with six to eight anchors, which is an indication of their relative inefficiency at holding a ship of these dimensions, and also of their relative fragility (Chaunu 1979:242)
[5] In a following wind, and in storm conditions, the square sail is much more suitable than the lateen (Lane 1934:38; Parry 1963:59; Gille 1966:172). It is also easier to alter its size under way, and its maximum dimensions are not subject to the strict limits imposed on the lateen by the length .of its yard. By contrast the lateen is much better adapted for sailing close to the wind (Landstrom 1978:51; Parry 1963:58) and in general is more adaptable to a range of wind conditions.
[6] Parry estimates that the average crew for the lateen-rigged Mediterranean vessel must have consisted of fifty men (Parry, 1963:60) while a comparable square-rigged Atlantic vessel perhaps required only twenty men and twelve apprentices (see also Lane 1973:123).
[7] One widely used port of call, Mocambique, was widely and rightly seen as a Portuguese graveyard. It was reported that men, dying of scurvy and other diseases, would flock ashore when the vessels arrived, but those that survived would be equally glad to be back on board after a few days in order to escape the nightmare of tropical disease. See Rego 1964:46.
[8] For further discussion on this see Law 1985b.
[9] For a discussion of the importance of communications for the maintenance of empire see Braudel 1975:37Iff. Note, however, that the Portuguese also made use of delegation. They wisely worked on the assumption that undistorted communication was possible for strategy but not for tactics. See Wallerstein 1974:327.
[10] For an analysis of parasitism in communication see Serres 1980.
[11] I use 'his' throughout since, so far as I know, all mediaeval and early modern mariners were men.
[12] Taylor notes that the first known Mediterranean rutter dates from 1296 (Taylor: 1956:104) and the first *portolan* chart, the Carta Pisana, from about 1275 (109).
[13] The latter related high or low tide of a port to the position in the sky of the new or full moon. From these data it was possible to calculate the approximate

times of high or low tides at any time in the month.

[14] Sailing directions 'were copied, mislaid, collected together again, and perhaps bound up to form a little leather book of ill-arranged, often conflicting information. Nevertheless, the rutter was the ship's master's *vade mecum*', Waters 1958:12.

[15] The similar notion that the development of devices should be interpreted within an analysis of the struggles and growth of systems or networks is one that has received some attention in the history and sociology of technology. See, in particular, Callon 1980; Hughes 1979; 1983.

[16] Taylor (1956:159ff) takes the view that this was started in 1456-7. Beaujouan (1966:71; and Poulle 1957:114) and Chaunu (1979:254) put the date nearer 1485.

[17] Whether, as Cortesao (1966:59) insists, the *idea* of astronomical navigation developed in Portugal in the early fifteenth century seems to me to be somewhat doubtful. Taylor's (1956:159) suggestion that Portuguese vessels may sometimes have carried professional astronomers in the middle of the century, though not unreasonable, is also without much proof. Again, there is historical controversy over the extent to which the Portuguese made use of astronomical navigation in the 1460s. Taylor (1956:159-60), without, I think it must be said, very much evidence, implies that this was the case. He is, however, in agreement with Waters (1958:47) and Cotter (1968:130) when they argue that regular measurements of the altitude were being made from points along the African coast - an activity which, while necessary data for astronomical navigation, none the less has to be distinguished from it. However, even this is open to dispute. See the sceptical views of Beaujouan 1966:71, Beaujouan and Poulle 1957:114 and Chaunu 1979:255.

[18] It has been argued that he was the first person to suggest that the astrolabe might be used in navigation, though this is claimed by others, improbably in the view of most, for Majorcan pilots at the end of the thirteenth century. See Cotter 1968:22; 62

[19] Once again there is a dissenter. Chaunu (1979:258 takes the view that the *Regimento* postdates the great voyages of discovery. However, Beaujouan (1966:73) and Diffie and Winius (1977:140-1) side with Taylor.

[20] Determination of the longitude was a very much more difficult problem which did not achieve successful solution until the development of accurate portable timepieces in the eighteenth century.

[21] At first these were discs of brass or wood, but later they were made of a solid, heavy, ring of brass, which was less disturbed by the wind. Waters 1958:55.

[22] It appears that the data for the sun's declinations were taken from tables calculated by Abraham Zacuto. See Taylor 1956:165.

[23] Full details of the contents of the *Regimento* are to be found in Taylor 1956:162~6; Waters 1958:52-3.

[24] This was because they too were located within a relatively stable context that included vessels and training schools. 1 have emphasised the interrelatedness of elements in the Portuguese effort elsewhere. See Law 1985b.


## Acknowledgements

The research that led to this paper was undertaken at the Centre de Sociologie de I'Innovation of the Ecole Nationale Supérieure des Mines in Paris. I am grateful to the Fondation Fyssen, the Leverhulme Foundation, the Ecole Nationale Supérieure des Mines, the University of Keele and the C.N.R.S. who made it possible to spend a period of leave at the Centre. I am particularly grateful to Michel Callon, Bruno Latour and Arie Rip for commenting on an earlier version of this paper.

## References

Bagrow, Leo and Skeiton, R.A. (1964), *History of Cartography,* London, C.A. Watts.

Beaujouan, Guy (1966), 'Science Livresque et Art nautique au XVe siecle', Mollat and Adam (1966), 61-85.

Beaujouan, Guy and Poulle, Emmanuel (1957), 'Les Origines de la Navigation aux XVe et Xve scecies', Mollat (1957),103-16.

Bijker, Wiebe, Pinch, Trevor and Hughes, Thomas (eds) (1985), *New Directions in the Social Study of Technology,* Cambridge, Mass., M.I.T. Press, forthcoming.

Boxer, C. R. (1969), *The Portuguese Seaborne Empire, 1415-1825,* London, Hutchinson.

Braudel, Fernand (1975), *The Mediterranean and the Mediterranean World in the Age of Phillip II,* translated by Sian Reynolds, London, Fontana/Collins.

Braudel, Fernand (1979), *Civilisation Materielle, Economie et Capitalisme, XVeX'VIIle siecle,* three vols, Paris, Armand Colin.

Callon, Michel (1980), 'Struggles and Negotiations to Define What is Problematic and What is Not: the Sociologic of Translation',, in Knorr, Krohn and Whitley (1980),197-219.

Callon, Michel (1985a), 'Domestication of the Scallops and the Fishermen of St. Brieuc Bay: Some Elements of the Sociology of Translation', this volume.

Callon, Michel (1985b), 'The Electric Vehicle: No Mystery', Chapter 2 in Callon, Law and Rip (1985a), forthcoming.

Callon, Michel and Latour, Bruno (1981),'Unscrewing the Big Leviathan: How Actors Macrostructure Reality and How Sociologists help them to do so', in Knorr and Cicourel (1981), 277-303.

Callon, Michel, Law, John and Rip, Arie (eds) (1985a), *Studies in the Dynamics of Science,* London, Macmillan.

Callon, Michel, Law, John and Rip, Arie (1985b), 'Introduction', Chapter 1 in Callon, Law and Rip (1985a).

Chaunu, Pierre (1979), *European Expansion in the Later Middle Ages,* translated by Katherine Bertram, Amsterdam, New York, Oxford, North-Holland.

Cipol la, Carlo M. (1965), *Guns and Sails in the Early Phase of European Expansion, 1400- 1700,* London, Collins.

Constant, Edward (1978), 'On the Diversity and Co-Evolution of Technological Multiples: Steam Turbines and Pelton Water Wheels', *Social Studies of Science,* 8,183-210.

Cortelazzo, Manlio (ed.) (1970), *Mediterrannee et Ocean lndien, Travaux du Sixieme Colloque International d'Histoire Maritime,* Venise, 20-24 Sept.

1962, Paris, S.E.V.P.E.N.
Cortesao, Armando (1966), 'Note sur les Origines de la Navigation Astronomique au Portugal', Mollat and Adam (1 966), 137-47.
Cotter, Charles H. (1968), A *History of Nautical Astronomy,* Hollis & Carter, London.
Diffie, Bailey W. and Winius, George D. (1977), *Foundations of the Portuguese Empire, 1415- 1580,* Minneapolis, University of Minnesota Press.
Eisenstein, Elizabeth L. (1979), *The Printing Press as an Agent of Social Change: Communications and Cultural Transformations in Early-Modern Europe,* Cambridge, Cambridge University Press.
Foucault, Michel (1979), *Discipline and Punish: the Birth of the Prison,* Harmondsworth, Penguin.
Gille, Paul (1966),'Navires lourds et Navires Rapides avant et après les Caravelles', Mollat and Adam (1966),171-8.
Gille, Paul (1970), 'Les Navires des Deux Routes des Indes (Venise et Portugal): Evolution des Types. Resultats Economiques', Cortelazzo (1970), 193-201.
Goody, Jack (1977), *The Domestication of the Savage Mind,* Cambridge, Cambridge University Press.
Hughes, Thomas P. (1979), 'The Electrification of America: the System Builders', *Technology and Culture,* 20,124-61.
Hughes, Thomas P. (1983), *Networks of Power: Electrification in Western Society,1880-1930*, Baltimore, Johns Hopkins University Press.
Knorr, Karin D. and Cicourel, Aaron V. (eds) (1981), *Advances in Social Theory and Methodology: Toward an Integration of Micro and Macro Sociologies,* London, Routledge & Kegan Paul.
Knorr , Karin D., Krohn, Roger and Whitley, Richard D. (eds) (1980), *The Social Process of Scientific Investigation, Sociology of the Sciences,* 4, Reidel, Dordrecht & Boston.
Knorr-Cetina, Karin D. and Mulkay., Michael J. (eds) (1983), *Science Observed; Perspectives on the Social Study of Science,* London and Beverly Hills, Sage.
Landstrom, Bjorn (1978), *Sailing Ships in Words and Pictures from Papyrus Boats to Full-Riggers,* London, George Aflln & Unwin.
Lane, Frederic C. (1934), *Venetian Ships and Shipbuilders of the Renaissance,* Baltimore, Johns Hopkins University Press.
Lane, Frederic C. (1950), 'Force and Enterprise in the Creation of Oceanic Commerce', supplement to *Journal of Economic History, 10,* 19-31; reprinted in Lane (1966), 399-41 1.
Lane, Frederic C. (1966), *Venice and History, The Collected Papers of Frederic C. Lane,* edited by a committee of former students, Baltimore, Maryland, Johns Hopkins University Press.
Lane, Frederic C. (1973), *Venice, A Maritime Republic,* Baltimore, Maryland, Johns Hopkins Press.
Lankton, Larry D. (1983),'The Machine Under the Garden, Rock Drills arrive at the Lake Superior Copper Mines, 1868,-1883', *Technology and Culture, 24,* 1-37.
Latour, Bruno (1983), 'Give me a Laboratory and 1 will raise the Word', in Knorr-Cetina and Mulkay (1983), 141-70.
Latour, Bruno (1984a), *Les Microbes, Guerre et Paix* followed by *lrreductions,* Paris, Metailié.
Latour, Bruno (1984b),'A Simple Model for Treating Technoscience Evolution', paper presented to conference on New Developments in the Social Studies of

Technology at Twente University, Enschede, the Netherlands, 5-7 July.
Latour, Bruno (1985a), 'Visualisation and Cognition', *Knowledge and Society, 6,* forthcoming. Latour, Bruno (1985b), 'The Meanings of Social'. this volume.
Law, John (1984), 'A propos des Tactiques du Controle Social: une Introduction a ia Theorie de I'Acteur-Reseau', *La Légitimité Scientifique, Cahiers Science, Technologie, Soci,4M,* 4, Paris, C.N.R.S.
Law, John (1985a), 'On Texts and Other Allies', *Culture, Technique,* forthcoming.
Law, John (1985b), 'Technology, Closure and Heterogeneous Engineering: the Case of the Portuguese expansion', in Bijker and Pinch, (1985), forthcoming.
MacKenzie, Donald (1984), 'Technology, the State and the Strategic Missile', paper presented at the Workshop of New Developments in the Social Studies of Technology, Twente University, Enschede, the Netherlands, 5-7 July.
McNeill, Wdliam H. (1982), *The Pursuit of Power. Technology, Armed Force and Society since A. D.* 1000, Oxford, Blackwell.
Magalhaes-Godinbo, Vitorino (1969), *L'Economie de I'Empire Portugais aux X'Ve et XVI Siecles,* Paris, S.E.V P.E.N.
Mollat, Michel (ed.) (1957), *Le Navire et I'Economie Maritime du XVe au XVIII Siecle, Travaux du Colloque d'Histoire Maritime 17 Mai, 1956, Academie de la Marine,* Paris S.E.V.P.E.N.
Mollat, Michel and Adam, Paul (eds) (1966), *Actes du Cinquième Colloque International d'Histoire Maritime, Les Aspects International d'Histoire Maritime au XVe etXVIe Skcles,* Lisbonne, 14-6 Sept., Paris, S.E.V.P.E.N.
*Ocean Indien (1964), Ocean Indien et Mediterrannée, Travaux du Sixième Colloque International d'Histoire Maritime et du Deuxième Congrès de I'Association Historique Internationale de I'Ocean Indien,* Lorenco Marques, 13-15 Aug. 1962, Paris. S.E.V.P.E.N.
Parry, J. H. (1963), *The Age of Reconnaissance,* London, Weidenfeld & Nicolson.
Penrose, Boies (1952), *Travel and Discovery in the Renaissance, 1420-1620,* Cambridge, Mass., Harvard University Press.
Pinch, Trevor J. and Bijker, Wiebe E. (1984), 'The Social Construction of Facts and Artefacts: or How the Sociology of Science and the Sociology of Technology might Benefit Each Other', *Social Studies of Science,* 14, 399-441.
Rego, A. da Silva (1964), 'Quelques Problemes de I'Histoire Maritime de I'Ocean Indien', *Ocean Indien,* 37-48.
Schwartz Cowan, Ruth (1984), 'The "Consumption Junction": Historical and Sociological Analyses of Technological Trajectories', paper presented to the Workshop on New Developments in the Social Studies of Technology, Twente University of Technology, Enschede, the Netherlands, 5-7 July.
Serres, Michel (1980), *Le Parasite,* Paris, Grasset.
Taylor, E. R. G. (1 956), *The Haven-Finding Art.. A History of Navigation from Odyesseus to Captain Cook,* London, Hollis & Carter.
Tooley, R.V. and Bricker, Charles (1976), *Landmarks of Mapmaking; An Illustrated Survey of Maps and Mapmakers,* Oxford, Phaidon.
Wallerstein, Immanuel (1974), *The Modern World System, 1; Capitalist Agriculture and the Origins of the European World-Economy in the Sixteenth Century.* New York, Academic Press.
Waters, David W. (1958), *The Art of Navigation in England in Elizabethan and Early Stuart Times,* London, Hollis & Carter.

Waters, David W. (1976), *The Planispheric Astrolabe*, Greenwich National Maritime Museum