

## Chapter One

# Fossil Objects

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### I

ON 28 July 1565 Conrad Gesner (1516–1565), the greatest naturalist of his century, completed his book *On fossil Objects*<sup>1</sup>. It is an appropriate date to choose as a starting point for this history of palaeontology. Gesner's book marked a crucial moment in the emergence of the science, for it incorporated three innovations of outstanding importance for the future; but at the same time its form and contents epitomise perfectly the scientific and social matrix within which that emergence took place.

The short title of Gesner's book is deceptive: more fully it is *A Book on fossil Objects, chiefly Stones and Gems, their Shapes and Appearances*. This shows at once that the word 'fossil' has changed its meaning radically since Gesner's day. By origin the word meant simply 'dug up', and Gesner, like all his contemporaries and his predecessors back to Aristotle, used it to describe *any* distinctive objects or materials dug up from the earth or found lying on the surface. This of course included fossils in the modern sense, but it also embraced much more. Gesner's book dealt with a number of objects that we would now recognise as the fossil remains of organisms, but they were described in the context of a wide variety of mineral ores, natural crystals, and useful rocks.

This change in the meaning of the word 'fossil' is far more than a trivial point of etymology: it is a clue to the first major problem in the history of palaeontology. This was not simply to decide whether or not fossils were organic in origin. Nor was it merely a matter of recognising their 'obvious' resemblances to living animals and plants, and of combatting 'absurd' ideas that they could be anything other than the remains

of those organisms. On the contrary, their resemblances to living organisms were generally far from obvious or easy to perceive; and even when perceived, it was far from absurd to suggest that those resemblances might not be causal in character.

Early naturalists such as Gesner were faced with a very wide variety of distinctive 'objects dug up'. With respect to organic resemblances, these objects can be arranged in a broad spectrum. At one end of the spectrum lie objects that had little or no similarity to organisms. Crystals such as gem-stones and useful rocks such as marble are of this character. At the opposite end of the spectrum are objects that resemble organisms so clearly that the analogy is impossible to overlook. Many fossil shells and bones are of this character. But between these extremes lies a very wide variety of objects having some degree of resemblance to organisms, but in which that resemblance is ambiguous and difficult to interpret. In modern terms this category includes many fossils with confusing modes of preservation, and others belonging to extinct groups of organisms; but it also includes many concretions and other inorganic structures with some fortuitous resemblance to organisms.

In retrospect, we can see that the essential problem was that of determining *which* of this broad range of objects were organic and which were not. It is therefore misleading to say that some early writers believed that fossils were organic whereas others did not. It is essential to discover what kinds of 'fossil' they had in mind<sup>2</sup>. Somewhere along the spectrum, objects with significant resemblances to organisms had to be distinguished from those in which such resemblances were either absent or purely fortuitous. However, the criteria from making this distinction were not self-evident. When in the course of time they became clearer, objects with a causally significant resemblance to organisms came to be termed 'organized fossils' or 'extraneous fossils', to distinguish them from the rest of the broad range of 'objects dug up'. But it was not until the early nineteenth century that the word 'fossil', without qualification, finally became restricted to this end of the spectrum—though even today a relic of its former breadth of meaning is still preserved in the use of the term 'fossil fuels' for coal and oil. Meanwhile the inorganic origin of many other 'fossil objects' was also becoming clearer. This left in the middle of the spectrum a gradually shrinking group of objects of uncertain origin; and in modern palaeontology this group persists under the name of *Problematica*, as a collection of objects that are doubtfully organic or at least of uncertain affinities.

The question of the nature of fossils was not, therefore, resolved in a simple struggle between 'correct' and 'erroneous' opinions: it was a much more subtle debate about the meaning and classification of the whole spectrum of 'fossil objects'.

## II

Before analysing the earlier stages of the debate about 'fossils' it is worth considering the context in which they were studied by sixteenth-century naturalists. Gesner intended his small book on 'fossils' to be no more than a preliminary essay, to be followed at a later date by a full-scale work on the subject. The larger work was never written: only a few months after completing the preliminary book he died at his home in Zurich in an outbreak of plague, leaving behind him a vast mass of unpublished materials. Because his work on 'fossils' was only a small part of a much wider programme to cover the entire range of natural history, his published *History of Animals* (1551-8)<sup>3</sup> gives us an indication of the character that his larger work on 'fossils' would have had. In its structure and contents we can see reflected the distinctive attitudes and methods of a Renaissance naturalist, and the same features can be detected in miniature even in the small book *On fossil Objects*.

The characteristic attitude to history of the men of the Renaissance, by which they regarded their own period as a time of re-birth and attempted recovery of the values and achievements of classical Antiquity, led naturalists such as Gesner to adopt an encyclopaedic approach to their subject. To some extent this was a deliberate imitation of the classical model set by Pliny in his *Natural History*, which was reprinted many times during the sixteenth century. But it also reflected their recognition of the value of *both* the writers of Antiquity *and* their own contemporaries. Gesner's *History of Animals*, for example, was intended to be a worthy successor of Aristotle's great work of the same name; but it set Aristotle's observations alongside those of Gesner's own contemporaries. It was designed to gather together all that had been written on animals from Aristotle's time to Gesner's own, to compare and collate these opinions, and so to provide a firm foundation for future study. It seemed essential to record in full the opinions of writers ancient and modern, even though their views often conflicted with each other, and even though the compiler himself was sometimes sceptical of their

certain that he was applying a name in the same sense as his predecessors. The effect of Gesner's innovation can be seen with striking effect if his book is compared with the earlier and more famous work *On the Nature of Fossils* (1546)<sup>5</sup> by the German naturalist Georg Bauer (1494–1555)—better known by his literary name Agricola. Both books dealt with much the same range of objects; but in the complete absence of illustrations it is often very difficult to know just what objects Agricola was describing, whereas in Gesner's book it is generally clear at once from the woodcut illustrations. Since the nature of most 'fossil objects' was poorly understood, it was difficult for any sixteenth-century naturalist to decide which features were essential for description and which merely accidental, or indeed to know how best to describe in words any features whatever. Illustrations provided a means of by-passing this problem, by allowing non-verbal communication between author and readers, and thereby mitigating the hazards of inadequate verbal means of expression. Gesner himself recognised the importance of what he was doing, for he said he was including as many illustrations as possible "so that students may more easily recognise objects that cannot be very clearly described in words"<sup>6</sup>.

The employment of illustrations to supplement and explain a scientific text was not in itself an innovation. In more established branches of natural history the use of woodcuts had already been brought to a high standard of artistic and scientific excellence. Leonhart Fuchs's magnificent *Commentaries on the History of Plants* (1542) and Andreas Vesalius's great work *On the Construction of the Human Body* (1543), each illustrated with drawings of superb quality, had been published more than twenty years earlier<sup>7</sup>; and Gesner himself had used hundreds of woodcuts in his *History of Animals*, the volumes of which were a monument to the usefulness of illustrations as an aid to identification (see Fig. 1.9). For depicting 'fossil objects', however, there was virtually no precedent, no iconographical tradition to follow. One minor work published some years earlier had included a few small woodcuts, two of which can be recognised as drawings of fossil shells (Fig. 1.2); but this seems to have been Gesner's only precedent<sup>8</sup>. His own book was similar in size and scope, but he included a far greater number of woodcuts, providing illustrations systematically for every part of his subject matter. But even drawings of 'fossils' suffered to some extent from the same limitations as verbal descriptions, since it was not always clear which features most deserved emphasis. Gesner was aware

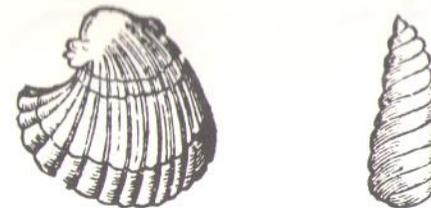


Fig. 1.2. Two woodcuts of fossil shells (1557), probably the first illustrations of fossils ever published in a printed book in the West<sup>8</sup>. They were re-published later by Gesner.

of this, saying he hoped that if his readers "find some difficult to recognise they will blame, not me, but the difficulty of the task". Nevertheless, crude though some of his woodcuts are, they initiated a technical change which was of major importance to the future science of palaeontology.

The further exploitation of illustrations as an aid in the identification of 'fossils' can be seen in the hundreds of woodcuts in Aldrovandi's book, which in this feature too is probably an indication of what Gesner's larger work would have been like (Fig. 1.3). Woodcuts, however, had their limitations: unless they were very large (as some of Aldrovandi's were) they enforced a relatively coarse style of drawing, which was ill adapted to the increasing emphasis on precise description. By the end of the century, therefore, naturalists were beginning to exploit one of the striking new inventions of Renaissance artists, namely the technique of engraving on copper. Although this was more costly, in the hands of a competent engraver it allowed far more detail to be shown, and far more subtle shading to give a greater illusion of three-dimensional solidity (Fig. 1.4). In this respect Aldrovandi's book on 'fossils' was already old-fashioned by the time it made its belated appearance; copper engravings had by then been used for more than thirty years for illustrating fossils, some of the first (see Fig. 1.11) having been published early in the seventeenth century by the Neapolitan naturalist Fabio Colonna (1567–1650)<sup>9</sup>. The change from woodcuts to copper engravings was only the first of many technical advances in illustration, generally taken over from the visual arts, by which palaeontologists have been able to improve the quality and precision of their non-verbal communication with each other. This dependence on

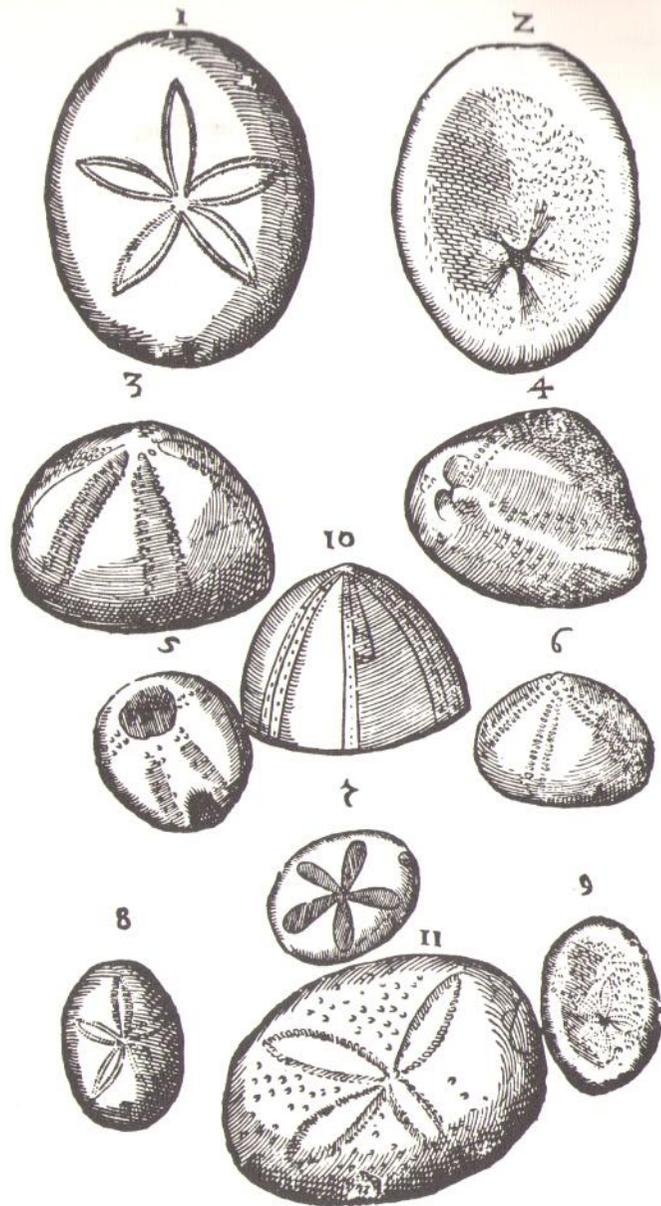


Fig. 1.3. A page of illustrations of fossil sea-urchins from Aldrovandi's large book of fossils<sup>4</sup>. Contrast the crudity of these 16th-century woodcuts with the delicacy of an early 17th-century copper engraving of a similar fossil (Fig. 1.4).

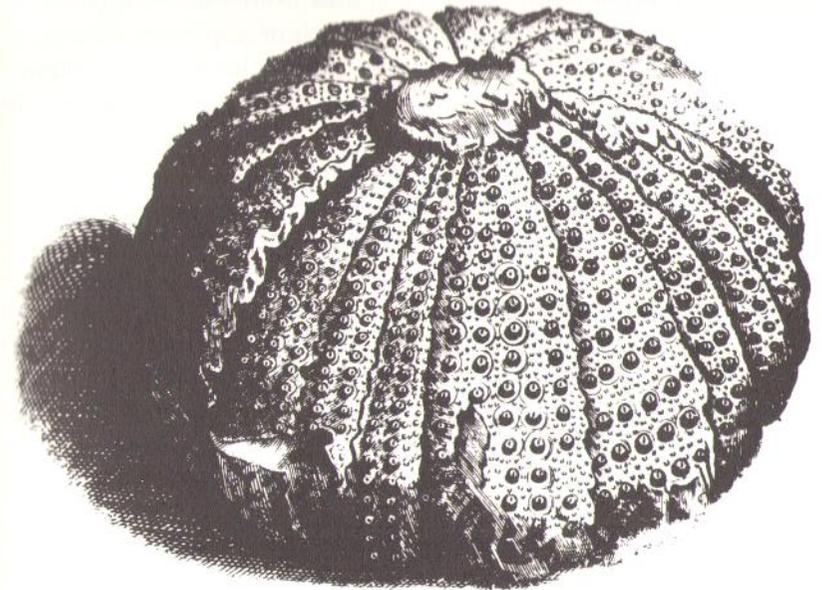


Fig. 1.4. A copper engraving of a fossil sea-urchin, from a museum catalogue published in 1622<sup>12</sup>. Compare with the relatively crude treatment of similar fossils in earlier woodcut illustrations (Fig. 1.3).

illustrations is not a reflection of the 'immature' state of the science, but is an essential element in its structure, stemming from the inherent nature of its subject-matter. Technical advances in illustration might be said to have played a part in the history of palaeontology similar to that of improvements in instrumentation in the physical sciences.

### III

Gesner's use of illustrations in natural history reflects not only his concern to identify precisely the material described by the Ancients, but also his emphasis on the importance of first-hand experience. His respect for the opinions of classical authors was tempered by a method of study in which great weight was placed on the value of personal observation. In all his work on natural history, Gesner compiled his material as far as possible from a basis of first-hand observation, or,

where that was not possible to him, at least from a study of preserved specimens. Indeed he followed Fuchs's example of employing a draughtsman and an engraver to make illustrations under his direct supervision, in order to ensure the highest standards of accuracy in representing the specimens he collected or was sent.

This emphasis on the importance of looking at nature for oneself is characteristic of a strand in sixteenth-century thought which was, to some extent, the opposite of the humanist emphasis on recovering accurately the writings of the Ancients. Advances in technology and voyages of exploration were beginning to provide a 'model' of human history that would turn attention away from an exclusive concern with recovering a golden past and would begin to persuade men that their own age might even surpass that of Antiquity. This feeling, especially among those most closely involved in practical pursuits affected by new discoveries, encouraged the view that nature too should be studied without uncritical regard for the opinions of the Ancients. Among those who wrote on 'fossils' the French ceramic craftsman Bernard Palissy (1510?–1590) is a good example of this anti-traditional tendency. Palissy's travels as a 'journey-man' potter brought him first-hand experience of a wide range of 'fossils', and especially of the materials for ceramics. At the same time he was proudly ignorant of the classical languages and the traditional teaching of the universities, and took a delight in exposing the supposed errors of more 'learned' writers.

This anti-authoritarian outlook has sometimes been linked directly with the Protestant rejection of Catholic tradition. For 'mainstream' Protestants, however, the importance of personal experience was always balanced by an emphasis on the centrality of the bible, which gave them a natural affinity with the wider humanist movement. Humanist scholars were concerned to recover not only the writings of classical Antiquity but also the biblical documents, which were equally a legacy from the ancient world and therefore equally amenable to the same textual methods: in both cases the aim was to get behind the accumulated corruptions of more recent centuries to the purity of the original texts. Gesner, who was born and lived most of his life in Zurich, one of the centres of Reformation thought, would have felt sympathy with this task: he had learnt not only Greek but also Hebrew in order to read the biblical documents in the original. It has indeed been argued that the Protestant concern to return to the original sources of Christianity positively encouraged a comparable concern to study at first

hand the whole world of nature, and Gesner makes a good case for this thesis<sup>10</sup>. There were, it is true, more radical currents of thought, in natural science as in religion, that rejected the authority of tradition more emphatically; but Gesner was too well aware of the value of the Ancients to follow such a path in natural history, just as his close friend the Zurich reformer Heinrich Bullinger was too well aware of the centrality of the New Testament to follow it in theology.

The encyclopaedic approach, combined with the emphasis on personal observation of nature, provide the context for the second innovation incorporated in Gesner's book *On fossil Objects*. The basis for this descriptive work was the formation of a collection of specimens. Published illustrations were, in effect, merely a convenient substitute for a museum: they could be duplicated in large numbers by printing, thereby placing the same data at the disposal of naturalists everywhere. However, even illustrations could be misleading and ambiguous, and their value was greatly enhanced if, in cases of doubt, it were possible to study the original specimens from which they had been drawn. This involved the deliberate formation and preservation of museum collections. Here again, as with illustrations, more established branches of natural history had already led the way. Botanic gardens were founded at many universities during the sixteenth century, and were supplemented by the invention of the 'dry garden' (*hortus siccus*) for pressed plants. Animals were more difficult to preserve, though at least skeletons and shells could be collected. The formation of museums containing materials for natural history grew naturally out of the Renaissance enthusiasm for collecting the relics of Antiquity; and in many early museums all kinds of object, natural and artificial, were assembled haphazardly.

For 'fossil objects', however, museum preservation was still more suitable than for animals and plants: it was not merely a useful but inferior substitute for an assemblage of living organisms, but rather, like a collection of antiquities, the best possible means of preserving the objects concerned. Agricola and other earlier writers may well have formed collections of their own, but Gesner's book is the first work on 'fossils' that clearly refers to such a collection. Gesner expressed his gratitude to his friend the physician Johann Kentmann of Torgau (1518–1574) for sending him specimens to supplement his own, and he repaid the debt by placing the catalogue of Kentmann's collection at the front of the composite volume in which his own work was bound<sup>11</sup>.

| ARCA RERVVM FOSSI-<br>hum Ioan. Kentmani. |   |                             |
|---|---|-----------------------------|
| 1 TERRAE                                  | * | 2 SVCCI NATIVL              |
| 3 EFFLORESCENTES                          | * | 4 PINGVES                   |
| 5 LAPIDES                                 | * | 6 LAPID. IN ANIMALIBVS      |
| 7 FLVORES                                 | * | 8 SILICES                   |
| 9 GEMMAE                                  | * | 10 MARMORA                  |
| 11 SAXA                                   | * | 12 LIGNA IN Saxa corporata. |
| 13 ARENAE                                 | * | 14 AVRVM                    |
| 15 ARGENTVM                               | * | 16 ARGENTVM VIVVM           |
| 17 AESSEV CV-PRVM                         | * | 18 CALCHA MET. PLVMBAGO     |
| 19 PYRITES                                | * | 20 PLVMBVM NIGRVM           |
| 21 CINEREVM                               | * | 22 CANDIDVM                 |
| 23 STIBI                                  | * | 24 FERRVM                   |
| 25 STOMOMA                                | * | 26 MARINA VARIA             |

*Quicquid terra finis, vniuersi recondidit imis,  
Thefauros orbis hac brevis arca tegit.  
Lam magna est tacita natura inquirere vires,  
Maior in hoc ipsum munere nosse Deum.  
Georg. Fabricium C.*

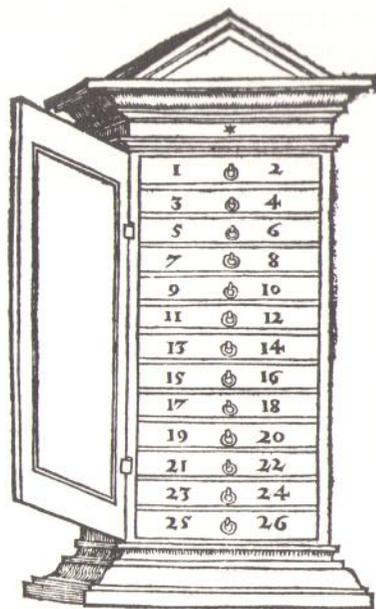


Fig. 1.5. The first published illustration (1565) of a museum collection of 'fossil objects': Johann Kentmann's "Ark" or cabinet<sup>11</sup>. Note the wide range of objects indicated on the key: for example "earths" (1), flints (8) and marbles (10); gold (14), silver (15) and iron (24); 'stones in animals' (6) and 'various marine' objects (26). Most fossils in the modern sense would have been included under 'stones' (5) and 'wood embodied in rocks' (12).

The importance of the museum as an innovation in this branch of natural history is symbolised by the frontispiece of Kentmann's catalogue—the only illustration it contained. His little cabinet with its numbered drawers (Fig. 1.5) was termed significantly an 'ark' (*Arca*), which emphasises its function for the preservation of 'fossil objects'. Without the establishment of a tradition of museum preservation, it is difficult to imagine how a science of palaeontology could have emerged. As with the use of illustrations, the importance of museums is not a sign of the immaturity of the science, an indication of a 'descriptive' phase not yet outgrown: on the contrary museums are a necessarily central feature of the activity of studying fossils, stemming again from the inherent nature of the material.

Kentmann's 'ark' and his published catalogue of its contents were soon followed by similar but grander schemes. A 'Room of Minerals'

(*Metallotheca*) was established in the Vatican, for example, to parallel the papal Library (*Bibliotheca*), and its contents were described in a catalogue by the papal physician and naturalist Michele Mercati (1514–1593), and later supplemented by the botanist Andreas Caesalpino (1519–1603). The naturalist Francisco Calzolari (1521–1600) likewise formed in Verona a large but miscellaneous museum of natural history, which was continued by his son; the published catalogues again give a good impression not only of the range of its contents but also of the atmosphere of such museums<sup>12</sup>. Catalogues of this kind established a continuing tradition in the publication of fossils and related objects, which reaches of course to the present day.

## IV

Gesner's debt to Kentmann is only one example of the pattern of activity that underlay all his work. His compilations depended not only on the previously published work of other authors, both ancient and modern, and on his own personal observations, but also on his ability to draw on new and unpublished information supplied by his network of scientific correspondents. He was not unusual in having many correspondents: scholarly letter-writing, as a revival of a classical tradition, was another way in which humanistic education directly benefitted the study of nature in the Renaissance period, besides providing in the Latin language a means of easy communication across national boundaries. In an age when travel was not to be lightly undertaken, contacts between scholars by means of letters were of course valuable for the exchange and stimulation of ideas in any branch of learning. They were, however, particularly important for a different reason in any branch of natural history. The subject-matter of astronomy or chemistry was not closely dependent on locality, whereas the study of botany or zoology necessarily was. It was therefore no accident that in the course of compiling his *History of Animals* and collecting material for a comparable botanical work Gesner had built up a network of correspondents of exceptionally wide extent, ranging geographically from Italy to England and from Poland to Spain, and crossing all the ideological and political frontiers of the divided Europe of the Reformation period.

This is the context for the third innovation incorporated in Gesner's book *On fossil Objects*. It is the first such work in which there is a clear

expression of a programme of co-operative research on 'fossils'. Gesner had already received specimens and drawings from Kentmann and several other correspondents, but his book was explicitly designed to elicit further information of the same kind. It had been written, he explained, 'rather hurriedly and without much preparation', in moments of leisure from other work, specifically in order to stimulate interest in the subject. It was designed 'to encourage other students of these objects in other parts to send me more examples of stones worth recording and suitable for accurate reproduction'. An indication of the wide distribution that this request received is given by the fact that half a dozen copies of Gesner's book are preserved in the libraries of Cambridge alone (most of them having been acquired at the time), although England was rather on the periphery of the world of sixteenth-century natural science. The very publication of Gesner's book in a preliminary state is thus a reflection of the research programme he hoped it would initiate.

The importance of this innovation, like the use of illustrations and the formation of museum collections, is difficult to exaggerate. While the study of animals and plants was certainly dependent on locality, the study of fossils was and is even more so. Most animal and plant species can be found in appropriate habitats over fairly wide areas, but even the commonest fossils generally have to be collected from extremely restricted localities—a particular limestone quarry, for example, or temporary excavations for the foundations of a particular building—which may not be known or accessible to any but those living close by. More than other branches of natural history, therefore, the study of fossils requires the cooperative efforts of many naturalists living in different places.

It is symptomatic of the sense of scholarly community felt by most sixteenth-century naturalists that Gesner dedicated his book on 'fossils' not, as was usual, to some local dignitary or princely patron, but to a Polish scholar whom he knew only by correspondence and had never met. The same sense of community is reflected also in the form in which he published his book. He collected and edited seven shorter works on related subjects by other authors, and published these with his own book as a volume entitled *Several Books on all Kinds of fossil Objects*<sup>13</sup>. By this means he was able to publish a short work by a fellow-naturalist who had died at a tragically early age, to give wider circulation to some previously published works by other scholars, and to

lend the prestige of his own name to two works by his friend Kentmann. With characteristic modesty he placed his own book last in the collection, although it was the most substantial.

It was not until the second half of the seventeenth century that the correspondence networks of Renaissance scholars such as Gesner began to be formalised into scientific societies issuing printed news-sheets to keep their members in touch with one another. But the embodiment of the scientific community in an institutional form began, however fitfully, earlier in that century. Duke Federigo Cesi's Academy of the Lynxes (*Accademia dei Lincei*) at Rome was only one of a number of short-lived scholarly communities with high and often utopian ideals for the transformation of society. It was intended that 'colonies' of Lynxes should be established in every city, on the model of an active monastic order, to create a widespread community of scholars devoted to new ideals in natural science. In fact only one such colony was ever founded, in Naples, but to this branch of the Academy belonged Fabio Colonna, and it was in the context of this idealistic community that he carried out his work on natural history<sup>14</sup>. Like his famous contemporary Galileo, Colonna was proud to place his title 'Lynx' prominently on the title-pages of his publications. It is perhaps no accident that his were some of the most significant studies of fossils to be published in the early seventeenth century; for these studies foreshadow, more closely than any others, the greatly extended discussion of fossils that took place later in the century within a similar institutional setting.

## V

Three important innovations are thus embodied in Gesner's small book *On fossil Objects*. The use of illustrations to supplement verbal description, the establishment of collections of specimens, and the formation of a scholarly community cooperating by correspondence—these were all innovations that had already been put to good use in other branches of natural history. However, it is only with the last work of Gesner's prolifically productive life that we can see the beginnings of their deployment in the study of 'fossils'; and the work published in the century following Gesner's death demonstrated their potential value for enlarging the scope of the discussion on the nature of 'fossils'. Before considering that discussion, however, it is important to note the

motives that led Gesner and his contemporaries to study natural history in general, and 'fossils' in particular.

Firstly, the world of nature was felt to be worth describing simply because it was the product of God's creative activity. The use of the natural world to provide rationally persuasive demonstration of the divine attributes had long been established in traditional scholastic theology, and continued to be influential in the Catholic theology of the Counter-Reformation. Protestant theology, on the other hand, stressed the impossibility of reaching the true knowledge of God by the exercise of fallen reason. However, this did not lead it to devalue the study of nature; on the contrary it emphasised that the believer, while knowing God only by grace and through faith, had a positive duty to acknowledge the divine artistry of the natural world in which he was placed, and indeed to delight in it. When Gesner dedicated his volume *On the Nature of Fishes and Aquatic Animals* (1558)<sup>15</sup>, he drew the Emperor's attention to its contents primarily as a demonstration of the marvellous works of God in the depths of the sea. Likewise in introducing his book *On fossil Objects* he became so delighted with the thought that the gems among his 'fossils' were earthly reminders of the jewelled construction of the heavenly City of God, that he had to recall himself with some reluctance to the mundane description of his book.<sup>16</sup> Such sentiments were no mere pious formalities: they expressed an essential part of the dynamic behind the descriptive work not only of Gesner but of many other sixteenth-century naturalists. Their interest and delight in all the varied products of God's creativity were important factors in their enlargement of the scope of natural history beyond the limits of those creatures or objects that happened to be useful to mankind. This lessening of an emphasis on man in natural history was as important, in its way, as the astronomical developments that undermined an anthropocentric viewpoint more radically in the realm of cosmology.

At the same time, however, sixteenth-century naturalists also had powerful utilitarian motives. These too had strong religious foundations, since both Catholic and Protestant theologies stressed the divinely authorised ability of man to utilise the products of the world in which he lived. A straight-forward expression of this utilitarian motive for the study of nature can be seen, for example, in Agricola's plain factual accounts of useful minerals and of mining techniques<sup>17</sup>. In some writers, particularly the chemists who followed Paracelsus, a practical motive was closely linked with a strongly anti-traditional and

even anti-intellectual outlook<sup>18</sup>. Palissy, while dismissing Paracelsus with as much disdain as he ignored Aristotle, is a good example of this tendency among writers on 'fossils'. In his most important work, the *Admirable Discourses* (1580), he provocatively used a dialogue form to contrast the first-hand experience of 'Practice' with the blinkered book-learning of 'Theory'; and the full title and contents of the book stressed the practical value of the 'secrets of nature' that would be discovered by following the precepts of 'Practice'<sup>19</sup>. The title of his earlier work, *A true Recipe by which all Frenchmen can learn how to multiply and augment their Riches* (1563), reflects with almost embarrassing clarity the utilitarian foundation of his science<sup>20</sup>. The context of Palissy's references to 'fossils' in both works is in fact a much wider collection of practical information on farming methods, on water conservation and springs and wells, on an ingenious design for an impregnable fortress, and so on; while even the 'fossils' are described primarily for their practical value as materials for ceramics and other useful crafts.

Gesner's work, though far from anti-traditional, does not for that reason lack utilitarian elements. On a simple level his interest in the practical value of natural history is shown by his systematic comments on the usefulness—agricultural, culinary, and so on—of each of the animals he described; and in his book on 'fossils' the same interest is shown by his inclusion of many useful rocks and minerals. A more specific utilitarian motive however, arose from the medical context of his work. Like most other writers who have so far been labelled 'naturalists', Gesner was by training not only a humanist scholar but also a qualified physician. In the later part of his life he was chief medical officer (*Stadtarzt*) of Zurich, just as Kentmann was in Torgau and as Agricola had been in Joachimsthal and Chemnitz. The chief motive behind the botanical work of the sixteenth century was quite explicitly medical: 'herbals' such as Fuchs's were written primarily to aid the correct identification of plants with curative properties<sup>21</sup>. This medical purpose underlay much of the natural history of Gesner and his contemporaries.

It was strengthened and extended, however, by the increasing popularity of Paracelsan medicine. By rejecting the Galenic concept of disease as an imbalance between contrasting 'humours' of the body, and by substituting the concept of a specific bodily failure requiring an equally specific remedy, Paracelsus and his followers had focussed

attention on the medicinal value of specific substances. Moreover, by regarding the physiological processes of the body as a series of chemical operations directly analogous to those taking place in the outside world, they extended the range of potentially valuable substances to include minerals and metals, as well as the long established botanical remedies favoured by more conservative physicians. Gesner himself was certainly much concerned in his medical work with the use of the newly developed technique of distillation for the extraction of active principles or 'quintessences' from a wide range of natural materials<sup>22</sup>; and among his contemporaries discussions of 'fossils' were often set in a similar context, as for example in the *Treatise on medical Waters and also Fossils* (1564) by the Paduan anatomist and physician Gabrieli Fallopio (1532-1563)<sup>23</sup>. There is little in Gesner's own book on 'fossils' about the medicinal value of the objects he was describing, but that is simply a result of its preliminary character: he promised that in his larger work he would 'fully describe every kind of stone and mineral, its power and nature and also its philology'. Once again, Aldrovandi's larger book is a useful indication of what Gesner might have produced: its section on 'stones' included descriptions of the usefulness of various stones and 'fossil objects' not only for building and other practical purposes but particularly for medicine.<sup>24</sup>

## VI

It is significant that in the phrase just quoted, Gesner placed the 'power' (*vis*) of his 'fossils' in first place, even before their 'nature': such, the phrase suggests, was the importance he attached to their 'power'. But it would be unhistorical to assume that by this word he meant merely what we would call the medicinal value of naturally occurring chemical substances; it had a much deeper significance for sixteenth-century naturalists. Whether or not they accepted all Paracelsus's teaching, many of them were profoundly influenced by the Neoplatonic philosophy that underlay it. At the roots of Paracelsan medicine was a renewed belief in the ancient concept of an ontological analogy between Man and his external world<sup>25</sup>. Man was the 'microcosm', the epitome of the universe, the reflection in miniature of the structure, variety and purpose of the 'macrocosm' outside him. Every feature of the universe around him could therefore be expected to have some

analogy, some token or symbol, within his being. It followed that to look for specific remedies for specific ills was no mere empirical hunch but rather an attempt to trace the implications of the fundamental pattern of nature. Indeed the whole universe of Renaissance Neoplatonism was a network of hidden affinities and 'correspondences', which might be made manifest by resemblances not only between microcosm and macrocosm but also between the heavens and the Earth, between animals and plants, and between living and non-living entities. However, this network of hidden affinities was also a network of forces and powers, of 'sympathy' and 'antipathy', which were able to act at a distance. On this basis many otherwise inexplicable phenomena, such as the attractational powers of a piece of lodestone or amber, could be given a rationally satisfying interpretation.

Within this universe the most powerful forces were those emanating from the heavenly bodies, for of all created entities the heavens occupied the most exalted position in the hierarchical structure of the Neoplatonic cosmos. Astrology in its ancient forms had long been suspect in Christian thought on account of its deterministic implications; but the 'natural magic' of the Renaissance made it acceptable once more in a subtly different form<sup>26</sup>. Among the documents recovered by humanist scholars had been those they ascribed to an ancient Egyptian priest named Hermes Trismegistus. Although these writings were later shown to date only from the early centuries of the Christian era, during the Renaissance period they were believed to be the work of a contemporary of Moses, an early Gentile prophet of Christ and the ultimate source of Plato's wisdom. With such an impeccably respectable origin, the 'Hermetic' accounts of the deliberate use of stellar powers or influences to produce terrestrial effects became acceptable as a basis for a new form of astrology. Instead of stressing the deterministic power of celestial forces over the fate of man, depriving him of free-will and initiative, this 'natural magic' demonstrated the ability of man to manipulate these forces to his own design and for his own ends. It was 'magic' in that it sought to operate through tapping an occult network of magical forces ramifying through the cosmos; but it was also 'natural' in that it rejected the use of demonic forces (and hence condemned the practices of witchcraft) and sought only to exploit the potentialities of a divinely created natural world. It can be argued, indeed, that it played a crucial role in the emergence of modern science, in that it provided the essential sanction for a study of nature

that was closely linked with purposes of practical manipulation, and thus that it lay at the roots of the distinctively modern synthesis of science and technology<sup>27</sup>.

Whether or not such a claim can be justified, it is certain that the study of 'fossils' in the sixteenth century cannot be fully understood except against the background of this complex amalgam of Hermetic Neoplatonism. In order to capture and exploit the powerful influences of the heavenly bodies it was necessary to identify the corresponding terrestrial entities in which those powers were concentrated in accessible form. Prominent among such entities were the precious stones, which by their colour, lucidity, brilliance and rarity seemed to reflect the ethereal qualities of the heavens. Within the context of natural magic it was therefore logical to attribute to these stones the most remarkable powers. Such powers were improved if the gems were cut or polished, for this increased their celestial quality of brilliance; and they could be enhanced still further by engraving them under the right astrological conditions with appropriate images or symbols, for this increased their efficacy in drawing down the powers of the celestial bodies with which their occult affinities lay.

The importance of natural magic as a reason for interest in 'stones' can be seen, for example, in Camillo Leonardi's popular *Mirror of Stones* (1502), which was reprinted many times in the sixteenth century. A direct descendant of the mediaeval lapidaries, this brief compilation placed great emphasis on the occult 'virtues' of gemstones, and Leonardi devoted about a third of the book to the discussion of 'talismans' carved with magical images<sup>28</sup>. The same interest can be seen in a wider context in the equally popular encyclopaedic work *On Subtlety* (1550) by the natural philosopher Girolamo Cardano (1501–1576)<sup>29</sup>. This was a compendium of information on all aspects of the universe, set in a Neoplatonic framework. Its contents descended from a discussion of first principles and of the fundamental elements, through a description of celestial phenomena, to a consideration of terrestrial materials; and then re-ascended the hierarchy through plants and animals, Man and his arts and sciences, supra-human 'intelligences', and so finally to God Himself. In the section *On Stones*, Cardano accepted completely the 'virtues' attributed to gemstones, but sought to give them a natural explanation in terms of their 'correspondence' with other entities<sup>30</sup>.

There can be little doubt that Gesner too, had he lived to write his full-scale work on 'fossils', would have described their 'power' similarly

In terms of natural magic. He had met Cardano in 1552, and was certainly familiar with his work. Moreover, among his *Several Books on all Kinds of fossil Objects* he chose to re-publish a French work on gemstones<sup>31</sup>, in which he actually restored some astrological passages that had been censored in the original edition. This work dealt explicitly with the occult powers of gems, and its citations of Pythagoras, Plotinus and 'Hermes' reveal clearly its affinities with Hermetic Neoplatonism. It is true that Gesner was sceptical about some of the alleged powers of engraved gems, but he did not disbelieve in the reality of celestial influences on the gems themselves. Another of his *Several Books* was the Greek text and a Latin translation of a mediaeval work on the twelve stones in the breastplate of the Jewish High Priests, which had been engraved with the names of the twelve tribes of Israel; and Gesner added to this a long appendix of his own, on their identification and synonymy<sup>32</sup>. They were often identified with the twelve mystical stones of the heavenly Jerusalem of the Apocalypse; and since an ancient tradition had equated them with the signs of the zodiac, their mystical and cabalistic significance also had an astrological dimension. In his own contribution to the volume, Gesner actually illustrated these same twelve stones, not as arranged in the breastplate but as polished or cut gems; and he grouped this extremely powerful assemblage of stones, like a necklace, around two rings—the commonest way of wearing a stone with desirable properties. One ring was set with that most brilliant stone, a cut diamond, and the other with a stone engraved with a scarab beetle, an 'image' closely associated with the hieroglyphs that were believed to record the pristine Hermetic source of natural magic. Of all the dozens of woodcuts illustrating his book *On fossil Objects*, Gesner chose this particular one, with all its powerful associations of natural magic, to decorate the title page of the whole volume, as if to epitomise its entire contents (Fig. 1.6).

For Gesner, then, as for many others who wrote on 'fossils', the potential use of these objects in natural magic was an essential part of his motive for studying them. However it was not sharply separated either from the materially useful value of 'fossils'—and especially their medicinal value—or from their value for contemplation as the works of God. Within a divinely created cosmos in which all parts were linked through a network of hidden affinities, all these purposes were fused into a coherent whole. This explains, for example, the otherwise peculiar mixture of topics that Aldrovandi appended to his description



published a separate short monograph on human gallstones, by Kentmann, in his composite volume<sup>34</sup>. In regarding such objects as 'fossils' Agricola and Gesner were following a long tradition; and to some extent it can be explained in terms of their interest in medicine and perhaps in natural magic. More significantly, however, what grouped all such objects with other 'fossils' was primarily their common property of 'stoniness'.

The stoniness of 'fossils' was the causal problem that was most often discussed. Aristotle had outlined an explanation in terms of vaporous exhalations, and this had been elaborated by the Arabic writer Avicenna and later by Albert of Saxony into a theory of a petrifying fluid (*succus lapidificatus*, etc.). Some such explanation was accepted by most sixteenth-century naturalists who wrote on 'fossils'. There was much to suggest that a petrifying agency was constantly at work producing stony objects of all kinds. Stalactites, for example, could almost be seen growing from the perpetually dripping water inside caves, and some springs had the uncanny power of coating objects with a layer of stone. There was a persistent belief among miners, fostered no doubt by the visible growth of secondary minerals on the walls of mine-shafts and adits, that the ores they were mining were being steadily replenished. The crystals lining the sides of mineral veins suggested that such materials as rock-crystal were being formed in the depths of the Earth just as surely as other crystals could be made to form from solutions in the chemist's laboratory<sup>35</sup>. Neither did the petrifying agency seem to be confined to the Earth's interior. Corals and calcareous algae showed its action in the sea, within the tissues of plants (the animal nature of corals was not discovered until the eighteenth century); gallstones and pearls proved likewise that stones could be formed within the bodies of animals and even Man himself: and meteorites and similar objects suggested, perhaps on the analogy of hailstones, that stony materials could also be produced above the Earth's surface. Objects in this last category were assumed to have originated within the atmosphere (a belief that is preserved incongruously today in the common stem of the words 'meteorite' and 'meteorology'), because within the framework of Aristotelian cosmology it was inconceivable that such irregular phenomena, like thunder and lightning, could be anything other than '*meteora*'. The petrifying agency thus seemed to pervade the entire sublunary sphere; and it seemed legitimate to study all its products together, whether they originated in, on or above the Earth.

The exact nature of the petrifying process was far from clear. Some Aristotelians described it in terms of 'vapours', others in terms of a fluid or 'juice' (*succus*). Falloppio thought there might be more than one kind of fluid, to account for the physical properties of the major classes of 'fossils', while Palissy interpreted everything in terms of percolating 'salts'. But whatever the exact explanation, such theories seemed to account, at least in principle, for the stoniness of 'fossils'.

Similarly within the Neoplatonic framework all the evidence of a petrifying process could be interpreted as signs of the 'growth' of stones. In Neoplatonic thought the distinction between living and non-living was simply unreal: all entities shared in some sense in the quality termed 'life', however much they differed in the mode of its expression. All stones, Cardano asserted, are in a sense alive, although the life of plants and animals is more manifest. But stones too clearly shared the characteristic of growth, as stalactites and crystals demonstrated. The decay of some minerals likewise suggested an analogy with disease, old age and death; and one much-discussed stone, *aetites* (probably a concretionary nodule), often contained a smaller stone within a central cavity, suggesting that it was in the act of reproduction. Even the Earth itself seemed analogous to a living organism, with percolating ground-water corresponding to the blood in the body. Whether the formation of 'fossils' was thought of in terms of some kind of precipitation from a fluid or fluids, or whether in terms of an organismic analogy of growth, the substance or *matter* of these objects seemed to be rationally intelligible. A stony matter was the natural character for 'fossils' of any kind. The *form* of 'fossils', on the other hand, seemed to be a separate problem.

The use of these categories of form and matter is partly a convenience for our analysis of the problem of fossils, for it reflects the nature of the material. In modern terms it is legitimate to distinguish questions of fossilisation, which affect chiefly the materials of which fossils are composed, from questions of biological affinity, which affect chiefly their morphology. However, this distinction, so inherently appropriate, was peculiarly congenial to the Aristotelian thought of most sixteenth-century naturalists. If the nature of any entity whatever could be analysed in terms of form and matter, the same categories could also be used to understand the nature of 'fossils'. The form of 'fossils' could therefore be studied as a problem separate from their matter.

Agricola had pointed out that many 'fossil objects' have characteristic shapes, some of which seem to imitate other objects; and he used these shapes extensively to describe his objects within the category of 'stones'. Thus for example one well-known stone, *belemnites*, imitated an arrowhead, while another, *ammonis cornu*, looked like a ram's horn. Cardano had emphasised the distinction between such resemblances, which invariably characterised certain kinds of stone, and those that were fortuitous—such as the vague likenesses that can occasionally be imagined on slabs of variegated marble. For Gesner, the Aristotelian concept of specific *differentiae* had been fundamental to all his biological work, his descriptions having been based on the reality of discrete 'species' of animals. In his preliminary survey of 'fossils' he therefore applied this concept of 'species', developing the hints that Agricola and Cardano had given, and made the *form* of 'fossils' the basis of his classification. The shapes of 'fossils', he said, like those of plants, 'are (so to speak) specific, and always appear to be attached to a certain class of object as though peculiar to it'. Moreover, the 'images' shown by these objects were all the finer, he said, in that they were clearly *natural* and not, like the Hermetic hieroglyphs, carved by merely human agency.

Gesner, as eclectic in his natural philosophy as in his sources for natural history, then grouped these Aristotelian units into classes that are reminiscent of Cardano's Neoplatonic survey of the cosmos. The 'fossils' were classed according to their resemblances to objects in other realms of nature; and the classes were arranged according to the position of their analogues in the hierarchical cosmic scheme, descending through that hierarchy (as Gesner pointed out) just as the soul in the opposite direction aspires to ascend towards God. Thus he began with stones having shapes related to geometrical figures or to the Aristotelian elements, the most fundamental entities in the universe, and then descended through those resembling the heavenly bodies and those related in some way to the realm of *meteora*, to those resembling terrestrial objects. These in turn included stones with a resemblance to the works of Man himself (and, by way of parenthesis, those objects actually owing their form to human workmanship, such as cut gemstones and engraved medallions), and so finally to those resembling various kinds of plants and animals.

## VIII

With the final classes in Gesner's scheme we have at last arrived at objects which, as a glance at his woodcuts shows, fall within the modern definition of the word 'fossil'. However before considering the interpretations that sixteenth-century naturalists placed on such organic resemblances, it is worth noting that a number of fossils in the modern sense were *not* included by Gesner in his classes of objects resembling organisms. This reflects the inherent difficulties that faced any naturalist, even to the end of the following century, in perceiving organic resemblances in fossils.

In the first place, there were difficulties arising out of the modes of preservation of fossils. The existence and severity of these problems may not be apparent even to the modern palaeontologist, because he may have successfully forgotten his initial difficulties in recognising and understanding the vagaries of fossilisation. For example, it is relatively easy to recognise the organic nature of many fossil shells of geologically recent origin. They are likely to come from unconsolidated sediments, from which they can be extracted complete and in good preservation; and they are probably almost unchanged in substance, apart from the loss of their original colouring. Most fossils, however, are much more difficult to interpret. The confusing diversity of their modes of preservation can make their nature anything but obvious. Even quite ordinary fossil molluscs can be very puzzling, if for example the actual shell has been dissolved away, leaving only an empty hollow with a 'negative' cast and mould in some compact rock; or the shell itself may have been recrystallised into a sparry material quite different in appearance from the original, and with a confusing similarity to crystalline materials of purely inorganic origin.

Extinct molluscs such as ammonites (Agricola's *ammonis cornu*) can be still more puzzling, since they are generally preserved as casts in a hard rock or in crystalline calcite, or with the shell replaced by another material such as the metal-like pyrite, or as paper-thin impressions flattened on the surface of a shale (Fig. 1.7). For early naturalists such difficulties were aggravated by the fragmentary preservation of many of the commonest fossils. The organic nature of belemnites, for example, would have been easier to perceive if they had been known in more

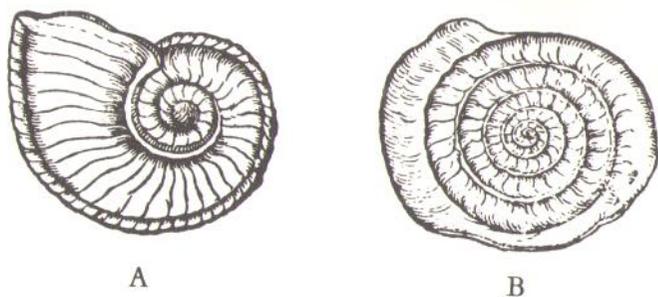


Fig. 1.7. Two woodcut illustrations of ammonites from Gesner's book (1565)<sup>1</sup>. One of them (A) he placed in the same class as various fossil shells, but the other (B) he thought was snake-like.

complete preservation: as it was, ordinary specimens preserving no more than the solid crystalline 'guard' were bound to seem closely similar to stalactites and other inorganic objects of comparable structure (Fig. 1.8, A). Likewise, complete specimens of fossil crinoids ('sea-lilies') are obviously organic in appearance, even if they look deceptively plant-like; but until such relatively rare specimens were discovered, the far more common fossils representing isolated pieces of their stems or single stem-ossicles were naturally very difficult to interpret (Fig. 1.8, B, C). Indeed this difficulty was greatly increased by their mode of preservation, for their normal calcite cleavage gave them a crystalline and therefore suspiciously inorganic appearance.

Conversely, where there *was* an obvious similarity in form between a fossil and some living organism it might be—in modern terms—purely fortuitous. One flint nodule, for example, might resemble a human foot just as closely as another resembled a sea-urchin: both objects would be reminiscent of an organic structure, without having an exact identity. We today may be sure that the resemblance is fortuitous in the first case and causally significant in the second, but without a clear understanding of the processes of fossilisation that conclusion would be far from obvious.

A second source of difficulty in perceiving organic resemblances in fossils arose out of the unfamiliarity of the organisms from which many fossils had originated. Here again the difficulty was minimal for some geologically recent fossils, for these were often closely similar to, if not identical with, living species. For many of the commonest fossils,

Belemnitæ icones hîc positas, secundum numeros deinceps enarrabimus.



Fig. 1.8. Gesner's woodcut illustrations (1565)<sup>1</sup> of belemnites (A) and crinoid ossicles (B, C); he knew no comparable living animals.

however, the difficulties of interpretation were aggravated by the fact that they belonged to almost or totally extinct groups. Belemnites, ammonites and crinoids are all good examples of this. Belemnites, being completely extinct, had no close living analogues whatever (their closest common relatives, the cuttle-fish, have no obvious similarity); living cephalopods with chambered shells like those of ammonites were not known until the seventeenth century; and living stalked crinoids were not discovered until the middle of the eighteenth. The perception of organic resemblance in a given fossil was therefore dependent, in part, on the contemporary state of biological knowledge of its living analogues.

The effect of these difficulties can be illustrated particularly clearly from Gesner's work, because we can gauge accurately from his *History of Animals* just how many living animals he was familiar with, and we can compare these with the fossil specimens illustrated in his work *On Fossil Objects*. Like many of his predecessors he was clearly aware of the organic similarities of fossil wood and fossil bones and teeth, and he placed these objects in chapters devoted, respectively, to objects

resembling trees or parts of trees, and to objects resembling parts of quadrupeds. Most of Gesner's objects that are fossils in the modern sense are the remains of marine animals, and can be compared with what he had described only seven years earlier in his volume *On the nature of Fishes and aquatic Animals*.

This was the most comprehensive work on aquatic animals ever to have been compiled. Gesner had been able to build on the firm foundations of Aristotle's excellent work on marine biology; he had drawn on the recently published works of the French naturalists Guillaume Rondelet (1507-1566) and Pierre Belon (1517-1564)<sup>36</sup>; he had received drawings and specimens from correspondents all over Europe; and he had spent some time in Venice studying at first hand the animals brought to the fish-market. Few naturalists in the sixteenth century had a wider knowledge of marine biology than Gesner, or were in a better position to recognise the organic resemblances of a wide range of common fossils.

It is therefore not surprising that Gesner included in his chapter *On Stones resembling aquatic Animals* a fair number of objects that we would regard as correctly placed in that category. For example he had one of the fossil fish from the Permian Kupferschiefe of Eisleben in Saxony: it was a complete specimen and was obviously fish-like, although it was flattened on the shale surface and preserved curiously 'with coppery scales'. He also recognised that the objects traditionally termed *glossopetrae* or 'tongue-stones' resembled the teeth of sharks and dogfish, although they were much larger: indeed he had illustrated and commented on this resemblance when describing sharks in his biological volume (Fig. 1.9). Various mollusc shells, of both gastropods and bivalves, likewise gave him no trouble, for he was familiar with a wide variety of living molluscs; and he saw the clear resemblance between one of his fossil specimens and a crab that Rondelet had described (Fig. 1.1).

Many of his specimens, however, were more difficult to interpret. Rather surprisingly, he successfully recognised that a flint cast of an echinoid resembled one of his living sea-urchins stripped of its spines and shell (Fig. 1.10 A, C): a remarkable triumph over the difficulties of fossilisation. On the other hand all the sea-urchins he was familiar with were kinds with small fine spines (Fig. 1.10 B), and he therefore failed to recognise the fossil remains of cidaroids with very large club-shaped spines. These spines (Fig. 1.10 F), which are usually

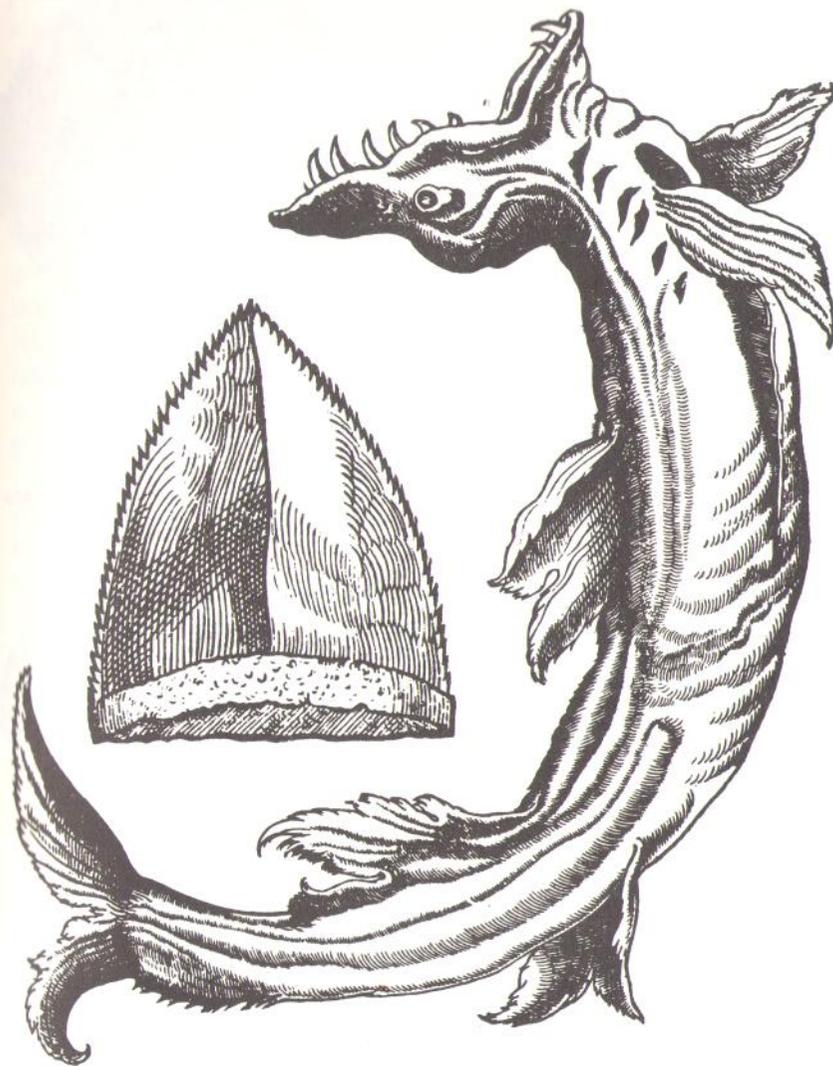
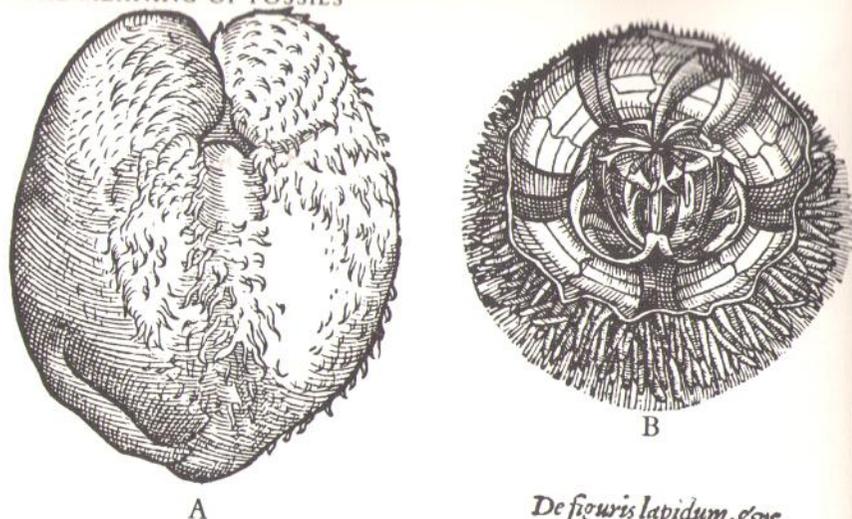


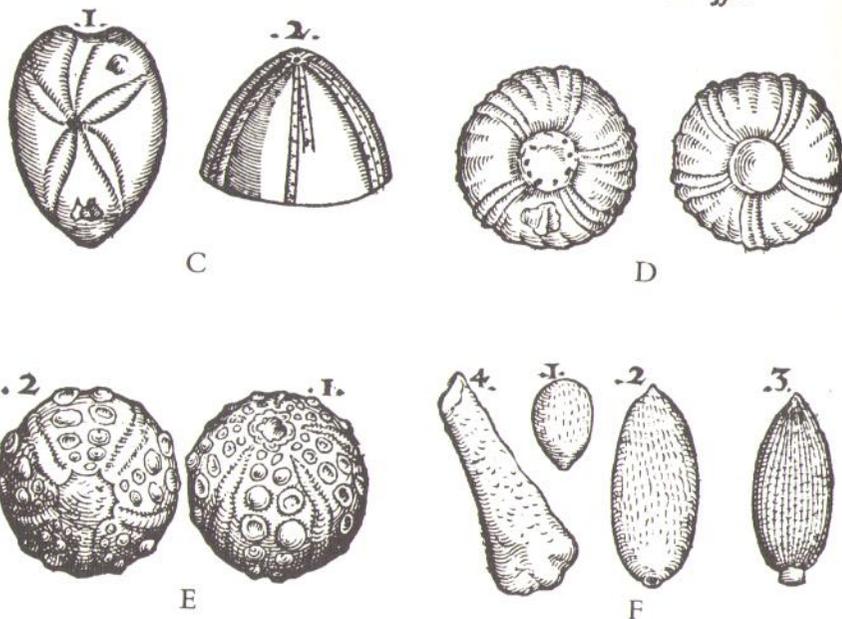
Fig. 1.9. Conrad Gesner's illustrations (1558)<sup>15</sup> of a *Glossopetra* (inset), and of the shark whose teeth it resembled. This is probably the earliest Western illustration of a fossil described in relation to a living animal.



A

B

*De figuris lapidum, &c.  
Ombriorum species à Ioanne Kent-  
mano ad me missa.*



C

D

E

F

Fig. 1.10. Gesner's woodcut illustrations (1558, 1565) of two species of living sea-urchins (A, B) and of three fossil echinoids (C, D, E) and their detached spines (F)<sup>1, 15</sup>. He recognised a similarity between A and C, but the cidaroids D-F were unlike the 'regular' echinoids he knew alive (B: note the fine spines; the complex jaw-apparatus or 'Aristotle's lantern' has been exposed by dissection).

preserved detached from the shell, were commonly considered to be acorn-like or fruit-like in shape, and Gesner placed them in the same chapter as his fossil wood; while for the tuberculated shells (Fig. 1.10 E) he fell back on a traditional notion that they were 'serpents' eggs', and assigned them to the chapter *On Stones which resemble Serpents and Insects*. In that chapter he also placed a loosely-spiralled ammonite, on account of its traditional interpretation as a coiled snake; whereas he noticed that a more tightly spiralled ammonite resembled ordinary gastropod shells (Fig. 1.7). Considering the difficulties already mentioned, it is hardly surprising that he saw no organic resemblance whatever in belemnite guards or crinoid ossicles: the dart-like belemnites and some wheel-like ossicles were assigned to the class of objects resembling human artefacts, while some star-shaped ossicles were placed in the class resembling heavenly bodies (Fig. 1.8).

In Gesner's work, then, we can see that even for one of the most competent naturalists of his age, with a remarkably wide and detailed knowledge of living animals and plants, the perception of resemblances between fossils and living organisms was far from straightforward. The fossil material in this collection was such that the resemblances he saw ranged from the obvious to the obscure. In terms of a spectrum it could not be simple to draw a line separating objects with such resemblances from those without.

## IX

Gesner refrained from any explicit discussion of the causal origin of his 'fossils', partly because his book was only a preliminary survey of the subject. It may be that he suspected that some of his objects had organic resemblances simply because they were the genuine remains of organisms. His treatment of *glossopetrae* in the context of a description of living sharks suggests that he may have believed they were true sharks' teeth, and he may have come to a similar conclusion about some of his fossil shells, bones and wood. However this is likely to have seemed to him to be an explanation of peripheral interest and significance. For the whole framework of his classification shows that the central problem was that of resemblances of *any* kind. Why should many stones be formed in distinctive shapes at all, and why should so many of these shapes be reminiscent, not only of organisms, but of other entities in the universe?

Since Gesner was sufficiently sympathetic with Neoplatonic thought to mould his classification of 'fossils' around it, he probably found it congenial enough to regard many (if not all) of the resemblances he perceived as the manifestations of the hidden bonds of analogy and correspondence that linked the cosmos into a unity. Possibly he regarded some of the resemblances as merely fortuitous, and the resultant assignments to his classes as no more than convenient aids to identification. But it is much more likely, since he said his scheme 'followed the very steps and arrangement of nature', that he believed the resemblances were significant. Even a *trochite* (a circular crinoid ossicle—see Fig. 1.8, B) could resemble a man-made wheel, on this view, because both embodied in their different spheres the same supra-material Platonic *idea*. Likewise an *astroite* (a pentagonal crinoid ossicle—see Fig. 1.8, C) could be star-shaped because it owed its form to Hermetic stellar influence. Within the framework of Hermetic Neoplatonism none of the resemblances that Gesner noted had to be regarded as fortuitous. So also the stones that resembled animals and plants could owe those resemblances to their bonds of affinity with various organisms, and not to their origin as the remains of those organisms.

In this way the Neoplatonic thought of the sixteenth century made the modern interpretation of fossils less persuasive than it might otherwise have been, simply because it provided an alternative explanation of the resemblances between some 'fossil objects' and living organisms. There were inherent difficulties, as we have seen, in recognising such resemblances at all; but even when they were recognised, it did not seem to follow that those fossils must have been the remains of once-living organisms. That may seem to us to be an obvious inference to make, but to sixteenth-century naturalists it was far from convincing. Owing to the puzzles inherent in their material, most of the organic resemblances they could perceive at all seemed far from perfect, and it is not surprising that they often referred to them merely as 'images' (*imagines*) or 'pictures' (*icones*). If the cosmos was indeed a web of hidden affinities, it would be natural that many 'fossils' should imitate the forms of other entities. As for the causal origin of these forms, that could be attributed to the action of the same 'moulding force' (*vis plastica*) that governed the growth of living organisms, operating instead within the Earth.

Yet even where the natural philosophy of Neoplatonism was rejected or modified, the modern interpretation of the organic resemblances

of fossils was still not persuasive. The reformed and purified Aristotelianism associated especially with the University of Padua was responsible for much fine biological research in the century that stretches from Vesalius's work to William Harvey's training there. On the problem of fossils, however, this Aristotelian thought, like the Neoplatonism it often opposed, had an interpretation of organic resemblances that seemed quite as persuasive as the modern explanation. Between living and non-living a sharper line was drawn than in Neoplatonic thought, and even the simplest organisms possessed a 'vegetative spirit' (*anima vegetativa*) that was manifest in their basic vital activities. However, it did not seem inconceivable that some at least of these activities could occur within the Earth. Simpler organisms were believed to be formed, at least on occasion, by 'spontaneous generation' (*generatio aequivoca*) from non-living material, and so their characteristic specific forms might be able to develop not only on the Earth's surface or in the sea, but also within the Earth, growing in this case from the 'stony' materials available there. More complex organisms might also be able to grow within the Earth, if their characteristic 'seed', holding their potential specific form, happened to penetrate there in percolating ground-water. For example, if the specific 'seed' of a fish were washed into the ground it might be able to grow from 'stony' material and generate a fish-like fossil in the rock. Such a fossil would have grown by a process directly comparable to the growth of a living fish, and it would owe its specific (say) perch-like form to an identical formative 'seed', but its matter would be different and it would *not* be the remains of a fish that had once been alive. It was plausible to explain in this way even those fossils that resembled marine organisms, since it was generally believed (mainly from observation of copious perennial springs) that there must be a direct subterranean circulation from the oceans, by which the 'seeds' of marine organisms could have been lodged in the Earth.

Thus in both Neoplatonic and Aristotelian terms it seemed rationally intelligible that among the whole range of 'fossils' there should be some with forms resembling living organisms. These might be produced by a moulding force that manifested the network of hidden affinities within the universe; or they might be generated by a process similar, in a limited way, to the generation of living organisms. In neither case, however, was it necessary to invoke the hypothesis that they were actually the remains of once-living animals and plants.

## X

Both Aristotelianism and Neoplatonism thus provided satisfying interpretations of organic resemblances, and particularly of the fact that they varied from the obvious to the obscure. There was, however, a further reason why the modern explanation of these resemblances remained a hypothesis of peripheral importance to sixteenth-century naturalists. Even where the resemblances were most obvious—where the objects were at the ‘easiest’ end of the spectrum—there was a serious difficulty about accepting them as genuinely organic in origin. To make this inference involved accounting also for the changes in physical geography that were implied by the *position* in which the fossils were found.

This difficulty was minimal, once more, for geologically recent marine fossils, since these are commonly found in unconsolidated sediments on low ground and often close to the sea. It was fairly easy to conceive how changes in geography could have displaced land and sea and brought such fossils to the positions in which they were found. Ancient harbours were known to have been left miles inland by silting, and earthquakes were known to have occasionally the same effect. But for most of the commonest kinds of fossils such an explanation stretched the sober imagination too far, for they were often found on the tops of hills far from the sea. To assert that they were organic in origin therefore involved a belief in geographical changes far more radical than those for which there was good historical evidence. Moreover, many of these fossils were found embedded in solid rocks, which had no obvious resemblance to loose sediments; and it was therefore far from clear how the fossils, even if organic, could have got *inside* the rock.

There were two alternative solutions to this problem, if the fossils being discussed resembled living marine animals so closely that their organic origin seemed unavoidable. The first solution was to argue that they owed their position on hilltops to the action of Noah’s Flood, which had risen high enough to cover even the highest hills. Tertullian and other patristic authors had used the existence of marine shells on hilltops as an argument for the universality of the Flood, in order to confute those contemporary pagan writers who asserted that the Flood

had been a merely local inundation. This became a standard explanation in mediaeval writing. It always required some degree of flexibility in textual interpretation, since the Flood recorded in Genesis, if taken literally, had hardly been long enough for marine organisms to have migrated to the flooded areas, nor violent enough to have swept their shells up to the positions in which they were found. The literal meaning of Scripture, however, was the least important of the varied methods of exegesis that were sanctioned by the authority of Origen, Jerome and Augustine, and literalism was no essential ingredient of orthodoxy.

The literal meaning, however, while less edifying than allegorical interpretations, was the necessary foundation for them; and the efforts of Renaissance humanist scholars to recover the pure original text of Scripture, reinforced by the Protestant emphasis on its centrality for faith, focussed attention more closely on the plain meaning of narratives like that of Noah’s Flood. To understand such passages correctly, commentators turned increasingly to the best secular knowledge of their day for aid and enlightenment. But this only heightened the problems they found they faced<sup>37</sup>. Not only did the increased range of biological knowledge pose problems about the recorded dimensions of the Ark, but more seriously a literally universal Flood required the production and subsequent disappearance of a huge volume of water. This could be explained, it was true, simply by attributing it to a miracle, but for many writers this seemed an unsatisfactory solution, for it placed the event outside the realm of natural law. Moreover, even if the water problem could be solved, a literally interpreted Flood would still be unsatisfactory as an explanation of marine fossils on hilltops.

The only alternative was to turn the patristic arguments upside down, and argue that pagan flood traditions were merely imperfect records of the Flood recorded in Genesis; that Deucalion for example was none other than Noah himself; and that the purpose of the Flood would have been adequately fulfilled if it was confined to the small areas then inhabited by Man. Although this solution raised further problems, such as why the building of an Ark had been necessary at all, it had the great virtue, in sixteenth-century eyes, of reconciling the Flood narrative to the natural philosophy of Aristotle. Noah’s Flood became merely one of many local inundations that were natural to the globe. Aristotle’s work *On Meteorology*, more geological in content than its title suggests, had outlined the continuous and generally gradual action of erosion and silting, which in the course of time could readily produce even major

changes in physical geography. This was however integrated into Aristotle's eternalistic cosmos: "it is clear", he had concluded, "that as time is infinite and the universe eternal, that neither Tanais nor Nile always flowed . . . for their action has an end whereas time has none."<sup>38</sup> Aristotle's eternalism was no stumbling-block to Christian thinkers merely on account of its extended time-scale, for a metaphorical exegesis of the 'days' of creation had been acceptable at least since the time of Augustine; but it did threaten the Christian doctrine of the createdness of the universe, by seeming to imply that God could not be fully transcendent over his creation.

The renewed interest in the literal exegesis of Scripture tended in the sixteenth century to heighten the problems of accepting an Aristotelian concept of the Earth's past history, because the calculations of historians and chronologers proceeded increasingly on the assumption that all the time-intervals used in Scripture, like those in secular chronicles, were strictly literal in connotation. Occasionally, however, it was possible to accept an Aristotelian picture of an ever-changing world of indefinite duration, for the purposes of natural philosophy, while at the same time to reject the metaphysical and theological implications of Aristotelian eternalism. This kind of compromise was encouraged particularly by the organisation of teaching at Padua, at which Aristotle's work was studied within a faculty of Arts and in a context primarily of medical education, and not within a faculty of Theology. Thus among natural philosophers and naturalists influenced by the Paduan tradition, if not among biblical commentators, it was not uncommon to accept an Aristotelian view of the ever-changing geography of the globe, with occasional local inundations of purely natural causation, of which the scriptural Flood had been but one. On this view, there might seem to be no problem at all about accepting the organic origin of fossils found on hilltops or even those embedded in layers of sediment. In practice however, this was not so straightforward, since it was difficult to *imagine* the radical changes in geography that were demanded by this explanation.

## XI

Seen in retrospect, a modern interpretation of the organic resemblances of fossils was thus delayed by the lack of any satisfactory explanation of geographical change. At the same time its acceptance was also made less pressing, as we have seen, by the existence of two alternative interpretations of why some 'fossils' should resemble animals and plants. These alternatives seemed far more plausible as explanations of most of the commonest kinds of 'fossils'. Only those at the 'easiest' end of the spectrum resembled living organisms closely enough for the modern interpretation to be at all persuasive.

It is therefore not surprising that most of the early writers who have often been portrayed as championing a 'correct' interpretation of fossils are those who were referring to the 'easiest' kinds of fossils. These were generally the shells of marine molluscs of geologically recent date. Such fossils were well preserved; they belonged to extant groups and often even extant species; and they were usually found in unconsolidated sediments on low ground near the sea. The problems of matter, of form and of position were thus minimal. Isolated comments on the organic origin of fossils can be found in many writers back into classical Antiquity, but whenever localities are mentioned it is clear that they were referring to these fossils at the 'easiest' end of the spectrum. Even the earliest such writer, Xenophanes of Colophon (6th century B.C.), is said to have mentioned Malta and Syracuse, both of which are localities in which finely preserved Cainozoic mollusc shells can be collected in abundance.

Likewise it is well known that Leonardo da Vinci (1452-1519), more than half a century before Gesner wrote his book on 'fossils', recorded in his unpublished notebooks his reasons for believing that fossil shells were organic in origin.<sup>39</sup> His comments however, show that he was referring chiefly to fossils from the Cainozoic strata of northern Italy, which contain an abundance of beautifully preserved shells similar in general appearance to the shells of molluscs now living in the Mediterranean. Leonardo's notes certainly show much acute observation of living molluscs and their ecology, and of the processes of sedimentation. He recognised that the similarities between the fossils and living molluscs were so precise that a causal explanation was almost inescapable. He

noticed that the fossil shells were similar not only in general form but also in many incidental features: for example they were preserved in various growth stages, and sometimes with other organisms adherent on them or bored into them. The occurrence of these fossils *within* a sediment was also no problem to him, since he understood enough of the process of silting and sedimentation to recognise the meaning of strata, and was able to account for their consolidation in terms of a process of 'drying out'.

This strikingly 'modern' interpretation, however, was relatively easy for Leonardo to make, not only because he was dealing with some of the 'easiest' kinds of fossils, but also because he had what he believed to be a satisfactory explanation of the geographical changes that his conclusion entailed. He was able to borrow from the mediaeval Aristotelian Albertus Magnus an explanation of how major interchanges of land and sea could have occurred without affecting the essential stability of the globe. Although he rejected the theory of spontaneous generation as an explanation of his fossils, Leonardo was favourably disposed in general towards the idea of stellar influences, and might indeed be regarded more truly as a Hermetic 'magician' than as a premature modern man of science. He also attacked the use of the Flood as an explanation of fossils, but this was not, as an earlier historical tradition supposed, an assault by an enlightened scientist on the prejudices of religious bigots. Leonardo was specifically attacking "ignoramuses", that is to say the unlearned; his essential motive was not to attack Christian orthodoxy but to defend the Aristotelian belief in the rational causality of natural events, which was difficult to apply to a literally interpreted Flood.

The same motive can be seen in the work of the Aristotelian physician Girolamo Fracastoro (1478?-1553). In order to explain 'action at a distance', such as magnetic attraction and infectious disease, without using the 'occult' Neoplatonic concepts of sympathy and antipathy, Fracastoro developed an earlier suggestion that *effluvia* or *seminaria* were being released continuously by such bodies as a lodestone or a diseased person (this has a spurious similarity to the much later germ theory of disease). However vague this explanation might seem, it had the virtue of bringing these otherwise mysterious phenomena within the scope of Aristotelian natural law. In 1517 fossil shells and crabs were discovered in foundations at Verona, and Fracastoro is said to have asserted that they were the true remains of shellfish, and to have ridiculed suggestions

that they were due either to the Flood or to a moulding force within the Earth<sup>40</sup>. These comments show the same motives as the work for which he is more famous. To interpret the fossils as organic remains, and to attribute their emplacement to the ever-changing positions of land and sea, avoided *both* the miraculous overtones of the vulgar belief in a universal Flood, *and* the occult implications of the Neoplatonic explanation: the fossils were thus explicable in terms of natural law. From Fracastoro's Aristotelian point of view however, spontaneous generation was equally acceptable as an explanation, and in fact he is said to have used this for the interpretation of some more 'difficult' fossils.

Even for an Aristotelian, then, the organic explanation was not obligatory for all fossils. Falloppio, for example, as one of the great line of Paduan anatomists, would have been well aware of organic resemblances in whatever fossils he was familiar with; yet he felt that their occurrence on hilltops far from the sea made their organic origin unacceptable. It would have entailed changes in geography that were literally incredible, even with an Aristotelian view of continuous terrestrial change; and an explanation in terms of spontaneous generation therefore seemed preferable.

For Neoplatonists too, the acceptance of an organic origin for some of the 'easier' fossils did not entail the same explanation for more 'difficult' specimens. Thus Cardano repeated arguments similar to Leonardo's—just possibly by knowledge of the unpublished notebooks—and clearly believed that some fossil shells betrayed changes in the position of land and sea<sup>41</sup>. He did not however ascribe these changes to a single Flood, for he believed there had been many local inundations. Yet most of the fossils he described were attributed in Neoplatonic terms to the action of a moulding force, and Cardano believed that their characteristic forms possessed some Hermetic power.

It is interesting to see how Cardano's organic interpretation of his 'easier' fossils could be misconstrued by a reader who was unfamiliar with its Aristotelian background. Palissy misread Cardano (in a French translation) and assumed that he had attributed these fossils to a universal Flood. Palissy himself wished to assert the organic explanation, for he was well aware of the similarities between many fossil shells and living shellfish, and at the same time found other explanations of those similarities unacceptable. Yet he rejected the vulgar notion of a universal Flood as inadequate to explain the widespread occurrence of the

fossils far above the present sea-level<sup>42</sup>. He was therefore in a dilemma which he was only able to resolve by arguing that the inland fossil shells, although truly organic, were not marine but freshwater in origin. But this solution then faced him with a further problem, since many of the fossils clearly resembled marine species, and furthermore he knew that they were much more diverse than the restricted range of living freshwater animals. Palissy could only meet this problem by suggesting awkwardly that some of the former inland lakes, in which the fossil shells had originated, had been rather salty and therefore able to support species of marine aspect, and that some of the more edible species had long since disappeared through over-fishing. This somewhat tortuous reasoning is a good illustration of the difficulties that any sixteenth-century naturalist faced in asserting the organic origin of fossils. On the other hand, the petrified substance of some of his fossils, and the solidity of the enclosing rocks, was no problem to Palissy, since he believed that percolating 'salts' could have affected this change with great rapidity.

Colonna may be taken as a final example of naturalists who asserted the organic origin of some fossils. His *Observations on some aquatic and terrestrial Animals* (1616) are important in more than one respect<sup>43</sup>. While many earlier naturalists, and supremely Gesner, had been familiar with a wide range of living organisms, they described their fossils, as we have seen, within an essentially mineralogical context. Colonna, on the other hand, was one of the first to place them instead in a primarily biological context, and to describe them alongside whatever living organisms they resembled (Fig. 1.11). This did not necessarily lead to an acceptance of their organic origin, and several excellent naturalists later in the seventeenth century continued to have well-founded doubts on this point. But it did serve to focus attention more closely on the precise nature of the resemblances; and it is no accident that, from Colonna onwards, most of those who did argue for the organic origin of fossils were primarily biologists. Colonna also applied the same precise nomenclature to his fossils as to his living animals, distinguishing different kinds of related fossils with more accuracy than ever before. He also grasped the relation between shells and the casts or moulds that they left in the fossil state, and thereby overcame the inherent problems of 'matter' sufficiently to recognise a wide range of fossils as organic in origin. In particular, he wrote a special essay on 'tongue-stones' (*glossopetrae*), arguing that they were the true teeth of

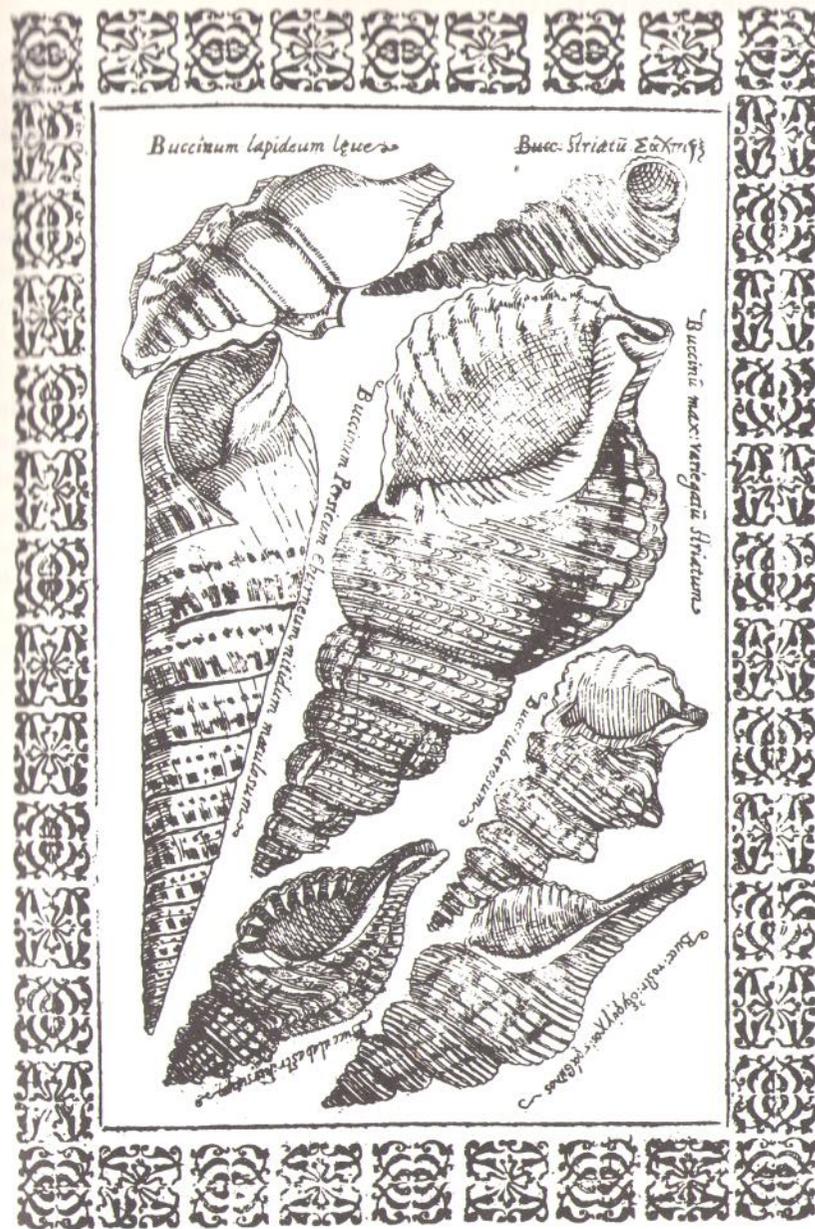


Fig. 1.11. One of Fabio Colonna's plates of copper engravings (1616)<sup>9</sup>. Note the careful differentiation of several living species of whelk shells ('Buccinum'), and the inclusion of a fossil specimen (top left) within the same scheme and on the same plate. This is one of the earliest uses of copper engraving for the illustration of fossils: note the economical use of the space available.

sharks, and he pointed out that they often occurred with the shells of oysters and other marine molluscs<sup>44</sup>. These conclusions, however, still faced him, as they faced any other naturalist, with the problem of the position in which the fossils were found; and although many of Colonna's fossils came from the hills of Puglia and were embedded in solid strata, he saw no alternative but to attribute them to the Flood.

## XII

Judged from the standpoint of modern palaeontology it might seem that this analysis of sixteenth-century studies on fossils is a story of failure. It is true that Gesner's work incorporated important innovations for the future development of the *activity* of a science of palaeontology, yet neither he nor his contemporaries made more than marginal progress towards recognising the organic origin of the fossils with which they were familiar.

It is questionable, however, whether we *should* make such judgements. From a historical point of view such apparent 'failures' may be more revealing than the more obvious 'success stories' of science. The 'failure' of a fine naturalist like Gesner to arrive at a clear conclusion about the origin of fossils, despite his wide knowledge of living animals and plants, may tell us more about the world of sixteenth-century science than the isolated 'correct' remarks about fossils that were so assiduously collected in an earlier historical tradition. We have seen that the problem of fossils was not a simple one of deciding on their organic origin, but a complex matter of discriminating the organic from the inorganic within a continuous spectrum of 'fossil objects'. There were limitations, inherent in the nature of the material available and in the state of biological knowledge, on the range of objects in which organic resemblances were likely to be seen. However, even when such resemblances could be seen, there was the further problem of the position in which many fossils were found; and in the absence of satisfactory explanations of geographical change this was liable to rule out an organic interpretation. In general, therefore, the modern interpretation was only applied in cases where the problems of matter, of form and of position were all minimal; and this inevitably restricted the applicability of the organic explanation to a small proportion of all the fossils that were known.

Beyond all these difficulties lay a more serious intellectual problem. Even when resemblances between fossils and living organisms could be clearly perceived, it did not seem to follow necessarily that the fossils were actually the remains of living organisms. This inference, so obvious to us today, was not avoided in the sixteenth century for reasons of intellectual conservatism or out of any sense of conflict with religious orthodoxy. It was usually ignored or rejected on the far more positive grounds that it was not a necessary inference within *either* of the two dominant—and 'progressive'!—intellectual frameworks of the time. Both the renewed Aristotelianism and the synthetic Neoplatonism of the sixteenth century can be seen in retrospect to have contributed much to the later development of 'modern science'; but on the question of fossils both of these natural philosophies provided the phenomenon of organic resemblance with explanations that were quite as persuasive, indeed more so, than the hypothesis of organic origin. Aristotelians could attribute organic resemblances to the growth *in situ* of objects combining the form of genuine organisms with the stony matter appropriate to all 'fossils'; objects for which the causal explanation lay in spontaneous generation or the implantation of specific 'seeds' within the Earth. Neoplatonists could attribute the same resemblances to the action of a pervasive moulding force or 'plastic virtue', which made visible the hidden web of affinities that bound all parts of the cosmos into one. In either case, the explanations successfully accounted for the fact that the resemblances varied from the striking to the barely perceptible, and they were therefore more widely applicable and more 'successful' than the hypothesis of organic origin.

With such powerful alternatives available, no single observation or specimen, however striking, could be decisive in favour of a wide-ranging theory of the organic origin of fossils. It might erode the edge of the established interpretations, by detaching certain objects and transferring them to the category of those for which an organic origin was acceptable; but it could scarcely undermine the explanatory power of the alternatives in accounting for the majority of 'fossil objects'. The organic explanation could not be extended to a broader range of objects until after the credibility of the alternative interpretations of organic resemblance had broken down; but that in turn required changes in the dominant philosophies of nature, extending far beyond the problem of fossils.

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## Chapter Two

## Natural Antiquities

## I

ONE day in October 1666, some fishermen brought a huge shark ashore near Livorno. It was one of those occasional chance events that have far-reaching consequences for the history of science. Falling, as it were, on intellectually prepared ground, it had a striking catalytic effect: it led to the dissolution of the stable situation described in the last chapter, and to the introduction of a new dimension into the debate about fossils.

The shark was landed within the realms of the Grand Duke of Tuscany, Ferdinand II, who, as a generous patron of the sciences, ordered its head to be taken to Florence to be dissected by the anatomist Niels Stensen (1638–1686)<sup>1</sup>. Stensen, who is better known by his literary name Stenonis (anglicised to Steno), had left his native Copenhagen in 1660 to pursue his medical studies at Leiden, which by this period had won the pre-eminence as a medical centre that Padua had had in the previous century. Because no university post was available for him in Denmark, Steno had then moved on, working briefly at Paris and Montpellier, and had arrived in Florence in 1665—exactly a century after Gesner's death. The quality of his anatomical work had already been recognised, and he was appointed by Duke Ferdinand to a hospital post that provided him with a living and allowed him ample time for research. He was also elected to the Experimental Academy (*Accademia del Cimento*), which had been founded at Florence by the Duke's brother, Leopold de' Medici, with ideals similar to those of the earlier Academy of the Lynxes at Rome. More specifically, the Experimental Academy sought to perpetuate and extend the experimental and mathematical