fossils up into the chalk country, he had recognized at least part of the stratigraphic column that was later mapped by William Smith.

Whitehurst’s attainments
In the Inquiry, Whitehurst used observation and applied the laws of nature to deduce several basic principles of geology:

1 The Earth had a history of development from a chaotic fluid state to one of regular order.
2 This history was deduced from observations which led to recognition of the principle of superposition.
3 A regular sequence of strata had economic implications – i.e., prediction of what might occur elsewhere.
4 Coal originated from ancient vegetation, whilst limestone contained marine shells.
5 Volcanic activity had occurred just as much, or even more, in the past as in recent historical times.
6 Certain strata were distinguishable by their fossil contents.
7 The sequence of Carboniferous strata around Matlock could be recognized elsewhere.
8 ‘Convulsions’ explained the contorted strata of mountainous regions.
9 The disposition of strata could be illustrated by means of sections.
10 The Coal Measure fossil Carbonicola could be compared with the modern freshwater mussel Unio.
11 The abundant fossil stems in the Derbyshire limestones were equivalent to the crinoids recently found in the Caribbean.
12 Heat affected the rocks beneath an intrusion – i.e., contact metamorphism.

Although uncertain about the mechanisms involved, Whitehurst argued for the phenomenon of igneous intrusion as well as extrusion. He recognized that mineralization led to veins cutting limestones; and he knew something of the nature of faulting, even if confused by the alleged gulfs under the River Derwent. With the lack of any Whitehurst archives or of records of the Lunar Society it is difficult to say how much of his ideas came from discussions with others, and similarly difficult to say to what extent he influenced the ideas of his successors, although White Watson and Farey both followed his Matlock stratigraphy. From the few records that survive, it seems that an outline of the Inquiry was already in his mind by 1763, 15 years before publication, and he had expanded his ideas as a result of Ferber’s visit in 1769. Even then it took another nine years before it was completed. If Whitehurst had not been distracted by his clock-making business and later his duties as Stamper of the Money Weights, he might have left us a legacy of the basis of geological science a few years before the recognized ‘giants’ James Hutton and William Smith.

Suggestions for further reading

Topics
Squeezing the fossil record: unravelling the evolution of stalked crinoids in the Caribbean

The fossil record has often been tainted by the label of ‘incomplete’, but such an insignia might be attached to our knowledge of any of the natural sciences.

What is relevant is not whether the fossil record is complete but, rather, is it adequate to answer questions regarding the history of life? Available evidence...
overwhelmingly indicates that it is. However, an ‘adequate’ fossil record may nevertheless present problems of interpretation. Many organisms have a multicomponent skeleton that disarticulates into its component parts, partly during life in some groups (e.g. arthropods, vascular plants), but completely in all such organisms following death (e.g. vertebrates).

Thus an oak tree may generate very numerous leaves, flowers, pollen and acorns during life, but most of its woody tissues – roots, trunk, branches and twigs – only become available for fossilization after death. An analogous situation among animals is the numerous moult stages in the life cycles of arthropods.

Other groups contribute most of their skeletal elements to the fossil record after death, such as chitons, the vertebrates and – the subject of this article – the echinoderms. Most of the fragmentary remains of organisms with multicomponent skeletons are small or minute, and the SEM is now used routinely to observe, interpret and illustrate their features, from fossil pollen and spores through the juvenile moult stages of extinct arthropods to rodent teeth. Our interpretations of Caribbean fossil echinoderms, including the results discussed herein, have relied heavily on the Philips XL30 scanning electron microscope at the University of Liverpool, which has enabled examination of both the gross morphological features (Fig. 1) and, where apparent, the stereom microstructure (e.g. Fig. 1c), providing exquisite images for systematic descriptions and comparison between localities.

In modern seas there are five groups of echinoderm – the echinoids (sea urchins), holothurians (sea cucumbers), asteroids (starfishes), ophiuroids (brittlestars) and crinoids (unstalked feather stars and stalked sea lilies). The last of these, the stalked sea lilies, are an ancient group of sessile, articulated, filter-feeding invertebrates that formed a prominent component of the marine benthos during the Palaeozoic (about 540–250 million years ago). However, the sea lilies almost disappeared in the mass extinction at the end of the Permian (250 million years ago) and subsequently failed to return to their former abundance and diversity. Further, during the past 100 million years or so they have disappeared from shallow-water environments as certain major groups of predators have increased in numbers and diversity.

This historic pattern has two major implications for the post-Palaeozoic fossil record of sea lilies. Their diversity was greatly reduced from its peak in the Palaeozoic, so they are relatively uncommon fossils in the post-Palaeozoic fossil record. Further, by vacating shallow-water environments, they are limited to sedimentary rocks deposited in deeper water, which are not as commonly exposed subaerially as those laid down in shallow-marine settings. The simple reason for this is that for deep-water sedimentary rocks to be exposed at the modern surface of the land, they have to be uplifted by considerable tectonic forces that only act in certain areas of the globe. One such place is the Caribbean. Approximately coeval sedimentary deposits exposed on three widely separated Caribbean islands, each formed in rather different palaeoenvironmental and tectonic settings, have now yielded faunas of disarticulated sea-lily plates (called ossicles). This is the first time that fossil crinoids have been found from a restricted time interval on more than one Antillean island, and enables authoritative comment to be made on their distribution and evolution for the first time. As Cenozoic fossil crinoids have a very patchy fossil record globally, these results are of more than just local interest.

The Miocene Antillean crinoids

Deep-water deposits containing sea lilies in the Lower and Middle Miocene (about 23.5–11 million years old) of the Antilles are known from Jamaica in the west and Barbados and the tiny Grenadine island of Carriacou in the east. The Jamaican deposits (Lower Miocene), exposed in a disused quarry near the north coast, are chalks that were laid down in at least 500 m of water, based on evidence provided by the enclosed fossil fishes. Crinoid remains have proved to be particularly rare and less than 10 ossicles have been found in 15 years of collecting.

In Barbados, the Lower Miocene crinoid-bearing beds form part of the accretionary prism – i.e. the wedge of sediment (mainly muds, silts and sands) several kilometres thick that has been scraped off of the South Atlantic tectonic plate as it has been subducted beneath the Caribbean tectonic plate. These sedimentary rocks were probably deposited at a water depth measurable in kilometres. Crinoid ossicles have been found as rare specimens in the collections of the Naturhistorisches Museum Basel, picked from samples taken from sections that are no longer exposed.

In Carriacou, the crinoid deposits are sedimentary rocks at the base of a sequence derived from volcaniclastic deposits that have been washed into deep water from around the ancient volcanoes that formed the island. Deposition occurred in at least 150–200 m, based on the evidence provided by a variety of deep-water fossils, including isocrinid crinoids (see below). Unlike Jamaica and Barbados, the crinoid-bearing deposits on Carriacou contain a huge abundance of ossicles and are readily accessible, although diversity is limited to only four species.

Thus Antillean Miocene crinoids are known in deposits representing environments as disparate as deep-water chalks, bathyal or abyssal muds and the submarine slopes of an extinct volcano. Although these environments were obviously very different, the
Although based on somewhat minimal material, it appears that, like the closely related echinoids, the modern crinoid fauna of the Antilles probably arose after a pattern of extinctions during the Eocene–Oligocene transition.

It is also notable that this is more than just a local model. Jamaica is separated from Barbados and Carriacou by about a thousand kilometres. Thus not

The common species belong to a group called the isocrinids which have distinctive columnals with a stellate arrangement of the features of the articular facet. One Miocene isocrinid species is common to Jamaica, Barbados and Carriacou. Neocrinus decorus (Wyville Thomson) (Fig. 1a–c) is still extant within the region and the columnals from the Miocene are morphologically similar to those of Holocene individuals. Stellate columnals of Isocrinus sp. are known from Jamaica and Carriacou only (Fig. 1d), but are different in morphology from those of extant Isocrinus species from the region. Two other crinoids are known from rare ossicles collected in Carriacou only. Democrinus? sp. belongs to a group of stalked crinoids known as the bourgueticrinids, which, unlike isocrinids, have a columnal that articulates on raised fulcra at each end. The columnals are small and slender and have a ‘bone-like’ appearance. The last taxon is a comatulid – that is, a ‘stalkless’ crinoid and not a sea lily – preserved as a single ossicle, the centrodorsal, to which the roots were attached in life. Although the comatulids are the most diverse crinoid group in the Antilles at the present day, they have a very poor fossil record in the region. This specimen, Horaeometra sp., is close to extant Horaeometra duplex (Carpenter), which lives within deeper water.

Significance

Comparison of the fossil crinoids from the Lower to Middle Miocene of the Antilles with those found in slightly older or younger deposits has proved impractical. Within the region, the underlying Oligocene rocks (about 33.7–23.5 million years old) have produced only a single indeterminate crinoid arm ossicle, probably derived from a stalkless comatulid. Nevertheless, this is more abundant than the Upper Miocene to Pliocene (11.0–1.75 million years old), an interval that has produced no evidence of fossil crinoids, yet is otherwise rich in invertebrate remains. Thus the Miocene columnals discussed herein, although limited to only three islands, represent an important source of data on crinoid occurrence and diversity within an otherwise barren part of the rock succession. That the included taxa are all closely related to those species alive in the region at the present day is notable, as the crinoids of Eocene (53.0–33.7 million years old) and older deposits are not.

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only is *N. decorus* known from a variety of approximately coeval substrates, but this species and *Isocrinus* sp. occur over a distance of over 1000 km. It is therefore suspected that the Antillean Lower–Middle Miocene crinoid fauna, as discussed herein, may occur over a broad area of the tropical western Atlantic.

**Suggestions for further reading**


**Turquoise**

R. J. King

Turquoise is probably the oldest gemstone known to have been extracted from the ground on a large scale. By about 3200 BC it was being mined by the Egyptian Pharaohs, who employed up to 3000 slaves as miners in their mines in the Sinai Peninsula. The mines – e.g. in the wadis Maghera and Shallal – were forgotten for centuries, but were refound by a Major C. K. Macdonald, together with ancient stone tools; and a suite of specimens from there was presented to the former Geological Museum of London in 1845. These ancient mines are of unique interest, for they represent the earliest mining operations recorded historically.

The turquoise mines of Persia (Iran) have also had a venerable history. Situated in the province of Khorasan, near Neyshābūr, they are said to have been in work since 2100 BCE. Tradition has it that they were originally the property of Isaac, the son of Abraham, and are therefore much older. They are still producing good-quality turquoise today (Fig. 1). Tavernier, the French gemologist, visited Iran in the mid-17th century. His diaries describe his visit to the principal mines north-west of Mashhad, the Shah being the sole recipient of turquoise from one mine, *Kohan Sakhreh* (Old Cliff). For thousands of years, the finest blue turquoise has been mined in Iran. The term ‘Persian turquoise’ became synonymous with the finest quality, a term used worldwide.

Commercially important occurrences of turquoise have been worked in the New World, especially in the west and south-western USA, where the gem was used by Aztec kings and rulers of other cultures. It was known and mined about 200 BCE by native Americans and many tribes of Mexico for personal adornment, talismans and inlaid mosaics.

Since then, turquoise has retained its value in people’s estimation. Even Shakespeare extolled its value in *The Merchant of Venice* (Act 3, Scene 1), and that level of appreciation has been maintained.

A wealth of folklore surrounds turquoise. It is said to possess all manner of mystical and magical properties. It is believed, for example, that the wearer of turquoise need not fear the unpleasantnesses of the evil eye and is afforded protection from falling. For many reasons it was chosen to be the birthstone of December. To enlarge on the superstitions which surround turquoise is beyond the brief of this article.

**The etymology of turquoise**

For a substance so long known, it is not surprising that its etymology is complicated, but the name turquoise is derived comparatively recently (17th century) from the French *Turquoise* for Turkish, as Persian (Iranian) turquoise was brought into Europe by Venetian merchants who purchased it in Turkish