

objects. The colonies have a wide range of external morphologies, including encrusted (flat, hemispherical or irregular), branched (hollow or massive, flattened or circular), and lacy network (Fig. 5.22). Individual colonies may consist of tens to hundreds of circular or polygonal tubes or boxes (zoecia) which contain the individual organisms.

5.5.5.1 Ecology

Bryozoans are widespread, colonial, sessile, suspension feeding organisms which have a limited tolerance for strong wave action, soft sediment surfaces and desiccation. They prefer normal marine salinity but can tolerate short-term salinity variations. Most bryozoans are marine, occurring in shallow to abyssal depths (most common down to 200 m water depth), although a few Recent forms live in freshwater. In spite of their broad environmental distribution, bryozoans are generally most abundant in shallow to moderately deep, marine settings.

5.5.5.2 Mineralogy

There are five orders of bryozoans with a fossil record. In the Cyclostomata, Trepotomata and Cryptostomata, the skeleton is composed of calcite with less than 8 mol% $MgCO_3$. Bryozoans belonging to the Ctenostomata are poorly mineralised with more than 50% organic matter. The most primitive members of the Ctenostomata and Cheilostomata possess a skeleton of calcite only, whereas the more specialised cheilostomes have a secondary thickening of aragonite. However, in general, most Palaeozoic bryozoans had a calcitic skeleton, while many Recent forms are composed of aragonite or mixed aragonite and calcite.

5.5.5.3 Geological Range

Bryozoans range from the Ordovician to Recent. They are relatively rare in modern environments, but were especially important as framebuilders or sediment binders in many Ordovician to Permian build-ups.

5.5.5.4 Significance for Reservoir Quality

Bryozoans may have relatively high primary porosity in the form of interparticle, intragranular and framework porosity, although this porosity is not always preserved during burial. Intragranular pores are usually poorly interconnected giving low permeabilities, and are therefore generally of minor importance in petroleum reservoirs. Framework and interparticle pores are usually better interconnected and may be important in some bryozoan build-ups, e.g. in the Middle Carboniferous of Central Spitsbergen, occasionally forming good petroleum reservoirs.

Bryozoans generally have a low potential for secondary porosity formation due to a stable primary mineralogy. However, bryozoan-rich sediments may still be highly porous when they form build-ups. Bryozoan build-ups formed topographical highs during deposition and were therefore prone to be subaerially exposed during sea level fluctuations. In a humid climate, these build-ups may be pervasively dissolved with the formation of secondary, non-fabric selective porosity. The Lower Permian bryozoan-*Tubiphytes* build-ups in the Midland Basin of West Texas, USA, are examples of this.

5.5.6 Echinoderms

The phylum Echinodermata comprises several classes, of which crinoidea and echinoidea are most common in the fossil record (Fig. 5.23). Modern representatives include the sea urchins (echinoids), starfish and brittle stars (stelleroids), and sea lilies and feather stars (crinoids). However, only crinoidea and echinoidea are dealt with in this book because these groups are most commonly encountered in the field. One of the characteristic features of the echinoderms is that, almost without exception, various degrees of endoskeleton calcification are found in the body wall. A single individual may be composed of a very large number of plates (often several hundred, or even thousands). On death, the individual plates, ossicles and spines disarticulate, unless the organism is quickly buried and thus avoids physical destruction of the skeleton. These plates are fairly sturdy and are often found whole in limey deposits.

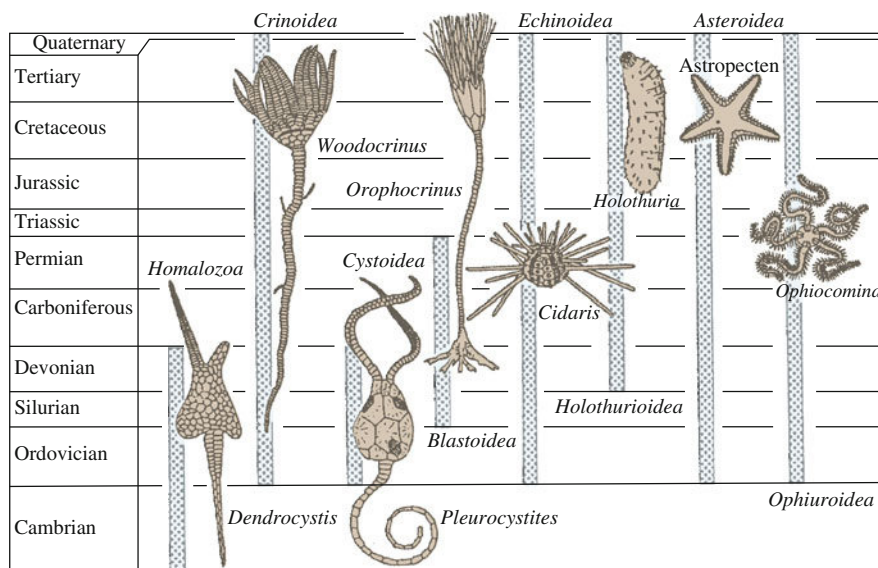


Fig. 5.23 Time range and classification of echinoids with representative genera illustrated (modified from Ziegler 1983)

Because of their microporous texture, echinoderm plates have a low density and may be readily transported into virtually all kinds of environments after death, though a high concentration of plates or the presence of articulated specimens normally indicates deposition within the area they inhabited.

5.5.6.1 Crinoids

The length of crinoids varies greatly, from a decimetre up to several metres (even 25 m). Their general structure is shown in Fig. 5.24. In the upper part is a cup (calyx), which consists of 10–15 plates in two or three rows. Five (or a multiple of five) arms (brachia) extend from the calyx and may have small branches (pinnulae). The mouth is centrally located in the top of the calyx, and the anus is often situated on an outgrowth from the calyx (anal conus). The calyx is situated on a flexible stem consisting of various types of small segments (columnal plates or stem plates). These columnals consist of variously shaped and sized plates, generally arranged in a single series (Fig. 5.25b). Each plate has a central round, or less commonly pentapetoloid, perforation, which together form an axial canal (Fig. 5.25a). The surface separating the stem segments often has a regular radial pattern of

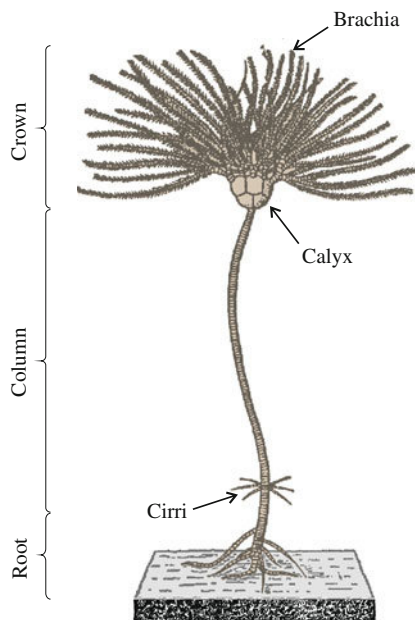


Fig. 5.24 Features of the general crinoid morphology showing a complete crinoid skeleton in living position (modified from Shrock and Twenhofel 1953)

fine chambers and furrows. The stem may have thin lateral branches (cirri) which serve to fasten the crinoid to nearby objects (Fig. 5.25c). Lowermost, the stem may

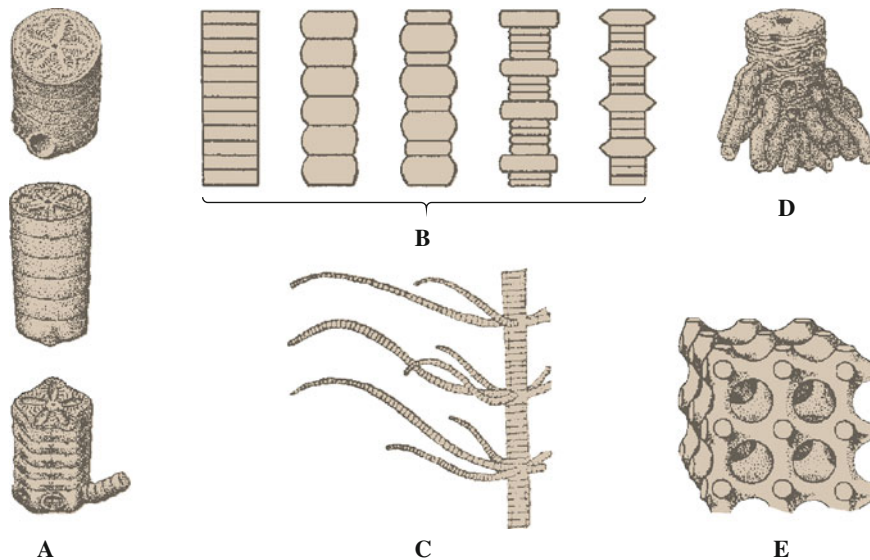


Fig. 5.25 (a) Parts of crinoid columnals showing their general morphology with radial grooves for connective tissues on the top plate. Note the round lumen in the centre of the plates. (b) Schematic drawing of columnals viewed from the side showing examples of the great variation in stem morphology. (c) Part of

the cirrate column of *Comastrochinus* sp. (d) Part of the root system of *Cyathocrinites* sp. (e) Enlarged section of an echinoderm showing the network of large openings which transects the structure (modified from Shrock and Twenhofel 1953, Rasmussen 1969, Scoffin 1987)

form a root-like, branched system that serves as a hold-fast to objects (Fig. 5.25d), or forms an anchor in loose sediments. When the crinoid dies, the column is quite likely to fall apart to a greater or lesser extent. Some fossil crinoids have the entire stem and root system preserved, but fragmental stems and single columnals are much more typical. The skeleton in Recent echinoderms is exceedingly porous (ca. 50%) with a reticulate pore structure (Fig. 5.25e). The pore diameter is about 25 μm .

5.5.6.2 Echinoids (Sea Urchins)

Echinoids have a hemispherical, disc- or heart-shaped endoskeleton consisting of interlocking plates. The outer surface is covered by spines situated on the interambulacral plates which alternate with the spine-free, mostly smaller, ambulacral plates (Fig. 5.26).

5.5.6.3 Ecology

All echinoderms are marine, preferring normal marine salinity and ranging from shallow water to abyssal

depths. Crinoids inhabited shallow marine environments during the Palaeozoic, sometimes forming small bioherms or beds dominated by crinoid debris, but since then they have been most common in relatively deep waters (>100 m). In contrast, other echinoderms have commonly inhabited shallow marine environments throughout their geological time range. Cystoids and blastoids are rare fossils but may occasionally be numerous within, or associated with, reefs.

Most echinoderms are benthonic and a few are pelagic. Echinoids are usually vagrant, whereas crinoids are generally sessile.

5.5.6.4 Mineralogy

The skeleton is composed of high-Mg calcite (5–15 mol% MgCO_3). Each plate, spine or sclerite has a single-crystal microstructure behaving optically as a single calcite crystal when viewed under the polarising microscope. However, the optically uniform crystals are really a mosaic of submicroscopic crystals whose *c*-axes are aligned almost perfectly parallel.

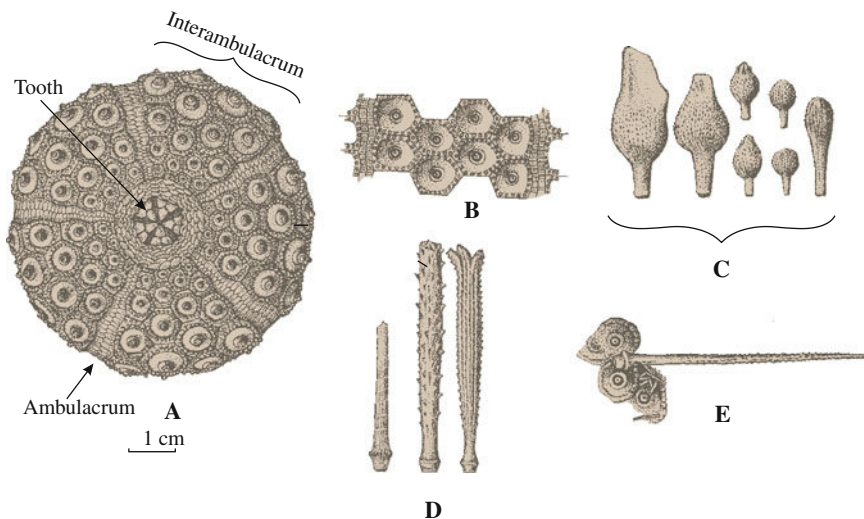


Fig. 5.26 (a) Adoral surface of the regular *Archaeocidaris* sp. with terminology. (b) Part of the surface showing ambulacra and interambulacra with tubercles. (c) Interambulacra with spines preserved. (d) Examples of different growth forms of spines

from regular echinoids. (e) Part of *Archaeocidaris* sp. showing a few ambulacral plates with spines preserved. (modified from Rasmussen 1969, Clarkson 1979, Scoffin 1987)

5.5.6.5 Geological Range

Echinoderms range from the Lower Cambrian to Recent, but were not common before the Ordovician. Their greatest abundance was during the Carboniferous. Crinoids appeared for the first time in Lower Ordovician sediments, but did not become abundant before the Silurian. They remained numerous in the Devonian and Carboniferous, sometimes forming small bioherms or beds dominated by crinoid debris. Their abundance declined in the Permian, but revived in the Mesozoic, although they never equalled their Palaeozoic peak. Crinoids remain prolific today.

Echinoids appeared for the first time in the Upper Ordovician, but are most common in Mesozoic and Cenozoic sediments. They remain a vital part of the invertebrate marine realm and are probably as abundant now as at any time in the past.

5.5.6.6 Significance for Reservoir Quality

Echinoderms are commonly overgrown by syntaxial calcite cement which completely obliterates both intra-granular and intergranular porosity in echinoderm-rich rocks. This, along with the common neomorphic replacement of the echinoderm skeleton, gives these

rocks low reservoir potential. Dolomitised crinoidal sediments may occasionally be oil producing, as for example in the Silurian crinoid-rich skeletal build-ups in the northeastern Anadarko Basin of Oklahoma, USA (Morgan 1985).

5.5.7 Post-mortem Destruction

As shown in the preceding review, carbonate grains differ widely in size with diameters ranging from a few micrometres in coccolithophores to more than a metre in some bivalves and sponges. Apart from grain type, grain size is also dependent on mechanical abrasion and bio-erosion prior to final burial. These physical, biological and chemical processes can be described as:

- **Mechanical destruction.** The rate of abrasion is highly dependent on the transport mechanism and energy available in the environment for particle movement. Shell fragments and other skeletal particles are rapidly crushed and ground down to become structurally unrecognisable in a high-energy environment such as a surf zone, while in low-energy environments the integrity of the original material may remain more or less intact.