1. *Taxon range zone* is defined by the first and last occurrence of a particular taxon.
2. *Concurrent range zone* is the interval between the first occurrence of a taxon and the last occurrence of another taxon.
3. *Partial range zone* is the interval between the last occurrence of a taxon and the first occurrence of another taxon partitioning the range of a third taxon.
4. *Successive first appearance zone* represents the interval between the successive first appearance of two taxa.
5. *Successive last appearance zone* is the interval between the successive last appearance of two taxa.

The successive last appearance zone is the type most commonly used in industrial biostratigraphy, because the samples are mainly derived from well drilling cuttings. In such sample sets, the actual first appearances are unreliable owing to downhole (caving) contamination. Precise positions of first appearances are required in order to recognise the first four interval zone types.

7.3.3.2 Other Biozones

1. *Assemblage zone* is a biozone characterised by the association of three or more taxa (Fig. 7.7). This zone is recognised without regard to range limits of taxa, and is usually of regional importance.
2. *Acme zone* is based on the numerical maximum of one or several taxa, and is also termed *abundance zone*. Taxon maxima are strongly influenced by local environmental conditions, and therefore this zone is usually of local stratigraphic importance.
3. *Taxon chronozone* represents the interval between two unique bioevents: the first evolutionary appearance of a taxon, and its extinction. Thus, this zone represents the total range of the taxon, and is of global nature (Fig. 7.8). The distribution of taxa, however, is to a varying degree facies-controlled, which leads to the development of geographically restricted taxon range zones. One or several of such local taxon range zones can be included in the total range of the taxon.

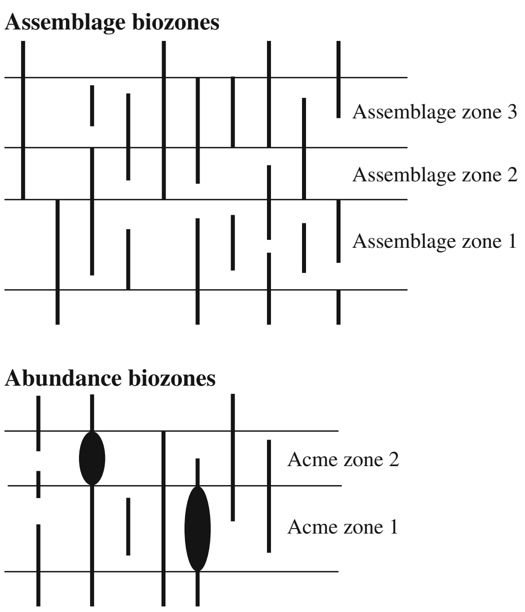

Fig. 7.7 Outline of the biostratigraphic assemblage and abundance zones

7.3.4 Biostratigraphic Correlation

Biostratigraphic correlation is based on the fact that during the course of geological time, biological evolution has taken place, whereby some species and higher taxa have died out and new ones have appeared (Fig. 7.3). Any particular species will therefore be represented only in sediments deposited within a limited time span. However, this method also has many limitations. Some fossil groups developed rapidly, with individual species only existing for a short period. Other groups evolved slowly and persisted throughout long periods of geological time. Some fossil organisms are found only in rocks deposited in particular environments or facies. Many were dependant on a certain salinity, oxygen content and water depth. Bottom conditions played a major role for infaunal (burrowing) animals.

Biozones of sedimentary successions are arranged into zonal schemes, which are the main tools of fossil-based correlation. The ideal index fossil for defining a biozone ought to belong to a fossil group which underwent rapid biological evolution and had a global distribution. It should not have had special environmental requirements, and should have been cosmopolitan with respect to habitat. One such fossil group is the graptolites, which are common in Cambro-Silurian shales. They were planktonic and drifted in the surface seawater. However, even this type of plankton may show

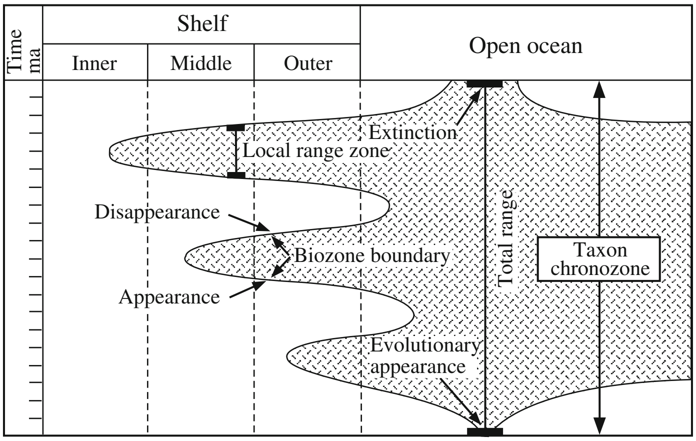

Fig. 7.8 Facies-related distribution of an imaginary fossil taxon exemplifying the difference between a taxon chronozone (global) and a biozone (local)

a distribution pattern which reflects ocean currents and temperatures etc. At the present microfossils are being used more and more for biostratigraphic correlation. Several animal and plant groups (e.g. conodonts, planktonic foraminifera, radiolarians and spores and pollen) have wide distributions and have the advantage that even small samples, e.g. from boreholes, provide adequate material for statistical treatment.

Although fossils are always helpful in stratigraphic correlations, we now avoid defining important geological boundaries, for example that between the Ordovician and the Silurian, by means of fossil occurrences. Such a boundary would have to be moved whenever one found a new occurrence of a certain fossil. The geological periods are now defined by international committees which select a type section with continuous sedimentation and preferably fossiliferous facies, and the boundary is physically marked as a fixed point in the section. The boundary is then unambiguously defined. All available means can then be used, including fossils, to correlate the boundary with other areas. This is the principle of the arbitrary boundary. In reality it is not entirely arbitrary. We try to put it on a section with optimal potential for correlation with other areas and the global time scale (Fig. 7.9).

Geologists used to define a stratigraphic boundary at a break (hiatus) in the sedimentary record. However, sediments later found elsewhere that had been deposited in the period represented by the hiatus, could not be assigned to either unit. For example, the boundary between the Tertiary and Cretaceous was defined in England where a hiatus is developed between these systems. As a result it was difficult to reach agreement on whether sediments which were deposited for example in Denmark during this period (Danian), should belong to the Cretaceous or the Tertiary.

7.4 Time Stratigraphy

Chronostratigraphy is an attempt to correlate rocks deposited at the same time, across larger areas. The accuracy achievable with chronostratigraphic correlation depends on whether the sediments contain evidence of well-defined geological events which were simultaneous across the region. These events may be biological (e.g. appearance of new species), sedimentological (e.g. deposition of ash layers) or geophysical (e.g. reversals of the Earth's magnetic field). Geological research has a long tradition of correlating synchronous events in geological history. Such correlations are independent of an absolute timescale. Only after the development of radiometric dating methods did it become possible to set up a series of datings approaching an absolute timescale, but radiometric datings are not absolute with respect to time.

We thus distinguish between two types of time stratigraphy: (1) Geochronology, which is the subdivision of the Earth's history into finite time units. A geochronological unit is a specific interval of geological time. (2) Chronostratigraphy or time-rock

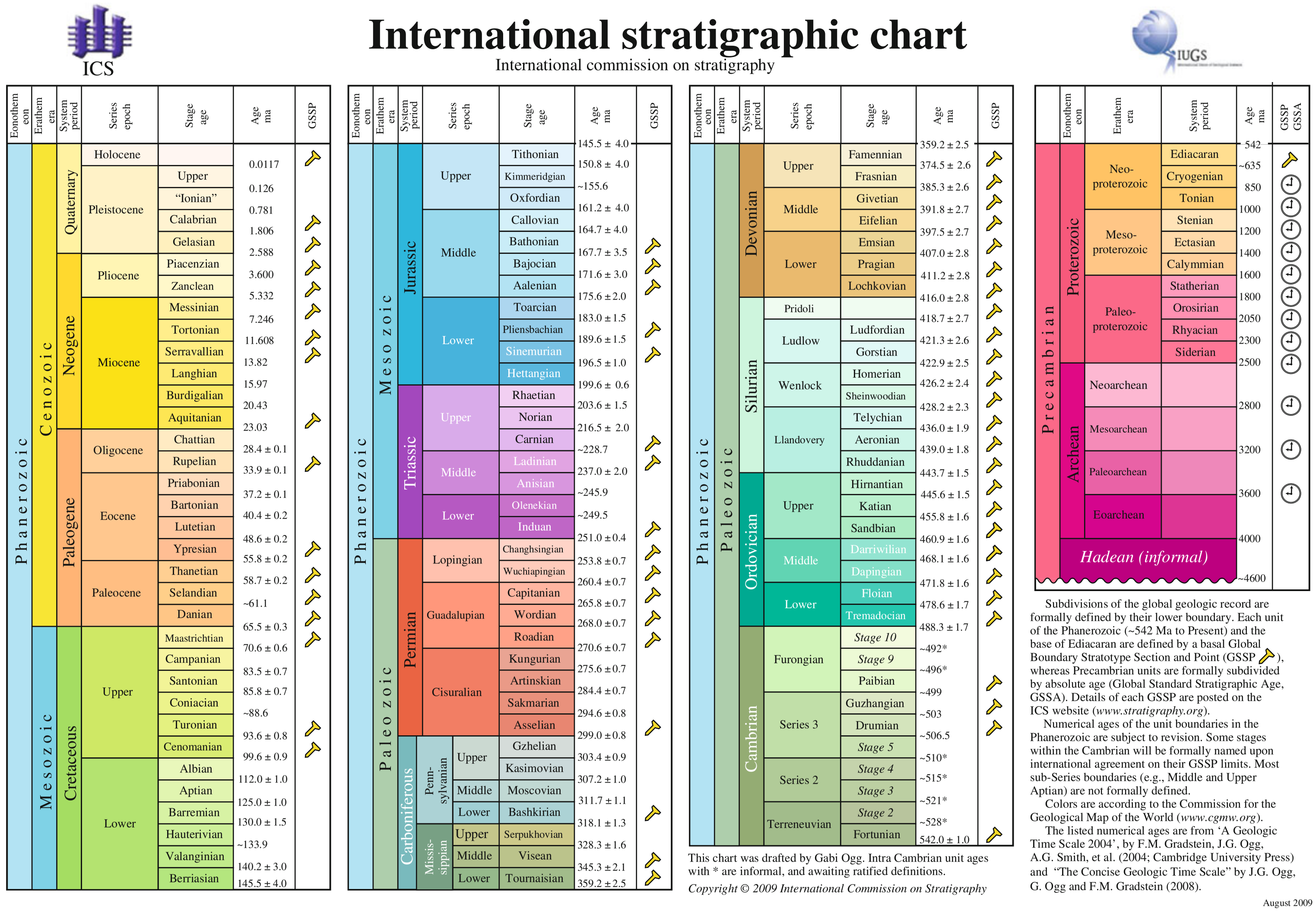

Fig. 7.9 Geological time scale for the Phanerozioc Aeon (from Gradstein and Ogg et al. 2009)

stratigraphy is the subdivision of sedimentary successions, and their correlation, on the basis of time. Chronostratigraphic units are by definition synchronous.

A geochronological unit represents a specific interval in the geological time scale. For example, the Jurassic *period* is a geochronological unit. A geochronological unit may define the time span between two specific geological events. We can say, for example, that some of the rocks in the North Sea were deposited during the Jurassic period. The corresponding chronostratigraphic unit (system) signifies the rocks which were formed during the same period. We therefore say that some of the rocks in the North Sea belong to the Jurassic *system*.

The basic chronostratigraphic unit is a *chronozone*. A chronozone includes all the deposits formed during a particular, relatively short, geologic time interval and which are defined by a geological phenomenon or by a particular interval of a rock succession. In most cases a chronozone is a *taxon chronozone*, which is defined as the period between the first appearance and last occurrence of a particular fossil taxon (Fig. 7.8). Whereas a biozone can only be defined where the fossil is present, a chronozone represents all the rocks that were formed during this period, regardless of whether they contain fossils. A *chron* is the interval of time during which the rock in a chronozone was formed. It is thus the geochronological equivalent of a chronozone.

A chronozone may be named after a biostratigraphic unit, e.g. a *Didymograptus extensus* chronozone, or after a lithostratigraphic unit, which can be recognised over large areas. Such characteristic strata are often called *marker beds, key beds*, or *datum beds*. Chronostratigraphic horizons are important for correlation within sedimentary basins, and form the framework for all facies reconstructions. If we have two *chronohorizons* or datum beds, we can measure the variation in thickness and composition of the sediments which were deposited during a particular time period. This may make it possible to map variations in sedimentation rate and the ratio of sandstone to shale. Maps showing the sediment thickness between two marker beds are called isopach maps. This is very useful for reconstructing sedimentary facies on the basis of borehole data, a standard method in connection with oil prospecting.

The best chronostratigraphic horizons (marker beds) are bentonite (ash) layers; on a smaller scale also coal beds, phosphate beds, thin limestone or sandstone beds, or particular fossil horizons. When analysing stratigraphic records from wells (logs) one tends to use beds which produce a distinctive log pattern. Seismic reflectors can also in certain instances be used as datum beds (horizons).

A *stage* is a chronostratigraphic unit which includes one or more chronozones, but which nevertheless covers a limited period of time, usually 3–10 million years (Fig. 7.9). This is the smallest unit in the chronostratigraphic hierarchy which is used for correlation all over the world. A stage is defined in a type section and usually designated by a geographical name near the type profile. For example, the Kimmeridge stage is well exposed on the Dorset coast at Kimmeridge. The correlation of a stage is usually based on biostratigraphy. An *age* is the period of time (geochronological unit) which corresponds to a stage.

A *series* is a chronostratigraphic unit larger than a stage. For example, the Late Jurassic is a series constituting part of the Jurassic system. The geochronological unit which corresponds to a series is an *epoch*. We can say that a certain limestone was deposited during the Late Jurassic epoch.

A geochronological *period* varies in duration from about 20–30 million years (Silurian) to about 60–70 million years (Cretaceous). The Quaternary period, however, is much shorter, only about 2.5 million years. The rocks formed during a period constitute a *system*. An *era* is comprised of two or more periods. The Palaeozoic era had a duration of about 300 million years, but the Cenozoic era did not last longer than the longest Palaeozoic periods (65 million years).

The largest units in the chronostratigraphic scale, *erathem* and *enothem*, are not used much, since it is seldom relevant to group rocks which were deposited over such long periods of time. However, when we discuss geological history in relation to the biological development on the earth, for example, it can be useful to speak about the Phanerozoic *aeon* which covers the Palaeozoic, Mesozoic and Cenozoic eras. The Precambrian is divided into two aeons: the Proterozoic (542–2,500 million years ago) and the Archean (2,500–4,000 million years ago).