Palaeoenvironments and palaeoecology of the Middle and Upper Jurassic succession of Gebel Maghara (Sinai)

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Ahmed Awad Abdelhady

Abstract

The Jurassic succession of Gebel Maghara North Sinai, Egypt, represents a mixed carbonate-siliciclastic sedimentary succession. Combining information from both fossils and rocks collected from four sections has allowed a plausible reconstruction of the palaeoenvironments and benthic communities of the area. As age-diagnostic fossils are rare, and in order to ensure maximal stratigraphic resolution, chronostratigraphic boundaries were determined based on quantitative biostratigraphy (Unitary Associations method). The proposed zones were found to be valid chronological markers and permitted correlation with the Tethyan ammonite zones.

The Jurassic succession of G. Maghara was deposited on ramp, and the architecture of the ramp facies was strongly controlled not only by eustatic sea-level changes but also by the extensional tectonics in connection with rifting of the Tethys north of Gondwana. Seven tectonically enhanced third-order sequences (DS1 to DS7) have been recognized. The first three sequences, ranging from the Toarcian to the Bajocian, record the invasion of the sea (intertidal to shallow subtidal conditions) across an intracratonic area resulting from eustatic sea-level changes during a quiescent rift stage. The remaining sequences reflect open marine mid to outer ramp settings. During an active extensional stage, horsts, which acted as barriers separating the G. Maghara sub-basin from the main ocean, subsided. Subsequent rejuvenation and reactivation of faults transformed the homoclinal into a distally steepened ramp topography during the Early Bathonian. As a result, a 200-m-thick deltaic wedge was created and, during the Early Kimmeridgian, a calcirudite and calcarenite dominated slope environment.

The macrobenthic palaeocommunities were investigated to identify relationships with environmental parameters and to trace the palaeoecological changes associated with sea-level fluctuations through time. The quantitative analysis of a data matrix comprising 198 macrobenthic taxa in 142 samples identified nine associations and three assemblages, interpreted to be representative of their original environment. Non-Metric Multidimensional Scaling (NMDS) delineated the same degree of habitat partitioning as hierarchical clusters with very little overlap. Detrended Correspondence Analysis (DCA) identified water depth as the primary environmental gradient controlling the distribution of the fauna, while Axis 2 has ordered the taxa according to differences in life habit, which is also related to substrate consistency. Based on diversities, the associations and assemblages were divided into two major groups, (1) low-stress polyspecific associations, (2) high-stress paucispecific associations.

The structure of the palaeocommunities is related to the various ramp environments and the sequence stratigraphic framework. The diversity of the macrofauna of G. Maghara exhibits a cyclic pattern that coincides with the 3rd order sea-level fluctuations and also with the Axis 1 scores of the DCA, which is a well-known bathymetric indicator. Hydrodynamic conditions were most likely the main factor controlling the benthic communities. Hydrodynamic conditions influenced the substrate type, redistributed nutrients, and were responsible for stratified water masses and hypoxia. Middle ramp settings during middle to late TST times were found to provide the best conditions for macrobenthos.

During Bajocian times, G. Maghara and the Levant margin were connected but at the same time isolated from the main ocean by islands and shallows (intracratonic setting). These barriers may have limited the dispersal potential of the macrofauna and prevented faunal exchange with even nearby areas. Although these barriers had disappeared by the Bathonian, the same biogeographic patterns prevailed, which may be related to the global sea-level lowstand. By the Callovian, a time of global sea-level highstand, in contrast, the fauna of the study area became very similar to that of northeastern Africa. Similarly, diversity and extinction rates increased from the Middle Bathonian onward, which may reflect immigration of cosmopolitan taxa due to the newly established open marine setting and the global sea-level highstand during the Callovian. Towards the Oxfordian, lowering of temperature may have limited the dispersal within the Ethiopian Province. As a result, a southeastern subprovince including Tanzania, Madagascar, and India became established. Although the geographic pattern of the different faunal groups exhibits some similarity, a positive correlation was found between the life habit of the taxa and their dispersal potential. The dispersal potential was highest for ammonites, followed by that of bivalves and then corals. Brachiopods had the lowest dispersal potential.

Keywords: Palaeoenvironments, Quantitative biostratigraphy, Sequence stratigraphy, Macrobenthos, Palaeocommunity analysis, Jurassic, Gebel Maghara, Egypt.

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1 Introduction

1.1 Overview

The climate of the earth is always changing and the fossil record offers a long-term view to understand these changes and their impact on the ecosystems over time. The latter provides a valuable tool to assess such changes in the present-day ecosystems and predictions of their future changes.

The Jurassic period is regarded as a fascinating time slice due to its well-known terrestrial systems and its diverse marine ecosystems. Within the invertebrates, several new groups appeared and a massive evolutionary radiation of the existing ones took place. The Jurassic Period also supported diverse encrusting and boring communities, in addition to a significant rise in the bioerosion of carbonate shells and hardgrounds (Taylor and Wilson, 2003).

The Jurassic succession of Gebel Maghara offers the best and most comprehensive succession of Jurassic strata in Egypt. It represents a wide variety of continental, deltaic, nearshore siliciclastic and carbonate shelf environments (Al Far, 1966; Picard and Hirsch, 1987), which contain a rich macrobenthic fauna characterized above all by brachiopods, bivalves, gastropods, and corals. Apart from taxonomic studies, this fauna has received no attention in the past.

Gebel Maghara is a dome-like structure covering an area of approximately 400 km^2 and lies in northern Sinai, 50 km south of the Mediterranean coast. It comprises the thickest and most complete Jurassic outcrop in northern Sinai (1800 m; Al Far, 1966; Keeley, 1994), and thus provides an excellent testing ground for assessing the interplay of eustacy and tectonics in ramp depositional environments.

The succession has been investigated from a stratigraphic point of view (e.g., Al Far, 1966; Picard and Hirsch, 1987) and most of the benthic macrofauna has been dealt with from a taxonomic point of view (e.g., Douvillé, 1916, 1925; Fourtau, 1924; Arkell et al., 1952; Said and Barakat, 1958; Farag and Gatinaud, 1960; Hirsch, 1980; Parnes, 1988; Hegab, 1989, 1991; Feldman et al., 1991, 2012).

Attempts to establish a biostratigraphic and sedimentological framework have been made in the publications just mentioned, but great uncertainties still exist, especially with respect to the stage boundaries and depositional environments. Although some ammonites were identified from the Jurassic of G. Maghara, their occurrence is patchy and not complete. Moreover, most of the benthic fauna such as bivalves, corals, and brachiopods are environmentally controlled and hence are of little stratigraphic significance. However, quantitative biostratigraphy provides a reliable method for biochronology (Galster et al., 2010; Monnet et al., 2011).

As a consequence of the scarcity of age-diagnostic fossils (ammonites), stage boundaries will be determined based on quantitative biostratigraphy (i.e. Unitary Associations) for maximal stratigraphic resolution with a minimum of superpositional contradictions inherent to complex biostratigraphic datasets (Monnet et al., 2011). This method makes potential correlation of alternative boundary levels more objective (Pálfy and Vörös, 1998). Sequence stratigraphic analyses are also lacking due to the fact that the facies exhibit a broad range and rapid laterally and vertically changes, partly caused by synsedimentary tectonics. Consequently, new investigation of the facies architecture (i.e., geometry, lateral continuity, and stacking pattern) is urgently needed for constructing a sound depositional model.

As the ecosystems of shallow seas respond relatively quickly to both long- and short-term shifts in ocean variables (Southward et al., 2005), such changes will be investigated based on a palaeoecological analysis of the macrobenthos. Macrobenthos is a powerful tool in interpreting palaeoenvironments; it reflects the physical habitat, as its abundance and distribution is largely controlled by abiotic factors (i.e. physical parameters within a given environment).

After identifying the chronostratigraphic boundaries, the dynamic palaeobiogeography of the study area during the different stages of the Jurassic (Bajocian to Oxfordian) will be reconstructed.

The goals of the thesis can be summarized as follows:

- high resolution biostratigraphic subdivision of the analysed time interval;
- construction of a depositional model of the area and tracing the basin evolution;
- reconstruction of the macrobenthic palaeocommunities and their environments;
- reconstruction of the dynamic palaeobiogeography of the study area during the Jurassic.

By reaching these goals the following questions will be answered:

- Is the facies heterogeneity controlled by eustacy or tectonics?
- How do the ecosystems respond to environmental disturbance?
- Can bivalves better cope with environmental stress than brachiopods?
- To which extent does the substrate influence the community structure of macrobenthos?

- Can changes in the community structure be linked to the sequence stratigraphic pattern?
- What were the best environmental conditions for the macrobenthos?
- To which extent did the tectonic and palaeogeographic situation of the basin affect the biogeographic pattern?
- Do the different macrofaunal groups display a similar biogeographic pattern, or do these patterns largely depend on physical barriers?

1.2 Palaeogeography and palaeoclimate

By the Triassic and Early Jurassic, extensive rifting associated with breakup of Pangaea took place, while spreading began in the Middle Jurassic (Golonka, 2007). From the Early to Late Jurassic, Gondwanaland drifted southwestward (Scotese, 2001), but the study area (and the Middle East) remained at an equatorial position during this time span. The opening of marine corridors (i.e., Hispanic, Mozambique, and Viking) and the rifting of the Tethys north of Gondwanaland were the major palaeogeographic consequences that took place during the Jurassic (Smith, 1983, 1989; Westermann, 1993; König and Jokat, 2010; Leinweber and Jokat, 2012; Porter et al., 2013). The appearance of new barriers and the disappearance of previous ones led to disruption in the monsoonal circulation (Parrish, 1992). The latter may also have led to major climatic changes (Kreft and Jetz, 2010).

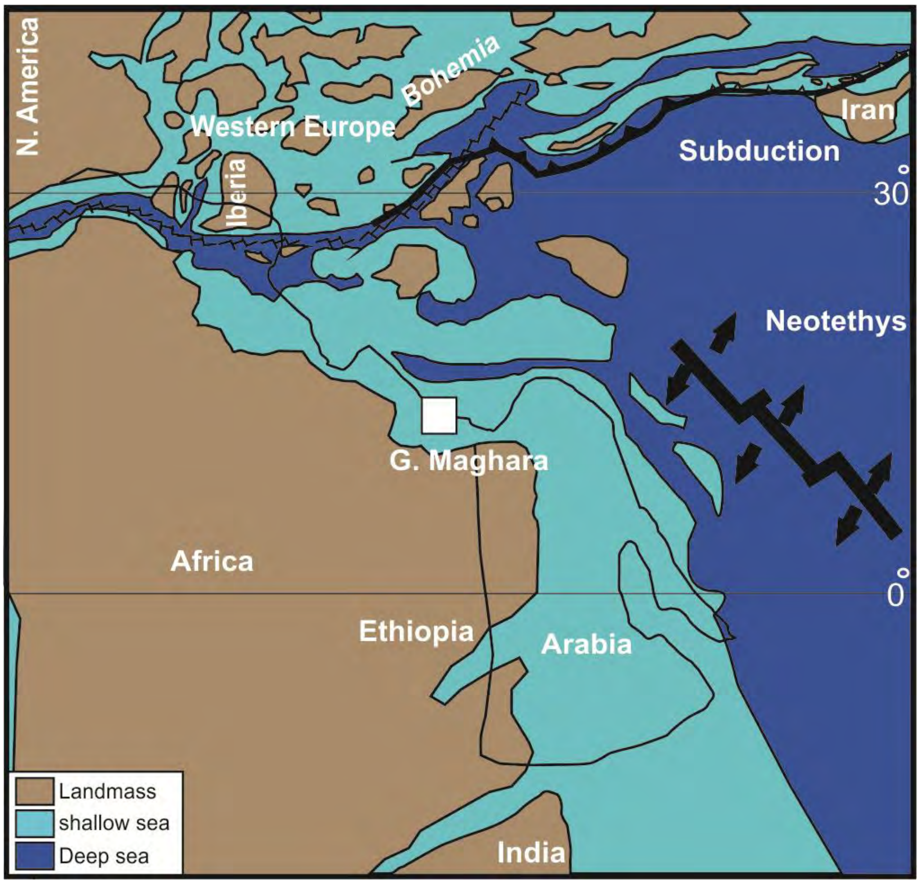


Fig. 1.1. Palaeogeographic position of G. Maghara during the Jurassic (Stampfli and Borel, 2004).

Based on palaeobiogeographic data including ostracods, ammonites, brachiopods, and bivalves, Arias (2008) concluded that the Panthalassic circulation was characterized two large subtropical gyres rotating clockwise in the northern hemisphere and anti-clockwise in the southern hemisphere. The Tethyan Ocean was dominated by monsoonal westerly-directed equatorial surface currents that in its westernmost part were deflected to the north, along the northern side of the Tethys Ocean during summer and in the opposite direction during winter (Arias, 2008).

According to Golonka and Ford (2000), greenhouse conditions prevailed during the Sinemurian-Toarcian, with a warm, humid environment and moderate temperatures into high latitudes with no evidence of significant continental glaciation. The maximum extent of polar ice during the Mesozoic was probably only one-third the size of the present day (Price, 1999). Kiessling and Scasso (1996) suggested that Antarctic surface waters may have been warmer on average than those in equivalent northern high latitudes, according to the distribution of pantanelliid radiolarians. According to Jenkyns et al. (2012), there was a general warming trend through the Late Jurassic (26°-30°C), which indicate tropical to subtropical environments up to the poles, while around the Callovian-Oxfordian boundary slightly colder seawater temperatures prevailed.

1.3 Geologic and tectonic setting

During the Mesozoic, northern Sinai was part of the Levant margin of the Eastern Mediterranean Basin (EMB; Garfunkel, 2004): a geographic area that encompassed western Syria, Lebanon, Jordan, and Israel. It constitutes part of the southern continental margin of the Tethys Ocean (Fig. 1.2B) formed by rifting starting in Triassic or even Permian times (Robertson and Dixon, 1984; Garfunkel, 1998, 2004).

The Triassic rifting of the Tethys north of Gondwana, accompanied by thermal subsidence of the lithosphere, led to the formation of small intracratonic subbasins (horst–graben systems) with differential subsidence in northern Egypt (Keeley, 1994; Moustafa et al., 1998; Ayyad et al., 1998; Garfunkel, 1998). G. Maghara is one of these sub-basins, consisting of an extensional half graben-like structure. These rift basins were filled with both continental siliciclastic and marine carbonate sediments. The opening of the basin started in Late Triassic–Early Jurassic time (Biju-Duval et al., 1979; Garfunkel and Derin, 1984; Mart, 1987).

On a regional scale, the Maghara Basin is part of an ENE–WSW oriented Jurassic basin in the North Sinai–Levant area, called the Maghara–Halal Basin (Picard and Hirsch, 1987). However, changes in thickness of the Jurassic rocks between G. Maghara and the

Halal-1 well indicate the existence of separate sub-basins in northern Sinai (G. Maghara, Halal, and Yelleg). The same tectonic setting has been reported from the northern Western Desert (e.g., Moustafa et al., 1998; Abd El-Aziz et al., 1998; Wescott et al., 2011).

The opening of the Neotethys resulted in the development of E-W to ENE-orientated faults (Hirsch, 1984). These faults dip northward in the Eastern Desert, producing a regional northerly sloping platform (Bein and Gvirtzman, 1977; Garfunkel and Derin, 1984). The resulting facies were thick marine carbonates and shales in the north and shallow-marine, thin siliciclastics to the south (Yousef et al., 2010; Fig. 1.2A).

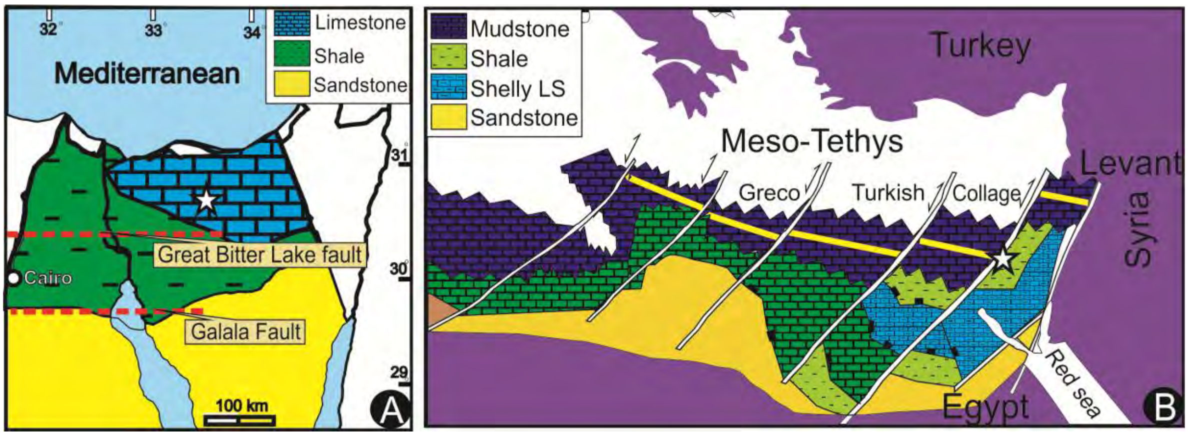


Fig. 1.2. Facies map of the Middle Jurassic of Egypt (A) and the late Jurassic of the East Mediterranean margin (B), compiled after several authors (see text). The study area is marked with an asterisk.

The northern Galala fault separates two Jurassic facies, a shaly facies in the north and a sandy one in the south (Fig. 1.2A). The Great Bitter Lake Fault separates the southern shaly facies and the thick limestone facies in the north, thus indicating that the northern Galala Fault and the Great Bitter Lake Fault formed during Early Jurassic times (see also Sestini, 1984).

According to Yousef et al. (2010), G. Maghara occupied an intracratonic setting from the Early Jurassic until the Late Bajocian. From Middle Bathonian times onward, the sediments contain glauconite and chert nodules, and the fauna can be well correlated with that of Europe, Ethiopia, and India, indicating open marine connections. Intense crustal extension and subsidence started in the Bathonian, allowing the development of an extensive carbonate ramp, which opened northwestward to the Tethys.

The Bathonian marks the transition to a stable passive-margin setting characterized by decreased rates of thermal subsidence, coupled with deposition of a thick subtidal carbonate succession during Callovian-Oxfordian times (Robertson and Dixon, 1984; Moustafa and Khalil, 1989, 1994). By the Early Kimmeridgian, a distally steepened ramp had developed and thick-bedded grainstones with minor marl interbeds were deposited on the slope. Around the Jurassic-Cretaceous boundary, erosion and uplift took place (a late phase of the Cimmerian orogeny). With the convergence and collision of Afro-Arabia with Eurasia in the Campanian, inversion of the extensional basins resulted in the Syrian Arc Fold System (for more details see Krenkel, 1925, Smith, 1971) and finally the G. Maghara obtained its current structural shape.

1.4 Stratigraphic framework

The Jurassic strata of Egypt exhibit strong eustatic and tectonic influences (Keeley and Wallis, 1991), probably due to the occurrence on an extensional rift margin (Young et al., 2000; Winn et al., 2001; Jackson et al., 2005; Herkat and Guiraud, 2006; Khalil and McClay, 2008). Divergent and convergent movements between the African and Eurasian plates account also for tectonic deformation of this area.

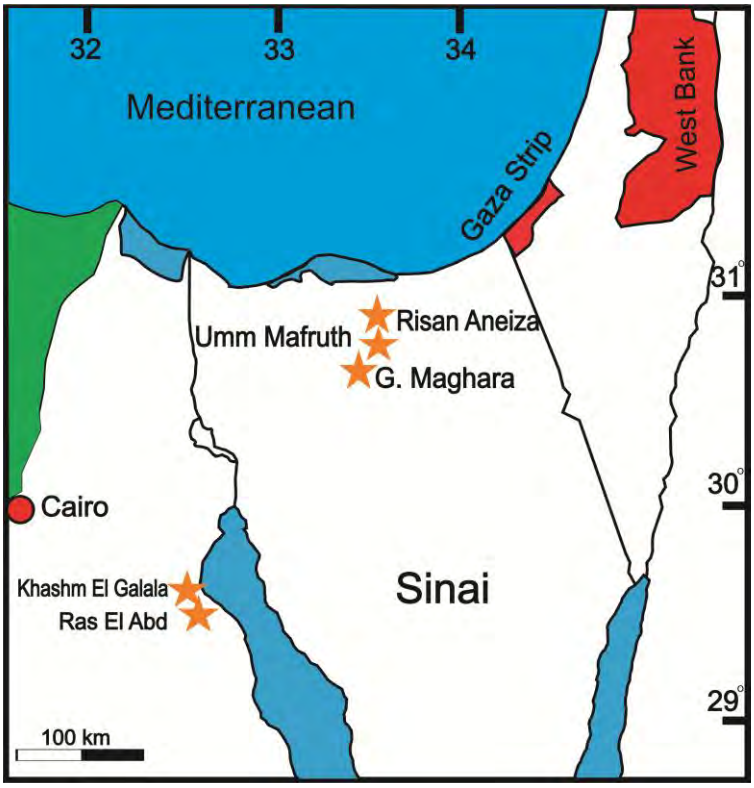


Fig. 1.3. Jurassic outcrops of Egypt.

Jurassic outcrops of Egypt are recorded from G. Maghara, which exhibits the thickest and most complete succession. Another outcrop occurs at Khashm El Galala, at the western coast of the Gulf of Suez, consisting of 100 m of fluvial to shallow marine Jurassic rocks (Sadek, 1926; Farag, 1957). At Ras El-Abd, 4 km south of Khashm El Galala, another Jurassic outcrop has been recorded (Farag, 1948). To the north of G. Maghara, Kimmeridgian limestones of the Masajid Formation were recorded from G. Umm Mafruth and G. Risan Aneiza (for details see Farag, 1948; Said, 1962; Jenkins, 1990; Issawi et al., 1999; Fig. 1.3).

The Jurassic succession at Gebel Maghara represents a sequential development of continental and marine sediments, starting in the early Jurassic (Toarcian) and lasting until the Kimmeridgian (Fig. 1.4.). G. Maghara represents an outstanding exposure of Jurassic strata in Egypt. In the large anticlinal structure, the large-scale sedimentary architecture of the strata is superbly exposed, making the recognition of facies associations possible even from a satellite image (Fig. 1.5). These excellent exposures are ideal for stratigraphic investigations.

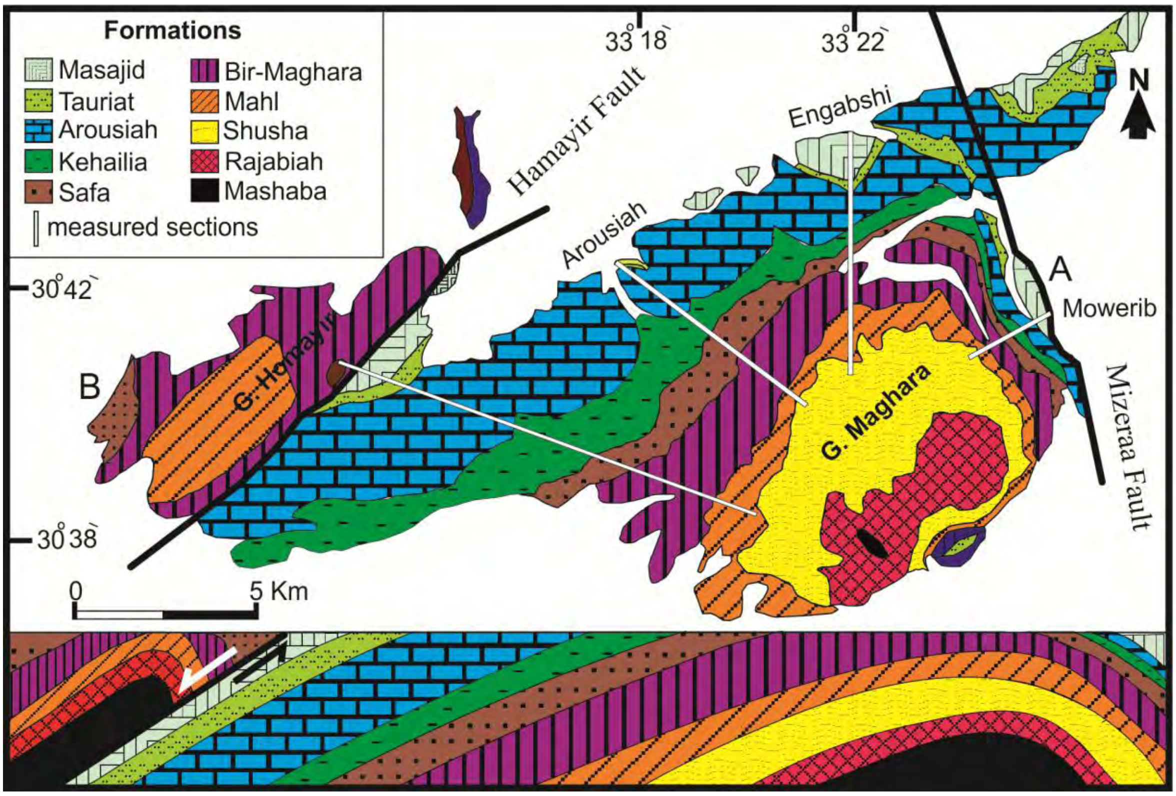


Fig. 1.4. Geologic map of G. Maghara area with cross-section of the Jurassic rocks (modified after Al Far, 1966; Hirsch, 1979) and position of the investigated sections.

Al Far (1966) divided the Maghara succession into marine and continental strata. The marine strata are represented by the Rajabiah, Bir Maghara, and Masajid formations, whereas the continental sediments include the Mashabba, Shusha, and Safa formations (Fig. 1.4). A meandering river system existing in the south apparently debouched its sediments into the Maghara Subbasin. The rivers deposited parts of their sediments inland forming a thin fluvial sequence to the south, which may have been flooded briefly during peak transgression (Al Far, 1966).

The present stratigraphic scheme for G. Maghara is based essentially on Al Far (1966), who provided a complete classification and description of the Jurassic strata. Picard and Hirsch (1987) modified Al Far´s classification and compared the succession at G. Maghara with that of the adjacent Negev desert. Keeley et al. (1991) provided a stratigraphic scheme for the Jurassic sediment of the western Desert, which can be more or less correlated to the rock succession at G. Maghara (Fig. 1.6). This thesis concentrates on the Middle to Upper Jurassic strata, which yield a rich fauna.

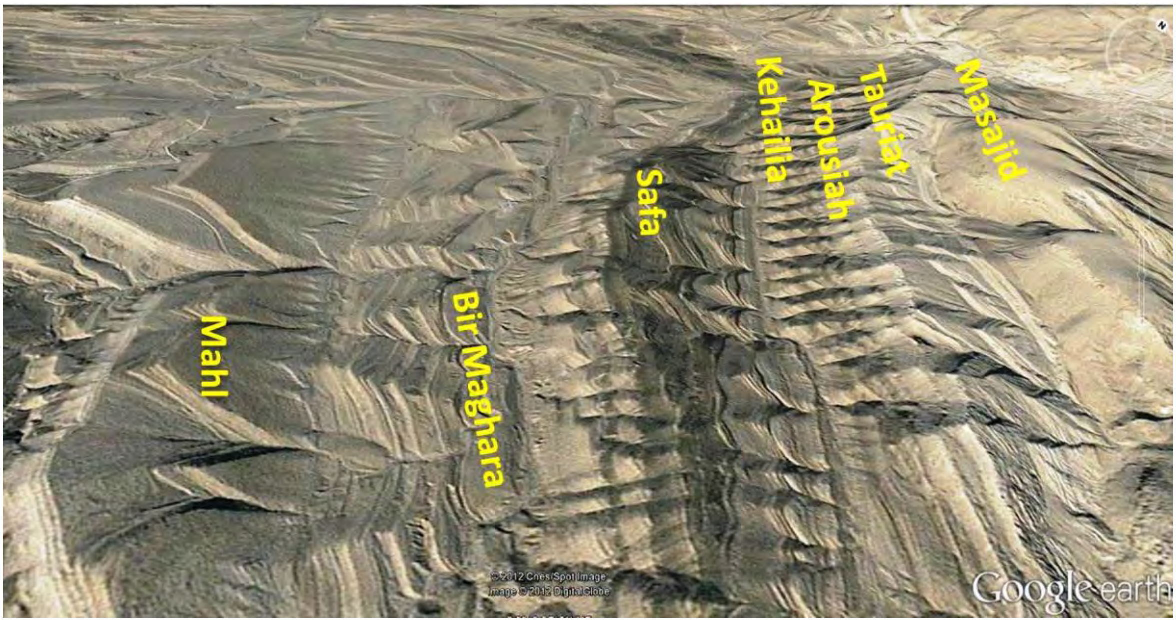


Fig. 1.5. Outcrop of the Middle-Upper Jurassic formations, exposed in the eastern saddle of the anticline of G. Maghara as seen on a satellite image.

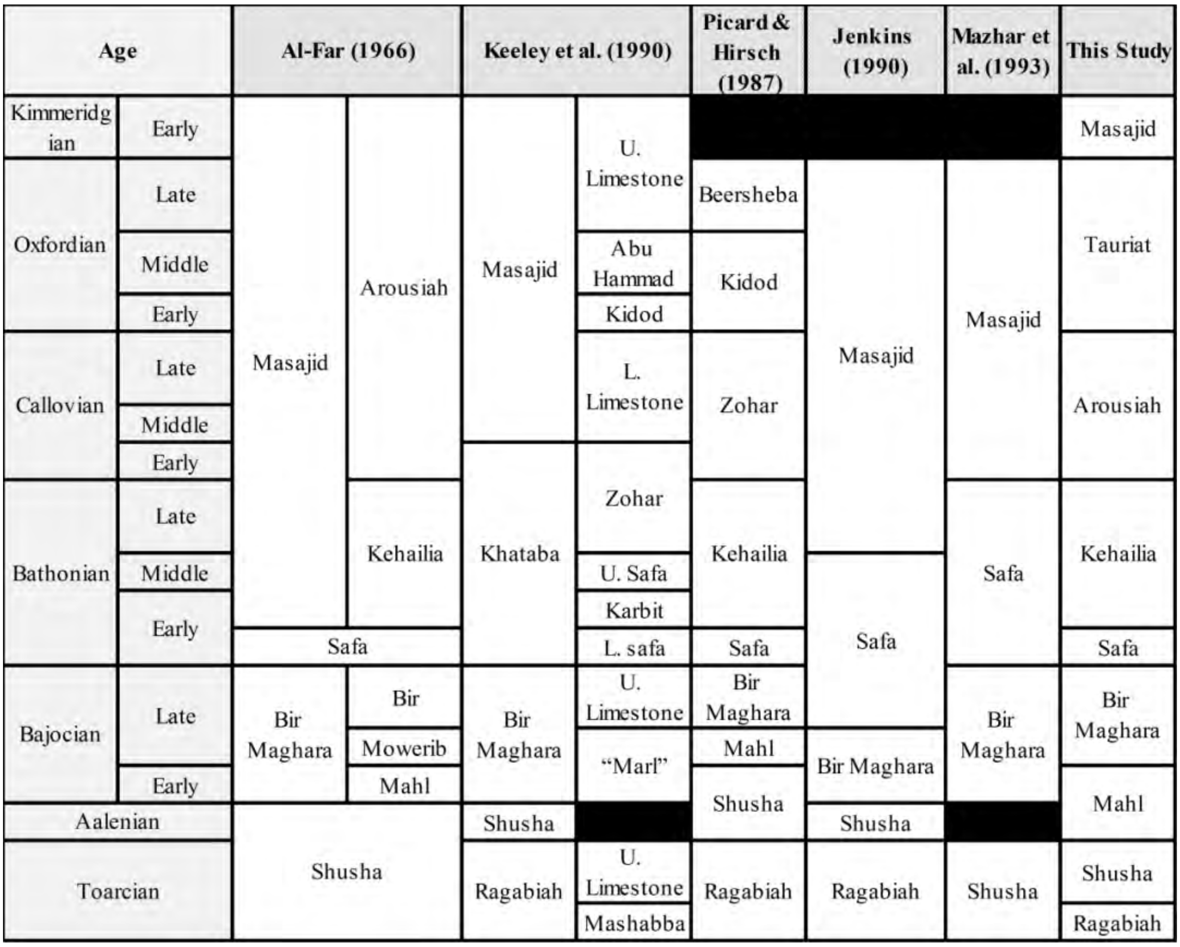
1.5 Data and methods

1.5.1 Field work

Fieldwork in the area of G. Maghara (North Sinai, Egypt) was conducted in October 1995 and from March to May 2012. During these periods, the complete area was surveyed and finally four sections in a W–E transect of around 20 km (Fig. 1.4) were selected for detailed study. Three sections (G. Homayer, G. Arousiah, and G. Engabashi) belong to the western flank of the anticline with a dip of the strata varying from 15 to 30°, while the G. Mowerib section is exposed on the eastern flank dipping at an angle exceeding 60° in some parts.

In order to resolve the facies arrangement of the single cycles and overall sequence architecture, the four sections were measured in detail (e.g., lithology, colour, grain size, sedimentary structures, bioturbation, macrofossils, ichnotaxa, and taphonomic features of biogenic hardparts) using a Jacob Staff, hand lense, and 10% HCl. Samples were taken during logging when thought appropriate and where significant facies and lithological changes were observed. Information on body and trace fossils were taken in the field. Quantitative samples of the macrofauna were taken.

In the case of marly beds specimens were collected from the surface until 100 individuals were obtained if it possible. Hard limestone beds were mechanically bulk sampled and in the case of dense occurrences counting and photographing were done in the field and only representative specimens were collected for further study in the laboratory. Beds showing evidence of reworking such as a high degree of fragmentation and size sorting were not included in the analysis. Trace fossils were documented in the field and integrated in the interpretation but were not considered in the cluster analyses. Facies were partly identified based on field observations.



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<tr><td>Kimmeridgian</td><td>Early</td><td rowspan="10">Masajid</td><td rowspan="7">Arousiah</td><td rowspan="6">Masajid</td><td rowspan="2">U. Limestone</td><td colspan="3"></td><td>Masajid</td></tr>
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<tr><td rowspan="2">Early</td><td>Karbit</td></tr>
<tr><td colspan="2">Safa</td><td>L. safa</td><td>Safa</td><td>Safa</td></tr>
<tr><td rowspan="3">Bajocian</td><td rowspan="2">Late</td><td rowspan="3">Bir Maghara</td><td>Bir</td><td rowspan="3">Bir Maghara</td><td>U. Limestone</td><td>Bir Maghara</td><td rowspan="3">Bir Maghara</td><td rowspan="2">Bir Maghara</td></tr>
<tr><td>Mowerib</td><td rowspan="2">“Marl”</td><td>Mahl</td><td rowspan="2">Bir Maghara</td></tr>
<tr><td>Early</td><td>Mahl</td><td rowspan="2">Shusha</td><td rowspan="2">Mahl</td></tr>
<tr><td colspan="2">Aalenian</td><td colspan="2" rowspan="3">Shusha</td><td>Shusha</td><td></td><td>Shusha</td><td></td></tr>
<tr><td colspan="2" rowspan="2">Toarcian</td><td rowspan="2">Ragabiah</td><td>U. Limestone</td><td rowspan="2">Ragabiah</td><td rowspan="2">Ragabiah</td><td rowspan="2">Shusha</td><td>Shusha</td></tr>
<tr><td>Mashabba</td><td>Ragabiah</td></tr>
</table>

Fig. 1.6.Chronostratigraphic correlation chart for the Middle and Late Jurassic formations of G. Maghara (solid blocks indicate gaps).

1.5.2 Laboratory work

The macrofauna was prepared in the laboratory, and identified down to the species level wherever possible. As the fossils are excellently preserved, taxonomic identification provided only few problems. Primary calcitic shells of brachiopods and bivalves were preserved. In addition, many originally aragonitic shells were preserved in calcite, others as internal moulds. The fauna does not show any evidence of notable deformation. Marl and shale intervals were richer in fossils than limestones. Ammonites and nautiloids are numerically important in several shell beds, but they were not included in the quantitative analysis because of their nektonic mode of life.

For the quantitative analysis of macrofossils, the benthic fauna was counted in order to allow a statistical treatment. The number of bivalve and brachiopod individuals was obtained by adding the number of right or left valves (pedicle and brachial valves in the case of brachiopods) to the number of the articulated valves (‘MNI’-method; Gilinsky and Bennington, 1994). Crinoid skeletal elements and echinoid spines are problematic; morphological criteria were used to merge these elements to arrive at a realistic estimate of the real number of individuals. In some cases, different kinds of taphonomic variables were quantitatively evaluated (e.g., articulation, fragmentation, encrustation, and bioerosion); these were determined as a percentage of the total sample.

Every taxon was coded by separate numbers, the first referring to the position within a geological section and the second referring to a serial number (e.g., E7-199 refers to *Collignonastrea jumarensis* Gregory, 1900 in the seventh sample from the section at G. Engabashi, Appendix B). All fossil material of this study has been deposited in the collections of the Bayerische Staatssammlung für Paläontologie und Geologie in Munich.

1.5.3. Notes on diversity

According to Tuomisto (2010), diversity can be quantified for any dataset where units of observation (individuals) have been classified into types (species). When the dataset consists of, or has been divided into, subunits (i.e. associations or assemblages), then one should differentiate between the total diversity (γ), which can be partitioned into subunits (β=between-habitat) and the mean diversity of a single subunit (α=within-habitat). Alpha diversity represents the number of species in an association or assemblage, which is assumed to represent the relict of a community (Whittaker, 1972).

The Shannon index H, which depends on the number of both individuals and taxa and varies from 0 for a mono-taxon community to high values in the case of a poly-taxon community, is the Alpha-diversity index used; $H= =\sum_i \{n_i/n\} \ln \{n_i/n\}$ where n_i is the number of individuals of the taxon i. Beta diversity expresses the taxonomic differentiation between communities or along environmental gradients (Whittaker, 1972; Tuomisto, 2010) and has been calculated by dividing the total number of species recorded in association by the average number of species found within the association samples (for details see Whittaker, 1960; Tuomisto, 2010).

Although species richness is related to species diversity, they are not the same thing; richness does not take into account the proportional abundances and is equal to the number of taxa (Tuomisto, 2010). The diversity was evaluated using rarefaction to normalize the sample size (Hurlbert, 1971). For the same reason, evenness, which is a metric ranging from 0 (minimal) to 1 (maximum) was also calculated, $E=e^{H}/S$ (Hammer et al., 2001). The dominance index refers to a high density of a single or few taxa, $D=\sum_i\{n_i/n\}^2$ (Hammer et al., 2001).

For the synecological analysis, the trophic nucleus of an association has been defined by those taxa that contribute 80% of the total specimen number per association (Neyman, 1967). The communities and their representative associations/assemblages were classified according to diversity into polyspecific (community with more than 1 taxon) and monospecific (only a single taxon). The term paucispecific as defined here refers to a low-diversity association/assemblage with less than 15 taxa in 50% of the individual samples. In polyspecific associations/assemblages 50% of the individual samples have more than 15 taxa.

1.5.4. Quantitative biostratigraphy (Unitary Associations)

Among many quantitative methods available, the Unitary Associations (UA) method was applied. The choice has been decided by the fundamental properties of the method (deterministic instead of probabilistic), which are optimal in the sense that they give maximal stratigraphic resolution with a minimum of superpositional contradictions, and by the positive comparative studies (Baumgartner, 1984; Boulard, 1993; Galster et al., 2010; Monnet et al., 2011). The UA method constructs concurrent range zones using a fully deterministic approach.

The steps of the method are as follows: (1) The data are compiled into a presence–absence matrix, with samples in rows and taxa in columns. (2) From these data, a discrete sequence of coexistent taxa of minimal duration (‘maximal cliques’; the fundamental unit of the UA) will be constructed. Each UA is characterized by a set of species allowing its identification in the stratigraphic sections. (3) Stratigraphic superpositions of maximal cliques are then inferred from the observed superpositional relationships between the taxa they contain. (4) The longest possible sequence of superposed UA is then used to construct a sequence of UAs. (5) Finally, the original samples are assigned to UAs whenever possible and are thus stratigraphically correlated. The difficult part of the UA theoretical model consists of finding and resolving conflicting stratigraphic relationships (i.e., cyclic structures; for details see Guex, 1991). In the present case, a data matrix was constructed with the Unitary Association method comprising 231 macrobenthic taxa in 93 samples collected from four sections.

1.5.5 Microfacies analysis

Identification of the sedimentological facies is based on field observations in addition to thin-section analyses. Analysis of carbonate rocks using the hand lens in the field were combined with detailed microfacies studies in the laboratory. Forty-two thin-sections were used to investigate the compositional variation of both limestones and sandstones in all sections. Each sample was viewed under a Carl Zeiss optical microscope connected to a digital camera ‘Cyber-shot’. The images obtained were transmitted to a personal computer and were analyzed by Axion Vision v4.8 software.

The classification used to characterize the microfacies follows Dunham (1962). Standard microfacies type (SMT) classification schemes of Wilson (1975) and Flügel (2004) and ramp microfacies types (RMT) of Flügel (2004) were applied. Sedimentary structures, colour, trace fossils, and grain size were the main criteria for siliciclastic facies interpretation. Depositional settings and palaeoenvironmental reconstructions of carbonates were interpreted based on compositional, textural, fabric, and sedimentary data and by comparison with modern environments (Tucker and Wright, 1990). Microfacies were identified along a ramp profile with three main facies belts: outer ramp, mid ramp, and inner ramp (Read, 1985; Burchette and Wright, 1992). Delta type and delta facies were interpreted according to Wright (1985) and Renaud and Kuenzer (2012).

1.5.6 Community analysis

A total 9130 fossils from 134 samples (Appendix C) were used for the multivariate analyses. The data have been normalized to percent abundance for comparison of guild proportions. Samples with less than 30 individuals have been removed from the analysis. Normalizing the data has been done to offset the effect of sampling errors. The final data matrix consists of 138 species and 68 samples. The Unweighted Pair Group Method with Arithmetic Mean (UPGMA) is one of the most popular methods of producing hierarchical clusters in ecology (Legendre and Legendre, 1998; Hammer and Harper, 2006). Q-mode cluster analysis of the species-abundance data set was used to identify the benthic associations. The dendrogram of the cluster has been constructed based on Ward’s method (Euclidian distance).

Moreover, the species/samples matrix has been examined with Non-Metric Multidimensional Scaling (NMDS) and Detrended Correspondence Analysis (DCA). The ordination techniques were implemented to extract high-resolution palaeoenvironmental signals from the data set (Holland et al., 2001; Scarponi and Kowalewski, 2004; Zuschin et al., 2013). NMDS is a useful tool for representing variations in species composition in low number of dimensions. In contrast, DCA has been used in quantifying the gradient in palaeoecological data (De'ath, 1999; Miller et al., 2001; Holland, 2005; Holland and Patzkowsky, 2007; Bush and Brame, 2010).

1.5.7 Palaebiogeographic analysis

The analysis is based on the newly collected material from the study area, including bivalves, ammonites, corals, and brachiopods. In addition, occurrence data from the Bajocian-Oxfordian time interval were downloaded from the Paleobiology Database (http://paleobiodb.org/#/) in January 2014. Taxa with taxonomic uncertainty (i.e., preceded by aff., cf., and ?) were excluded. Subgenera were elevated to generic rank. All taxa concerning bivalves, ammonites, brachiopods, and corals were downloaded twice (species-level and genus-level). In addition, a paper-based database for bivalve species (the Bivalve Catalogue of Fürsich and Werner at the Geozentrum Nordbayern) was used to edit the data matrix (Appendix D). The biogeographic units, their names and ranks are according to Westermann (2000) and Cecca and Westermann (2003). The time slices were resolved to stage level (i.e., Bajocian, Bathonian, Callovian, and Oxfordian). The palaeogeographic reconstructions of Scotese (2001) were applied.

The Unweighted Pair Group Method with Arithmetic Mean (UPGMA) is one of the most popular methods of producing hierarchical clusters in ecology (Legendre and Legendre, 1998). In addition, ordination methods represent a useful approach for visualizing the global relationship of geographic regions according to their taxonomic composition (Achab et al., 1992; Liu, 1995; Liu et al., 1998; Kreft and Jetz, 2010; Vento et al., 2013). Several authors (e.g., Gower and Ross, 1969; Rohlf, 1970; Legendre and Legendre, 1998) highly recommended taking the advantage of both clustering and ordination by combining the results of the two types of analyses on the same diagram during interpretation. As most of the similarity coefficients are affected by different sample sizes, the results become unreliable; consequently, the minimum number of taxon occurrences of an area to be included in the analyses has been set to five. All of the analyses were carried out on Past V.3 (http://www.nhm.uio.no/norlex/past/download.html; Hammer et al., 2001).

2 Stratigraphy

2.1 Lithostratigraphy

Based on observations in the field and on rock and fossil samples in the laboratory, the four measured sections (G. Homayir, G. Arousiah, G. Engabshi, and G. Mowerib) have been drawn in detail (Appendix A) and all information (i.e., lithology, sedimentary structures, macrofossils, trace fossils, and authigenic minerals) have been plotted. The transgressive-regressive cycles have also been interpreted.

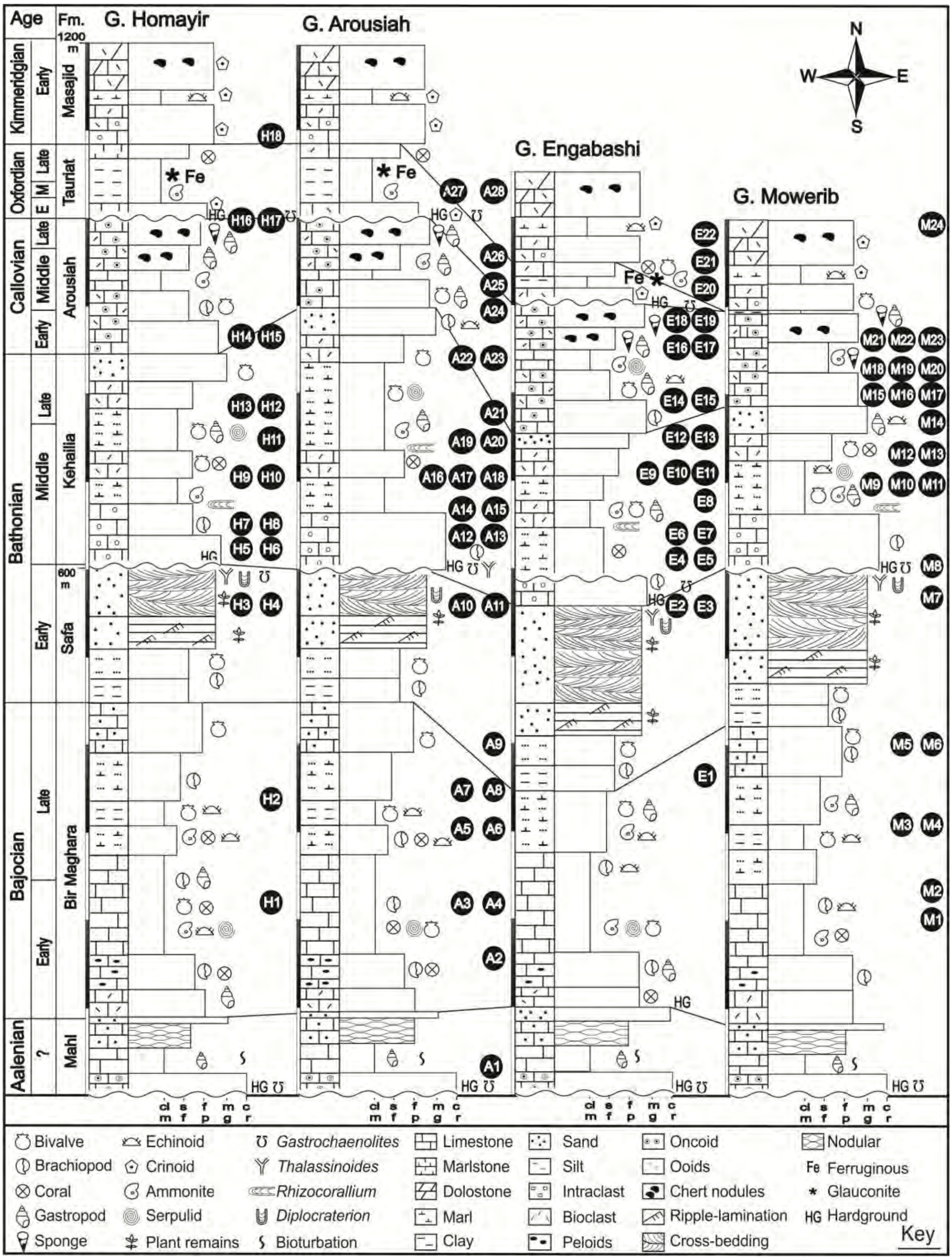

Fig 2.1. Stratigraphic columns of the measured sections with positions of macrofossil samples.

Combining information from both fossils and rocks permitted some modifications of the stratigraphic scheme of Al Far (1966) for the Middle-Upper Jurassic succession. The succession has been subdivided into seven formations (i.e., Mahl, Bir Maghara, Safa, Kehailia, Arousiah, Tauriat, and Masajid). All of these formations were originally introduced by Al Far (1966) or Picard and Hirsch (1987). These formations are laterally continuous and occur in the four measured sections except the Tauriat Formation, which is absent at G. Mowerib (Figs. 2.1, 2.2). The age determination of these formations was estimated based on the quantitative biostratigraphic method (see section 2.2).

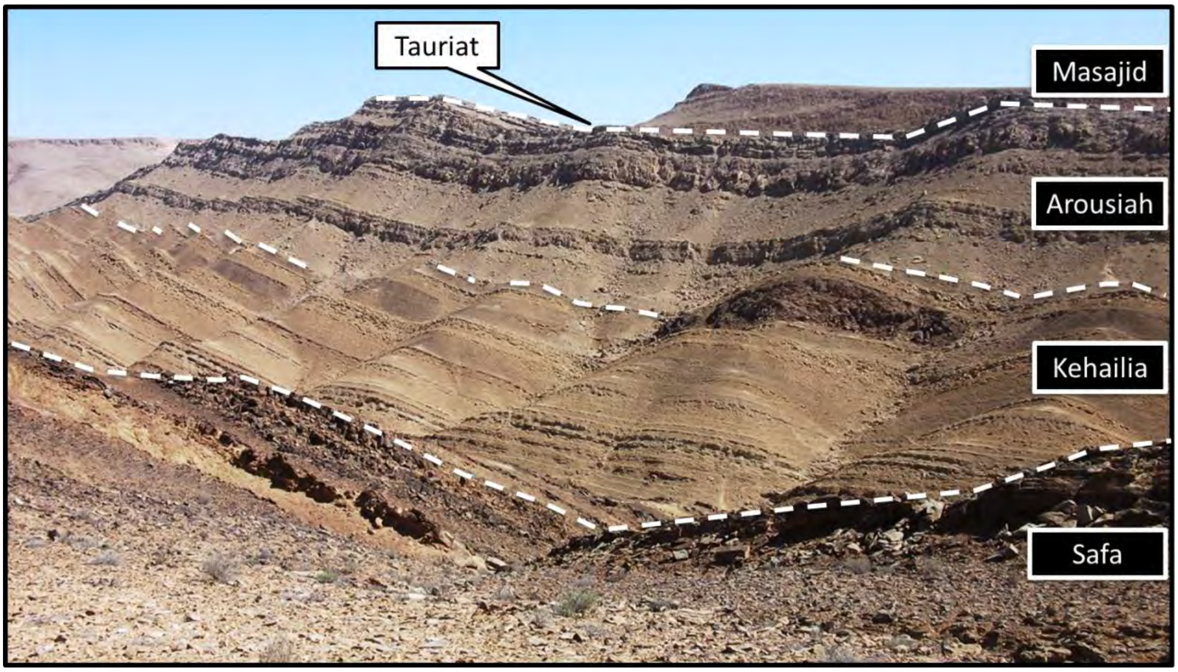

Fig. 2.2. Absence of the Tauriat Formation in the section of G. Mowerib (the eastern flank of the G. Maghara anticline).

2.1.1 Mahl Formation (Aalenian)

The Mahl Formation consists in its lower part of massive, oncolitic algal limestones with intercalated sandstones and shales. Fossils are limited to a single marly wackestone unit with many trochid gastropods. The Mahl Formation overlies the Shusha Formation unconformably, the top of the latter being a ferruginous ersosional surface (Fig. 2.3C), indicating a depositional break at the base of the Middle Jurassic. The formation was originally a member of the Bir Maghara Formation (Al Far, 1966), which was raised to formation rank by Picard and Hirsch (1987). It represents a very shallow tidal facies with extremely rare fossils. Absence of diagnostic fossils makes the age determination very difficult, but based on regional correlation of the upper and lower contacts, the Mahl Formation probably corresponds to the Aalenian.

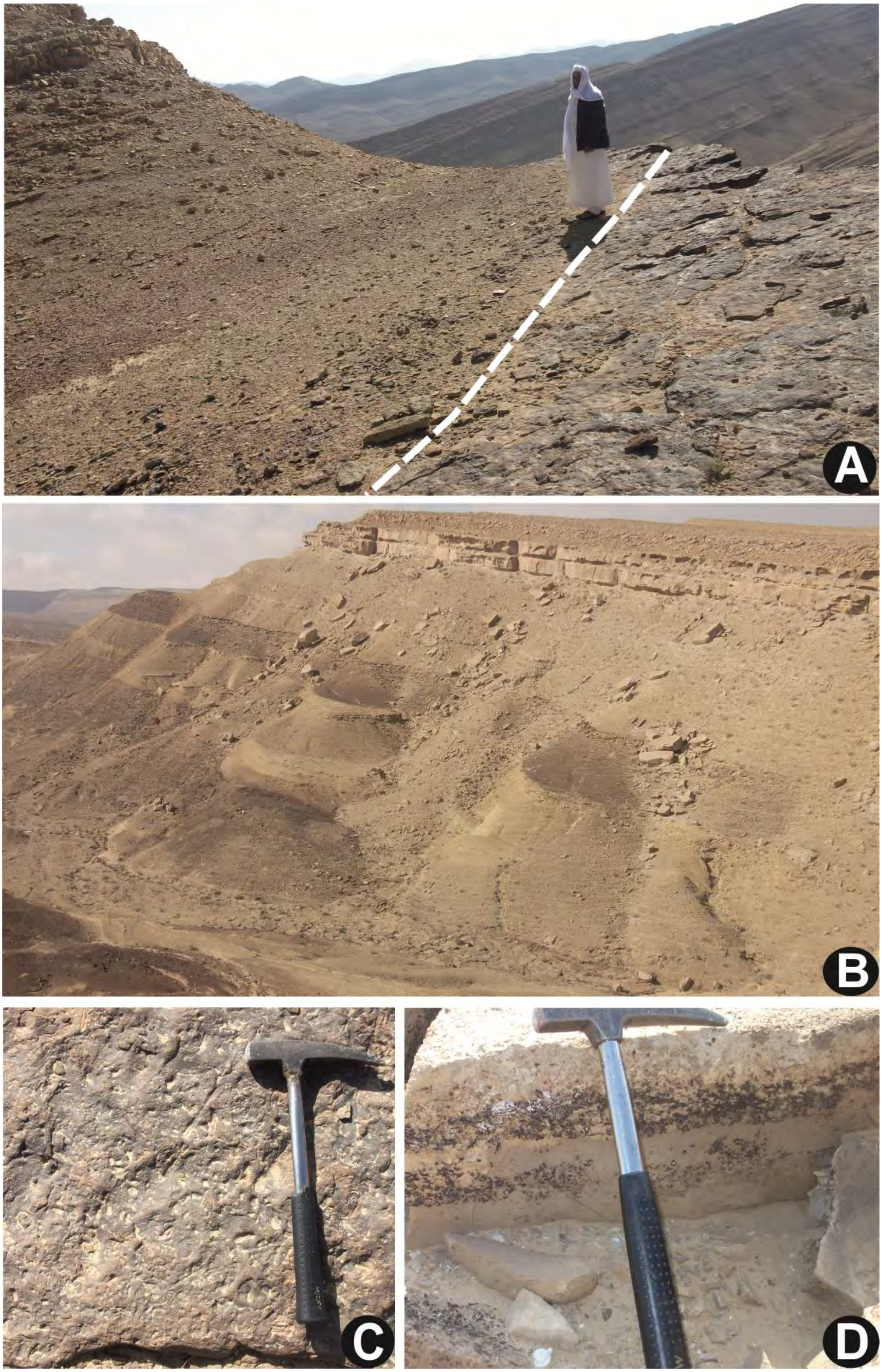

Fig. 2.3. Field photographs of the Aalenian Mahl Fm. (A) Shusha/Mahl contact at Shusht El Maghara (highest point of the Anticline). (B) Type section exposed at Wadi Mahl. (C) Erosional surface at the top of the Shusha Fm. (D) Oncolitic limestone at the base of the Mahl Fm., G. Engabshi section.

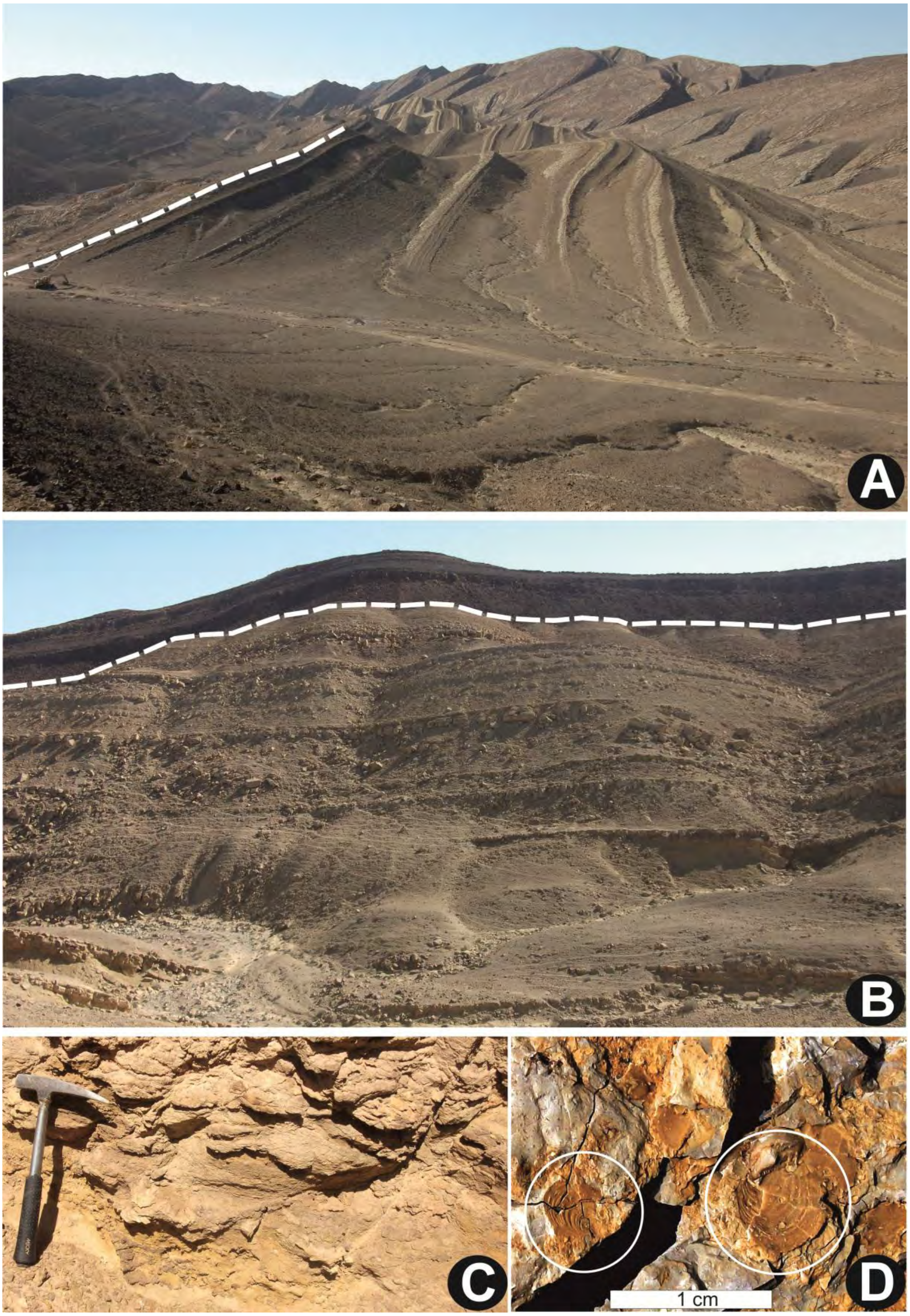

Fig. 2.4. Field photographs of the Bajocian Bir Maghara Fm. (A) Mahl-Bir Maghara contact at the G. Mowerib section. (B) Type section East of Bir Maghara well. (C-D) Bositra-rich shale at the top of the Bir Maghara Fm. at G. Engabashi section.

2.1.2 Bir Maghara Formation (Bajocian)

The Bir Maghara Formation conformably overlies the Mahl Formation (Fig. 2.4). The lower part consists of highly bioturbated, oncolitic packstone and shale, with few fossils including gastropods and corals. Upward the shale is capped by a brown bio-pel-wacke- to packstone with interbedded variegated clay and gypsum. An Early Bajocian age is well defined by beds containing *Normannites egyptiacus*, whereas at the top *Ermoceras* and *Magharina* indicate a Late Bajocian age. In the upper part of the formation, a relatively diverse fauna of brachiopods, bivalves, gastropods, ammonites, and corals is present. Fossils are abundant in sandstones and sandy limestone. This formation represents a shallow subtidal setting dissected episodically by high terrigenous input.

2.1.3 Safa Formation (Early Bathonian)

The Lower Bathonian Safa Formation unconformably overlies the Bir Maghara Formation (Fig. 2.5). It consists of an alternating succession of trough cross-bedded, hematitic arkosic sandstones (Fig. 2.5), ripple-laminated sandstones, and shale with minor limestone beds. Several lenticular economic coal seams occur. The fauna is relatively poor, as much of the formation is marginal-marine. The limestones and sandstones contain *Daghanirhynchia daghaniensis* and *Africogryphaea costellata.* A few shells of *Protocardia* and *Grammatodon* have also been recorded. A low sand ridge in the uppermost part of Safa Formation probably represents a longshore bar, built chiefly by wave action, occurring at some distance from, and generally parallel to, the shoreline, being submerged at least at high tides. The lithofacies, fauna and flora indicate deltaic conditions.

2.1.4 Kehailia Formation (Middle Late Bathonian)

Al Far (1966) assigned the Upper Bathonian-Kimmeridgian marine succession of G. Maghara to the Masajid Formation. He divided this formation into two members, the lower silt-rich Kehailia and the limestone-dominated Arousiah Member. However, based on detailed litho-biofacies analyses the Masajid succession of Al Far has been divided herein into four formations as follows:

The Upper Bathonian Kehailia Formation unconformable overlies the Safa Formation. It consists of yellow calcareous silt and marl with thin, yellow glauconitic limestone intercalations and occasional sandstone interbeds (Fig. 2.6). The Kehailia Formation represents the lower member of Al Far's (1966) Masajid Formation. Based on the ammonite fauna, the Kehailia Formation represents the Middle-Late Bathonian time slice.

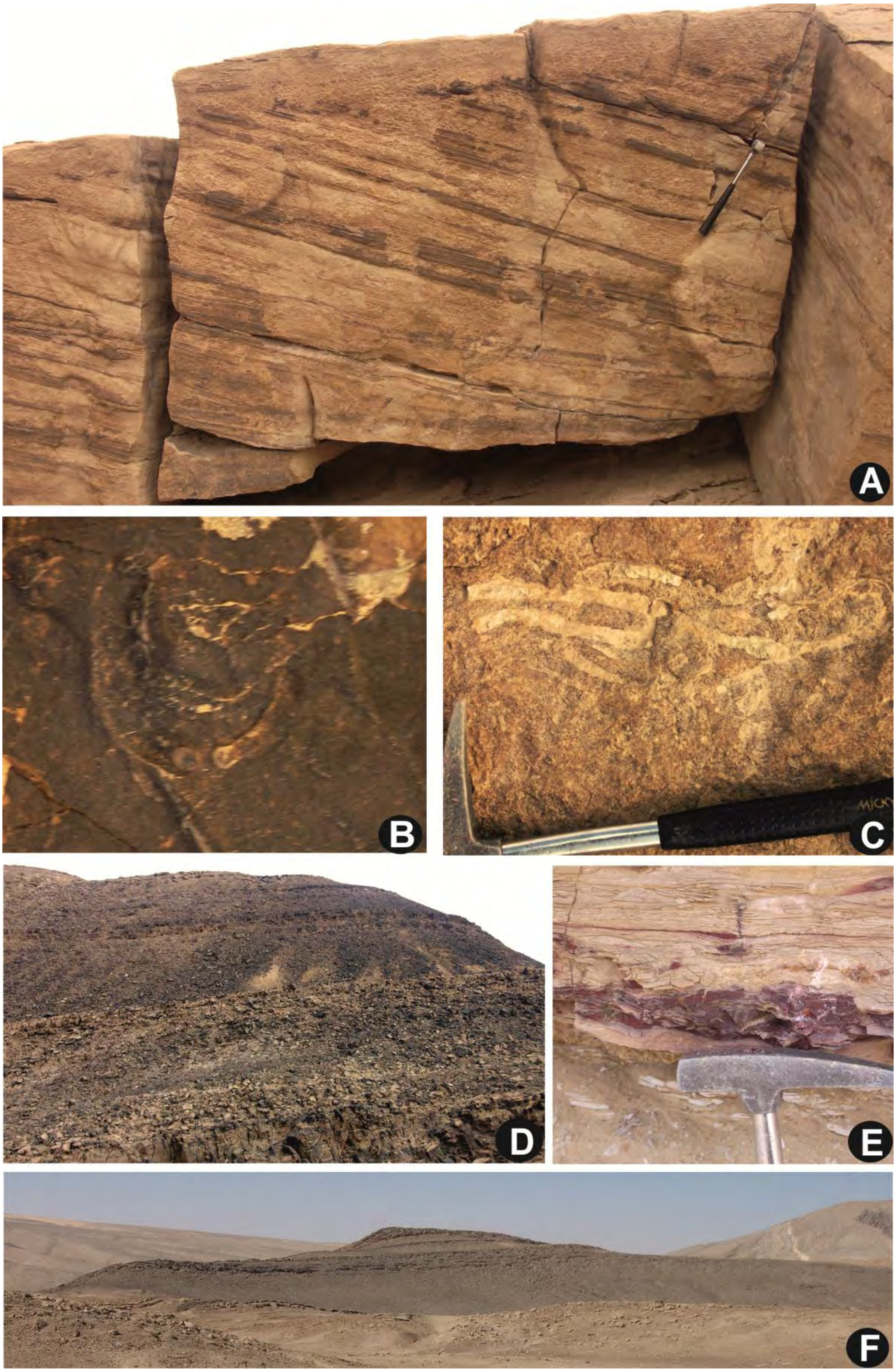

Fig. 2.5. Field photographs of the Early Bathonian Safa Formation. (A) Cross-bedded sandstone typical of the Safa Formation. (B) *Diplocraterion* at the base of the Safa Fm., G. Arousiah section. (C) *Rhizocorallium irregulare*, top of the Safa Fm., G. Engabashi section. (D) Type section of the Safa Fm. exposed at Wadi Safa. (E) Intertidal siliciclastic unit at the base of the Safa Fm., G. Arousia section. (F) Safa Fm. exposed at G. Alasmer (= black in Arabic: the name refers to the dark colour of the ferruginous sandstone beds of the Safa Fm.), top of G. Homayir section.

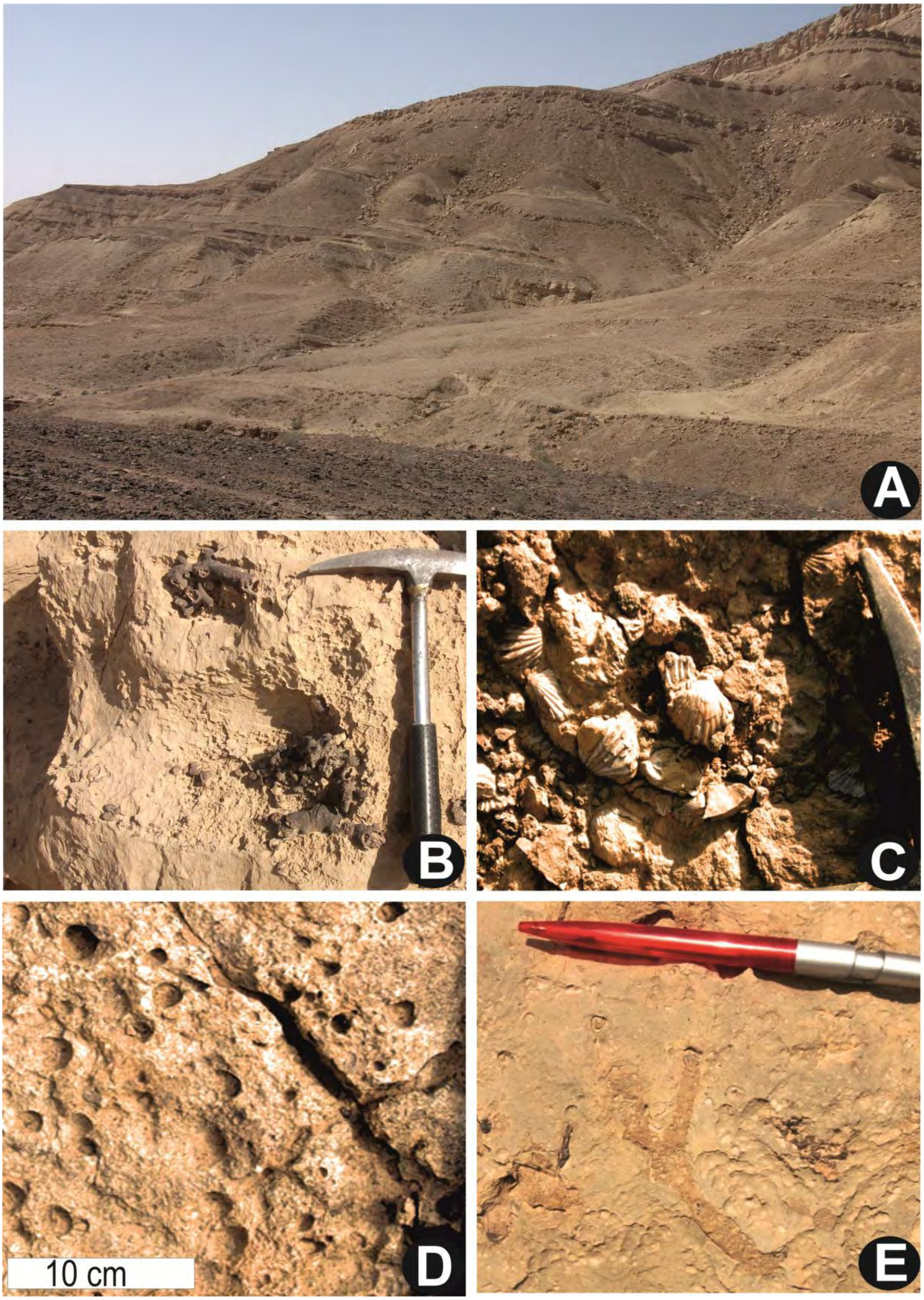

Fig. 2.6. Field photographs of the Middle to Late Bathonian Kehailia Fm. (A) Type section at Wadi Kehailia. (B) Sponges in wackestone bed at G. Engabashi section. (C) Brachiopod-rich marl, G. Engabashi section. (D) Hardground with many *Gastrochaenolites* borings, G. Arousiah section. (E) *Thalassinoides* in a hardground at G. Arousiah section.

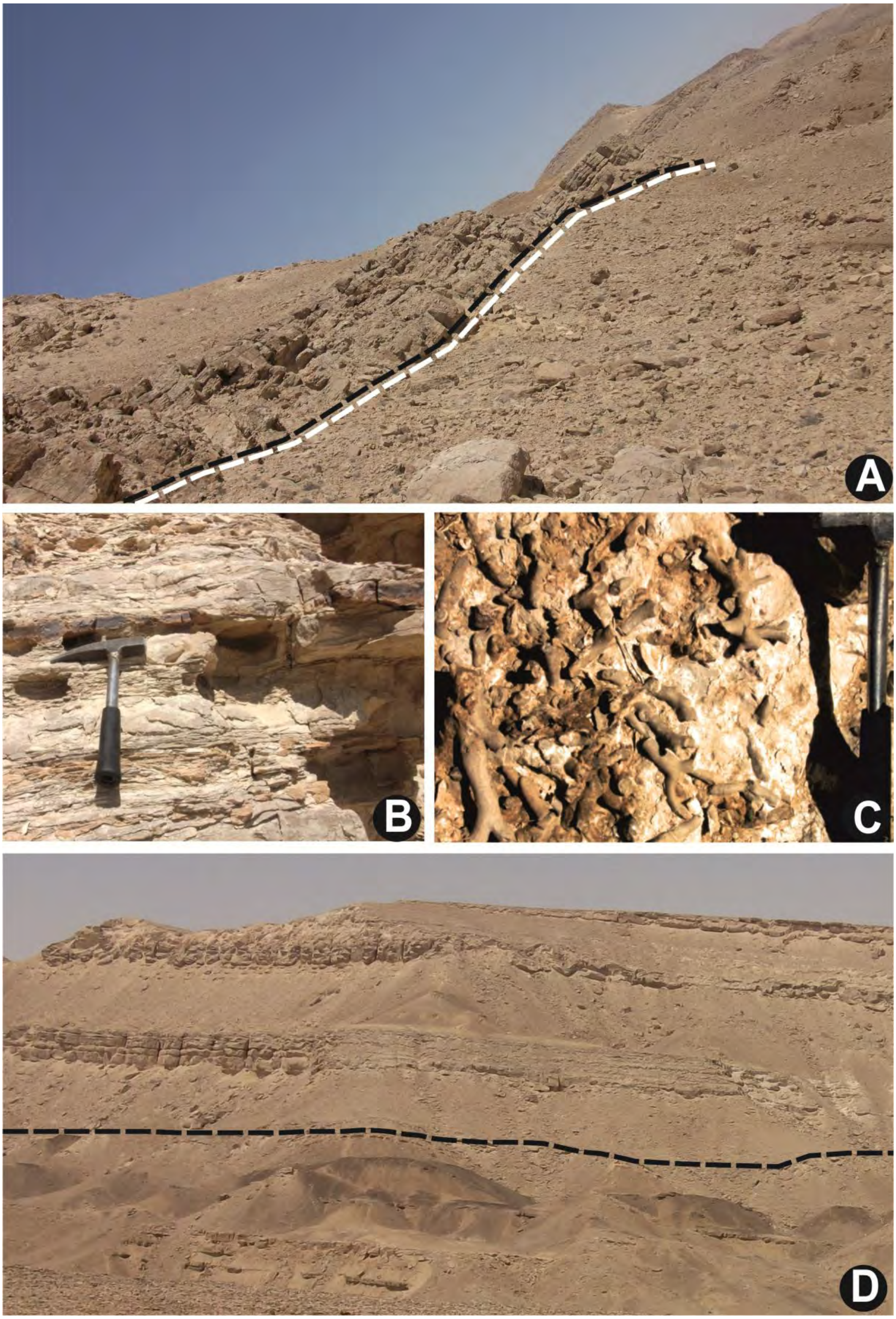

Fig. 2.7. Field photographs of the Callovian Arousiah Formation. (A) Kehailia-Arousia contact, G. Engabashi section. (B) Nodular and layered silica concretions, G. Engabashi section. (C) Concentration of siliceous sponges, G. Engabashi section. (D) Kehailia-Arousia contact (stippled) and the Arousiah type section exposed at G. Arousiah.

2.1.5 Arousiah Formation (Callovian)

The Callovian Arousiah Formation represents the upper member of Al Far's (1966) Masajid Formation. It overlies the Kehailia Formation, but the boundary has been tectonically obliterated. It consists of thick-bedded hemipelagic calcilutites, occasionally onco-wackestones. Detrital quartz sand or marl is rare. Silicification is prevalent as is indicated by nodular and layered chert bands as well as by the silicified fauna (Fig. 2.7).

The Upper Callovian ammonites *Erymnoceras philbyi* Arkell, 1956 and a few specimens of nautilids are the only cephalopods recorded here. Lewy (1981) recognized an unconformity between the earliest and late Callovian strata based on the absence of Middle Callovian ammonites, but the occurrence of ammonites in the whole sections are patchy and scattered. Picard and Hirsch (1987) noted a hardground surface between the Callovian limestones and the overlying Oxfordian Tauriat shales at Gebel Arousiah. They interpreted this as a short depositional break.

2.1.6 Tauriat Formation (Oxfordian)

The Oxfordian Tauriat Formation unconformably overlies the Arousiah Formation. It consists of greenish-yellow calcareous glauconitic shales (Fig. 2.8C), overlain by marl and thin packstones. The lowermost beds are composed of marl and glauconitic packstone. The topmost beds contain *Pholadomya* and colonial corals. Oxfordian ammonites dominate and include *Euaspidoceras*, *Sowerbyceras and Perisphinctes* in addition to belemnites (Douvillé, 1916). This formation is absent in the Mowerib section (Figs. 2.1-2.2), either as result of local tectonics or due to lateral facies changes. The Tauriat Formation was deposited in deeper water, where restricted conditions existed, so that only nektonic ammonites are present.

2.1.7 Masajid Formation (Early Kimeridgian)

The Masajid Formation unconformably overlies the Tauriat Formation (Fig. 2.8). The formation consists of dolomitic, crinoidal grainstones, rich in light-brown to light-yellow lenticular and layered chert concretions similar to those of the Callovian. Fossils are rare in this formation, but some bivalves and echinoid spines have been collected from marl interbeds at the top. Silicification of faunal constituents is also observed. The formation is recorded north of G. Maghara at G. Umm Mafruth. The outcrop consists of dolomitic limestone with cherts and contains a similar echinoid and gastropod fauna as in G. Maghara (Farag, 1947; Said, 1962).

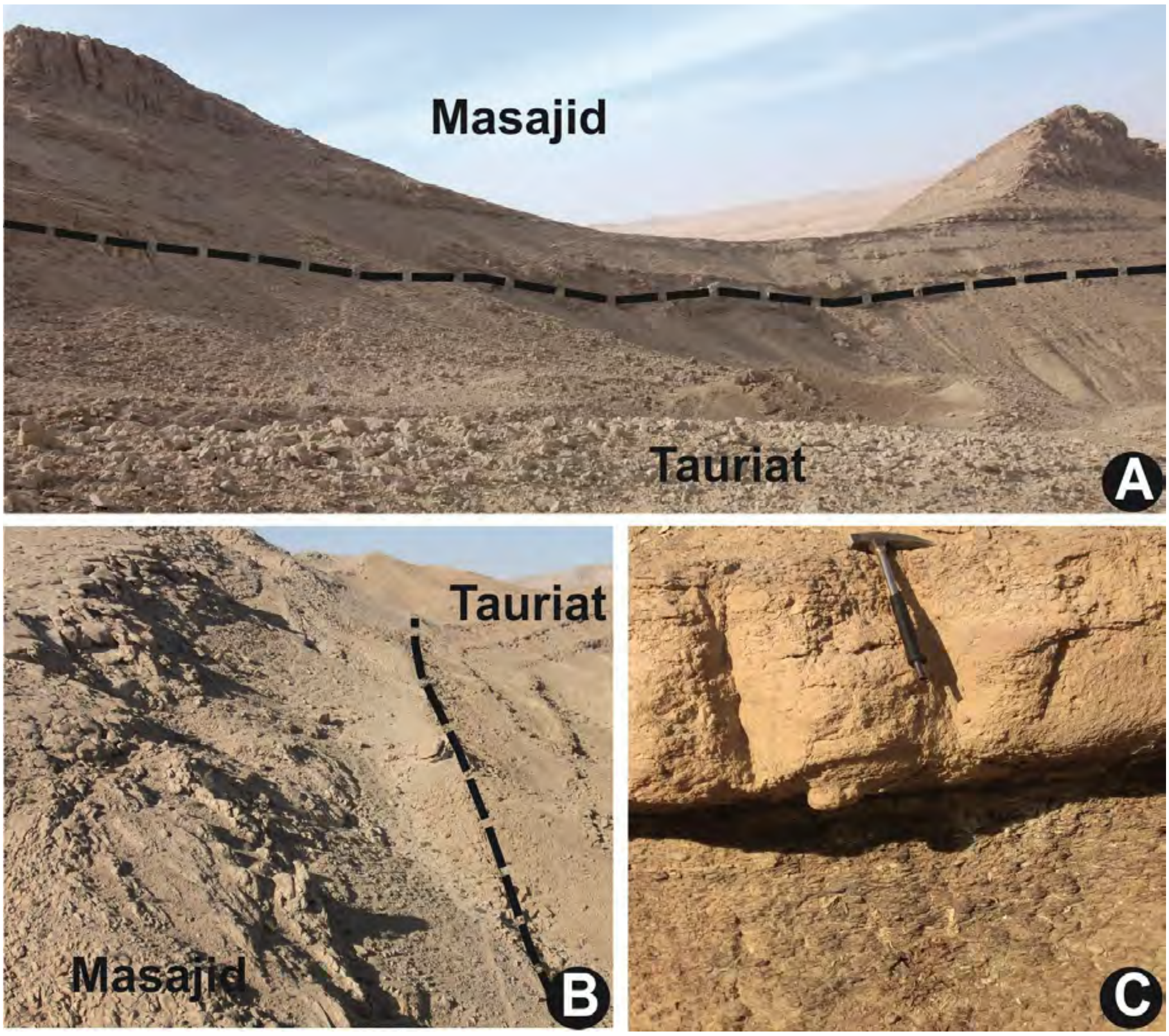

Fig. 2.8. Field photographs of the Tauriat-Masajid contact exposed at Wadi Masajid (A) and at G. Homayir (B), and the ammonite-rich Tauriat shale at G. Engabashi section (C).

2.2 Quantitative biostratigraphy

2.2.1 General issues

Many studies have mentioned a bias regarding singleton taxa, which may represent sampling or preservational noise rather than a diversity signal from a dataset. However, Fitzgerald and Carlson (2006) based on information from Palaeozoic brachiopods, suggested including such taxa in analyses after testing their legitimacy. Moreover, the regression analyses by Cascales-Miñana and Bienvenido Diez (2012) revealed that the number of singletons did not distort the measures of taxonomic diversity and did not influence representation of the main evolutionary patterns of vascular plants.

Shortest-duration taxa may be the most informative taxa for testing diversity gradients, biases in origination, extinction, and turnover rates. Removing these singleton taxa, therefore, may represent incomplete conservative treatment of the data and may remove more important rapid evolutionary stages (Fitzgerald and Carlson, 2006). Based on the field observations and taphonomic characteristics of the fauna from G. Maghara (i.e., rarity of mixing and reworking of shells, limited role of early diagenetic dissolution, the autochthonous nature of the taxa, in addition to that fact that many of singleton taxa are ammonites), singletons were included in the Unitary association method.

2.2.2 Unitary Associations method (UA)

The biochronological analysis was based on the Unitary Associations (UA) method. The analysis was preceded by removal of taxa with uncertain systematic position, because primary analyses indicated that they significantly increase the amount of biostratigraphic contradictions while being of no correlation value. The dataset contains 80 such uncertain taxa (Appendices B, C). The analysis led to 29 UAs. The dataset contains 1073 conflicting stratigraphic relationships (1593, before removing the uncertain taxa) between 56 maximal cliques. These numbers represent the complexity of the dataset and the difficulty of being treated by the classical empirical biostratigraphic methods. The UA-graph provides accompanying tools for assessing the quality of the dataset itself, such as tracing the origin of the conflicting stratigraphic relationships between taxa. The high contradiction observed within the database may result from the fact that many taxa have a poor lateral documentation and long ranges, in addition to poorly constrained superpositional relationship (most of the taxa are ecologically controlled such as bivalves, gastropods, brachiopods, and corals).

The results of the UA method is complemented by a reproducibility matrix (Fig. 2.9A), which indicates which UA is identified in which section. This enables to assess the lateral (geographical) reproducibility of each UA, which is important for correlations. As some UAs have a low lateral reproducibility and thus a poor correlation potential, the UAs are merged into unitary association zones (UAZ) of higher geographic reproducibility (Fig. 2.9B). These merges are suggested automatically by the Past software, but one of these suggestions was split based on lithologic criteria in addition to the results of the reproducibility matrix.

The basic result of the UA method is a composite range chart displaying the vertical distribution of the taxa within the proposed UA (Fig. 2.10). Based on lateral reproducibility of each UA (Fig. 2.9A), physical absence (but virtual presence) of certain UA in some beds or some sections was recognized and the biochronological boundaries were estimated. If the lateral reproducibility of a single UA is low, a set of UAs (suggested merges; Fig. 2.9B) which are most reproducible, will construct the biochronozones. Two relative values of reproducibility are given, the number of sections in which a given UA has been identified (R1) and the proportion of identified UA versus potentially identifiable ones (R2; for details see Guex, 1979; 1991). The values of reproducibility R1 and R2 are only guidelines. Subjective criteria such as coincidence with major lithological boundaries, marker beds, and bioevents were taken into account for the identified biochronozones. If, for any given UA, R1 falls below 3.0 and R2 falls below 0.3 it is considered insufficient for the definition of a biochronozone or subzone (Guex, 1979; 1991).

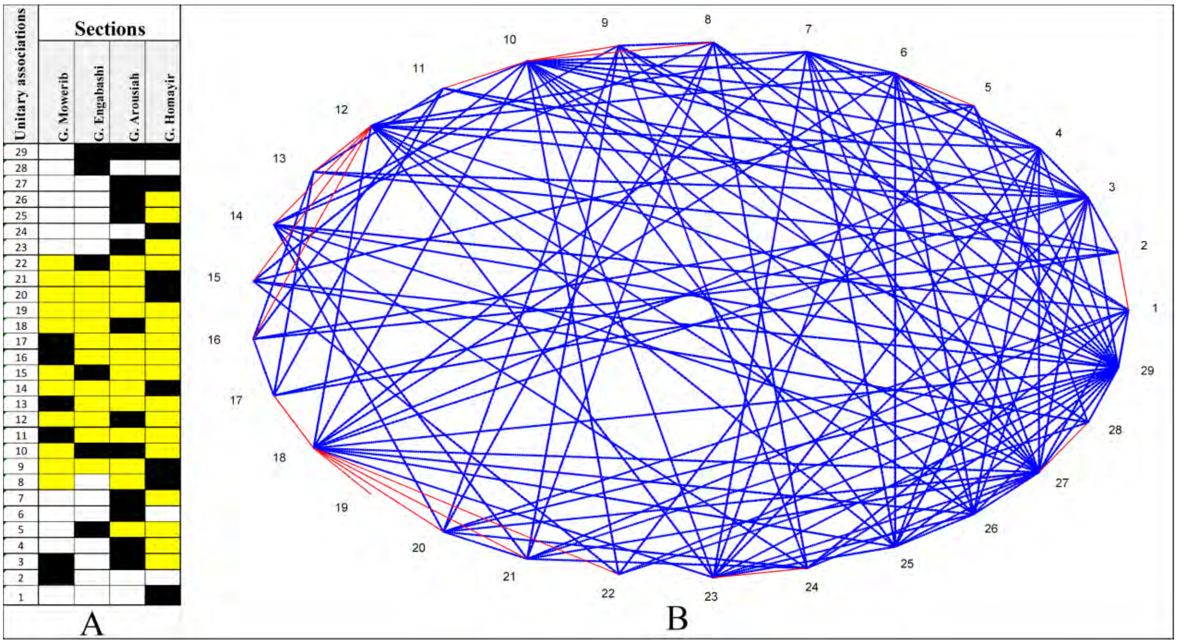

Fig. 2.9. (A) Reproducibility matrix. Black squares mark coexistence, yellow ones documented virtual coexistence (see text). (B) Suggested UA mergers (biozonation). These mergers are shown as red lines, while blue lines show superpositional relationships.

2.2.3 Unitary Association Zones (UAZ) and interregional correlation

In the proposed zonal scheme, the species representing each UAZ were selected based on their biostratigraphic validity (i.e., ammonites, occurrence in many sections, and relative abundance). The ammonites of the UAZ were also compared with the equivalent Tethyan ammonite zones based on the index ammonite taxa of the study area (Figs. 2.11-2.12), which have been used as age indicators (Arkell et al., 1952, Arkell, 1956; Imlay, 1984; Parnes, 1988; Enay et al., 1986, 1987; Enay and Mangold, 1994, 1996). When the UA have a valuable lateral continuity (high reproducibility) they were used as age boundary, while in case of low reproducibility, these UA may be only an equivalent to a Tethyan ammonite zone(s). Biochronology was estimated based on Gradstein et al. (2012).

UAZ 1 *Normannites egyptiacus* (170.3–169.5 MY)

UAZ 1 is Early Bajocian in age and is defined by the first and last occurrence of the ammonite *Normannites egyptiacus* (Fig. 2.11) and by the occurrence of *Thamboceras mirium, Normannites flexus,* and *Strigoceras (S.) strigifer*. This zone is also marked by a high relative abundance of the brachiopod *Cymatorhynchia quadriplicata*. It consists of pack-/grainstones of the lower part of the Bir Maghara Fm. in G. Mowerib and G. Homayir.

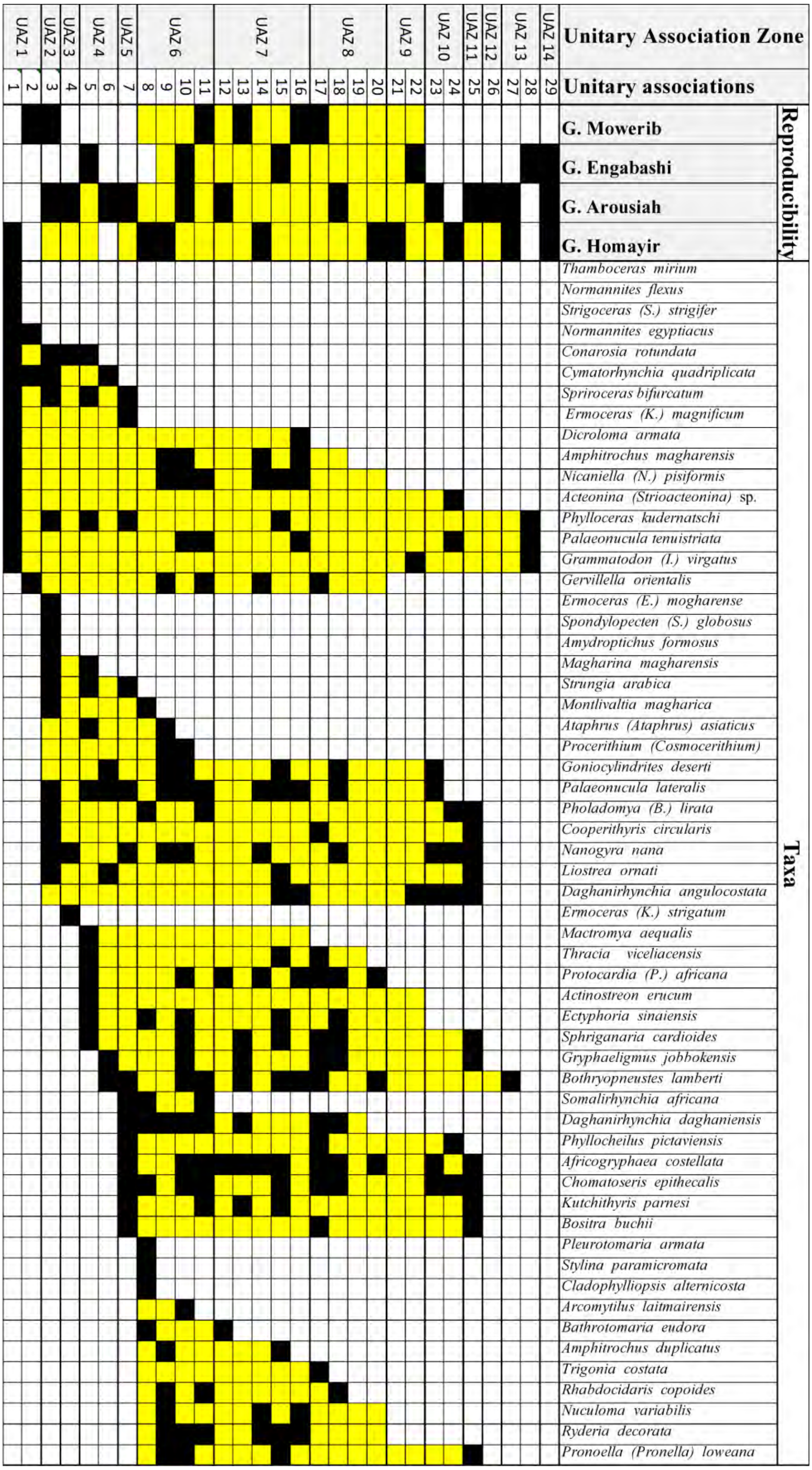

Fig. 2.10. The reconstructed UA range chart and UA zones resulting from the successive biochronological analyses of the raw dataset. Black squares mark coexistence, yellow ones documented virtual coexistence (see text).

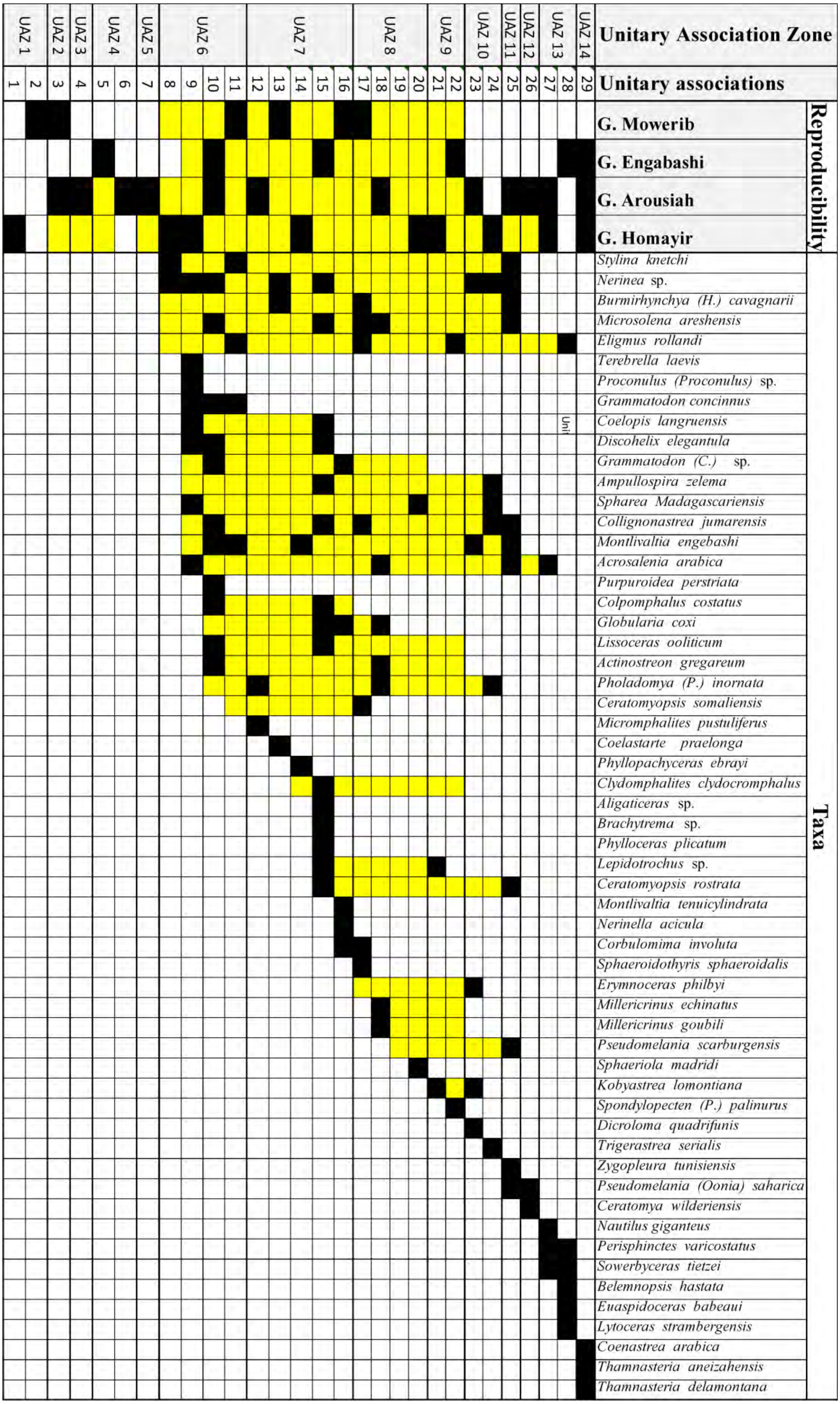

Fig. 2.10 (continued).

Normannites and *Lissoceras* are common not only in G. Maghara and the Middle East (Douvillé, 1916; Arkell et al., 1952; Parnes, 1988), but also in the Early Bajocian of Southern Alaska (Imlay, 1984). UAZ 1 corresponds to the Tethyan ammonite zones *Stephanoceras humphriesianum, Sonninia propinquans, Witchellia laeviuscula,* and *Hyperlioceras discites*.

UAZ 2 *Ermoceras (E.) mogharense* (169.5–169.1 MY)

UAZ 2 is early Late Bajocian in age and comprises the total range of *Ermoceras (E.) mogharense* (Fig. 2.12)*, Spondylopecten (S.) globosus,* and *Amydroptichus formosus*. In addition, it is characterized by a high relative abundance of the brachiopod *Conarosia rotundata*. It corresponds to the upper part of the Bir Maghara Formation in the G. Mowerib, G. Arousiah, and G. Homayir sections. The abundances and species richness are low. *Ermoceras* and *Leptosphinctes* characterize the Upper Bajocian of the Ethiopian Province, including Libya, Israel, southern Turkey, southern Iran, and Saudi Arabia (Parnes, 1988; Enay et a1., 1986, 1987; Enay and Mangold 1994, 1996). UAZ 2 probably corresponds to the Tethyan ammonite zone *Strenoceras niortense.*

UAZ 3 *Ermoceras (K.) strigatum* (169.1–168.7 MY)

UAZ 3 is middle Late Bajocian in age comprising the upper part of the Bir Maghara Formation and is defined by the total range of the ammonite *Ermoceras (K.) strigatum* in addition to the first occurrence of *Magharina magharensis*. It is recognized in the G. Arousiah and G. Homayir sections consisting of fine-grained siliciclastic rocks and marls. UAZ 3 corresponds to the Tethyan ammonite zone *Garantiana garantiana.*

UAZ 4 *Magharina magharensis* (168.7–168.3 MY)

UAZ 4 is marked by the last occurrence of *Magharina magharensis* (Fig. 2.12) and *Cadomites (C.) psilacanthus* with a high abundance of *Protocardia (P.) africana* and *Actinostreon erucum.* It is late Late Bajocian in age, characterized by high species diversity and a small ferruginous fauna. It consists of clay and sandy limestone that encompass the topmost part of the Bir Maghara Formation in the G. Arousiah, G. Engabashi, and G. Homayir sections. Both abundances and diversities are high. *Cadomites (C.) psilacanthus* was recorded from the Late Bajocian of France and Germany (Fernández-López et al., 2009). UAZ 4 corresponds to the Tethyan ammonite zone *Parkinsonia parkinsoni.*

UAZ 5 *Africogryphaea costellata* (168.3–167.4 MY)

UAZ 5 comprises abundant *Africogryphaea costellata* together with the rhynchonellid *Daghanirhynchia daghaniensis.* This zone encompasses a delta succession characterized by very low diversity faunas. It is Early Bathonian in age, comprises the Safa Formation, and was recorded in the G. Arousiah and G. Homayir sections. Early Bathonian ammonites are rare or even absent not only in Egypt but also in the Indo-Malgach Province (=Ethiopian, Kenya, Madagascar, and India; Fernández-López et al., 2009). However, a single species (*Thambites planus*) was recorded from the base of the Safa Formation (Arkell et al., 1952; Parnes, 1988). UAZ 5 corresponds to the Tethyan ammonite zones *Sonninia propinquans, Witchellia laeviuscula,* and *Hyperlioceras discites*.

UAZ 6 *Stylina paramicromata* (167.4–167.0 MY)

UAZ 6 is early Middle Bathonian in age comprising the total range of the corals *Stylina paramicromata* and *Cladophylliopsis alternicosta,* the gastropods *Purpuroidea perstriata, Terebrella laevis,* and *Pleurotomaria armata*, and the bivalve *Grammatodon (G.) concinnus* in addition to high relative abundances of the solitary coral *Chomatoseris epithecalis* and the terebratulid *Eudesia (Sphriganaria) cardioides*. It is found in a marly silt horizon with few limestones interbeds encompassing the lower part of the Kehailia Formation in the G. Arousiah and G. Homayir sections. UAZ 6 corresponds to the Tethyan ammonite zones *Procerites aurigerus* and *Zigzagiceras zigzag.*

UAZ 7 *Micromphalites pustuliferus* (167.0–166.6 MY)

UAZ 7 comprises the total range of *Micromphalites pustuliferus* (Fig. 2.12), *Phyllopachyceras ebrayi, Coelastarte praelonga, Montlivaltia tenuicylindrata,* and *Nerinella acicula* in addition to a high relative abundance of the bivalve *Nicaniella (N.) pisiformis. Micromphalites* has been recognized from the Middle Bathonian of India (Pandey et al., 2009) and from Saudi Arabia (Enay et al., 1987). UAZ 7 corresponds to the Tethyan ammonite zones *Cadomites bremeri, Morrisiceras morrisi,* and *Tulites subcontractus* (see also Fernández-López et al., 2009). It is mainly associated with silt and marl characterized by very high species diversities and encompasses the middle part of the Kehailia Formation. UAZ 7 is late Middle Bathonian in age.

UAZ 8 *Sphaeroidothyris sphaeroidalis* (166.6–166.1 MY)

The zone comprises the total range of the terebratulid *Sphaeroidothyris sphaeroidalis* and the heterdont bivalve *Sphaeriola madridi* with high relative abundances of the bivalves *Trigonia costata, Nuculoma variabilis, Ryderia decorata,* and *Pronoella (Pronoella) loweana*. The zone encompasses the topmost part of the Kehailia Formation, consists of thin-bedded sandy onco-packstones and was recorded in the G. Arousiah, G. Engabashi, and G. Mowerib sections. UAZ 8 corresponds to the Tethyan ammonite zones *Clydoniceras discus* and *Hecticoceras retrocostatum.* UAZ 8 is Late Bathonian in age.

UAZ 9 *Spondylopecten (P.) palinurus* (166.1–164.6 MY)

UAZ 9 is Early Callovian in age and comprises the total range of *Spondylopecten (P.) palinurus* in addition to a high relative abundance of the rhynchonellid *Daghanirhynchia angulocostata*. This zone encompasses the upper part of the Kehailia Formation, which consists of sandstones with minor oo-packstone interbeds and was recorded in the G. Homayier and G. Engabashi sections. An Early Callovian age was assigned to this zone. UAZ 9 corresponds to the Tethyan ammonite zones *Macrocephalites gracilis* and *Bullatimorphites bullatus.*

		Saudi Arabia	Levant Margin	Present paper	
Kimmeridgian	Early				
Oxfordian	Late			UAZ 14	*Perisphinctes varicostatus*
	Middle			UAZ 13	
	Early			UAZ 12	
Callovian	Late		*Pachyceras*	UAZ 11	*Pachyceras lalandeanum*
	Middle	*Pachyerymnoceras*	*Erymnoceras*	UAZ 10	*Erymnoceras philbyi*
	Early			UAZ 9	
Bathonian	Late	*Dhrumaites*	*Bullatimorphites*	UAZ 8	*C. clydocromphalus*
	Middle	*C. clydocromphalus*	*Micromphalites*	UAZ 7 UAZ 6	
				UAZ 5	
	Early	*Thambites planus*	*Thambites planus*		
Bajocian			*Cadomites*	UAZ 4	*Magharina magharensis*
	Late	*Spiroceras*	*Spiroceras bifurcatum*	UAZ 3	*Ermoceras (K.) strigatum*
		Ermoceras	*Ermoceras runcinatum*	UAZ 2	*Ermoceras (E.) mogharense*
	Early	*Normannites* *Dorsetensia*	*Normannites* *Dorsetensia*	UAZ 1	*Normannites egyptiacus*

Fig. 2.11. The index ammonites of G. Maghara and their equivalents in Saudi Arabia and Levant Margin (for sources see text).

UAZ 10 *Erymnoceras philbyi* (164.6–164.0 MY)

UAZ 10 is Middle Callovian in age and encompasses the middle part of the Arousiah Formation. It comprises the partial ranges of *Erymnoceras philbyi, Trigerastrea serialis,* and *Dicroloma quadrifunis* in addition to a high relative abundance of *Ampullospira zelema*, and was recorded in the G. Homayier and G. Arousiah sections. *Erymnoceras, Pachyceras,* and *Pachyerymnoceras* are abundant in the Middle Callovian of Saudi Arabia (Arkell et al., 1952; Enay et al., 1986), in the Levant Margin (Hudson, 1958; Lewy, 1983; Imlay, 1970; Gill et al., 1985) in addition to India (Thierry, 1980). Probably, UAZ 10 is equivalent to the Tethyan ammonite zones *Erymnoceras coronatum* and *Reineckeia anceps.* UAZ 10 is found in a marl unit rich in ferruginous concretions and laminated silica nodules.

UAZ 11 *Zygopleura tunisiensis* (164.0-163.5 MY)

UAZ 11 comprises the total range of *Zygopleura tunisiensis* and the first occurrence of *Pseudomelania (Oonia) saharica* in addition to high relative abundances of "*Nerinea*" sp. and *Goniocylindrites*. This zone encompasses the upper part of the Kehailia Formation, which consists mainly of onco-wacke-/packstones and corresponds to the Late Callovian. UAZ 11 was recorded from G. Arousiah. A single specimen of the genus *Pachyceras lalandeanum* was recorded from this interval. This species was also recorded from the Upper Callovian of Israel (Levy, 1983; Gill et al., 1985). Most likely, UAZ 11 is equivalent to the Tethyan ammonite zones *Quenstedtoceras lamberti* and *Peltoceras athleta.*

UAZ 12 *Ceratomya wilderiensis* (163.5–160.8 MY)

UAZ 12 comprises the total range of the bivalve *Ceratomya wilderiensis* and the last occurrence of the gastropod *Pseudomelania (Oonia) saharica.* It is Early Oxfordian in age and was recorded from G. Arousiah. It consists of marl with few thin limestone beds. UAZ 12 encompasses the lower part of the Tauriat Formation and is probably equivalent to the Tethyan ammonite zones *Cardioceras cordatum* and *Quenstedtoceras mariae.*

UAZ 13 *Perisphinctes varicostatus* (160.8–159.7 MY)

UAZ 13 comprises the total range of *Perisphinctes varicostatus* and *Sowerbyceras tietzei* (Fig. 2.13)*,* in addition to *Euaspidoceras babeaui*, *Lytoceras strambergensis, Nautilus giganteus,* and *Belemnopsis hastatus*. It corresponds to the middle part of the Tauriat Formation, which is composed of condensed shales with minor silt intercalations. *Euaspidoceras* and *Perisphinctes* are abundant genera in the Middle Oxfordian (Arkell, 1956). UAZ 13 probably corresponds to the Tethyan ammonite zones *Perisphinctes plicatilis* and *Gregoryceras transversarium,* which indicate a Middle Oxfordian age.

UAZ 14 *Coenastrea arabica* (159.7–157.3 MY)

UAZ 14 comprises the total range of the corals *Coenastrea arabica*, *Thamnasteria aneizahensis*, and *Thamnasteria delemontana*. All these colonial coral occur in a high abundance. UAZ 14 corresponds to the upper marly part of the Tauriat Formation and is of Late Oxfordian age. It was recorded from the G. Engabashi, G. Arousiah, and G. Mowerib sections. The upper contact of UAZ 14 coincides with the sharp boundary between the marly Tauriat Formation and the calciruditic Masajid Formation, which contains different faunal assemblages comprising echinoids, crinoids, and chaetetid sponges, and thus may coincide with the Early Kimmeridgian. Probably, UAZ 14 corresponds to the Tethyan ammonite zone *Perisphinctes bifurcatus* and to the lower part of the *Epipeltoceras bimammatum* Zone.

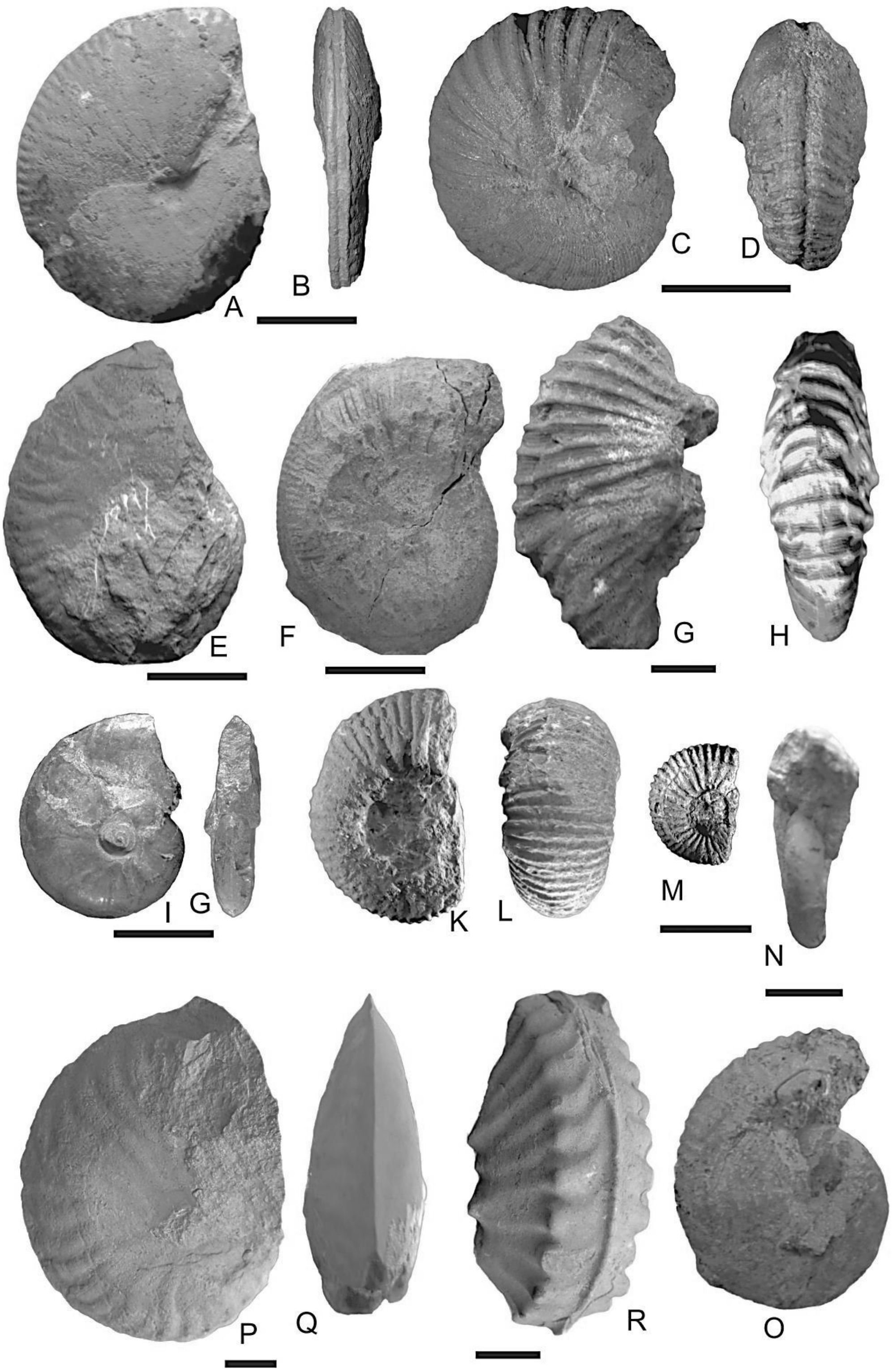

Fig. 2.12. The index ammonites of G. Maghara. (A-B) *Thamboceras mirium*, Bir Maghara Fm., Early Bajocian, G. Homayir section. (C-D) *Ermoceras (Kosmermoceras)* strigatum, Bir Maghara Fm., Late Bajocian, G. Homayir section. (E) *Strigoceras (S.) strigifer*, Bir Maghara Fm., Early Bajocian, G. Engabashi section. (F) *Cadomites (C.) psilacanthus*, Bir Maghara Fm., Late Bajocian, G. Engabashi section. (G-H) *Ermoceras (E.) mogharense*, Bir Maghara Fm., Late Bajocian, G. Engabashi section. (I-G) *Magharina magharensis*, Bir Maghara Fm., Late Bajocian, G. Engabashi section. (K-L) *Normannites egyptiacus*, Bir Maghara Fm., Early Bajocian, G. Engabashi section. (M) *Normannites flexus*, Bir Maghara Fm., Early Bajocian, G. Engabashi section. (N-O) *Phyllopachyceras? ebrayi*, Kehailia Fm., Middle Bathonian, G. Arousiah section. (P-Q) *Clydomphalites clydocromphalus*, Kehailia Fm., Middle Bathonian, G. Arousiah section. (R) *Micromphalites pustuliferus*, Kehailia Fm., Middle Bathonian, G. Arousiah section. Scale:1=1 cm.

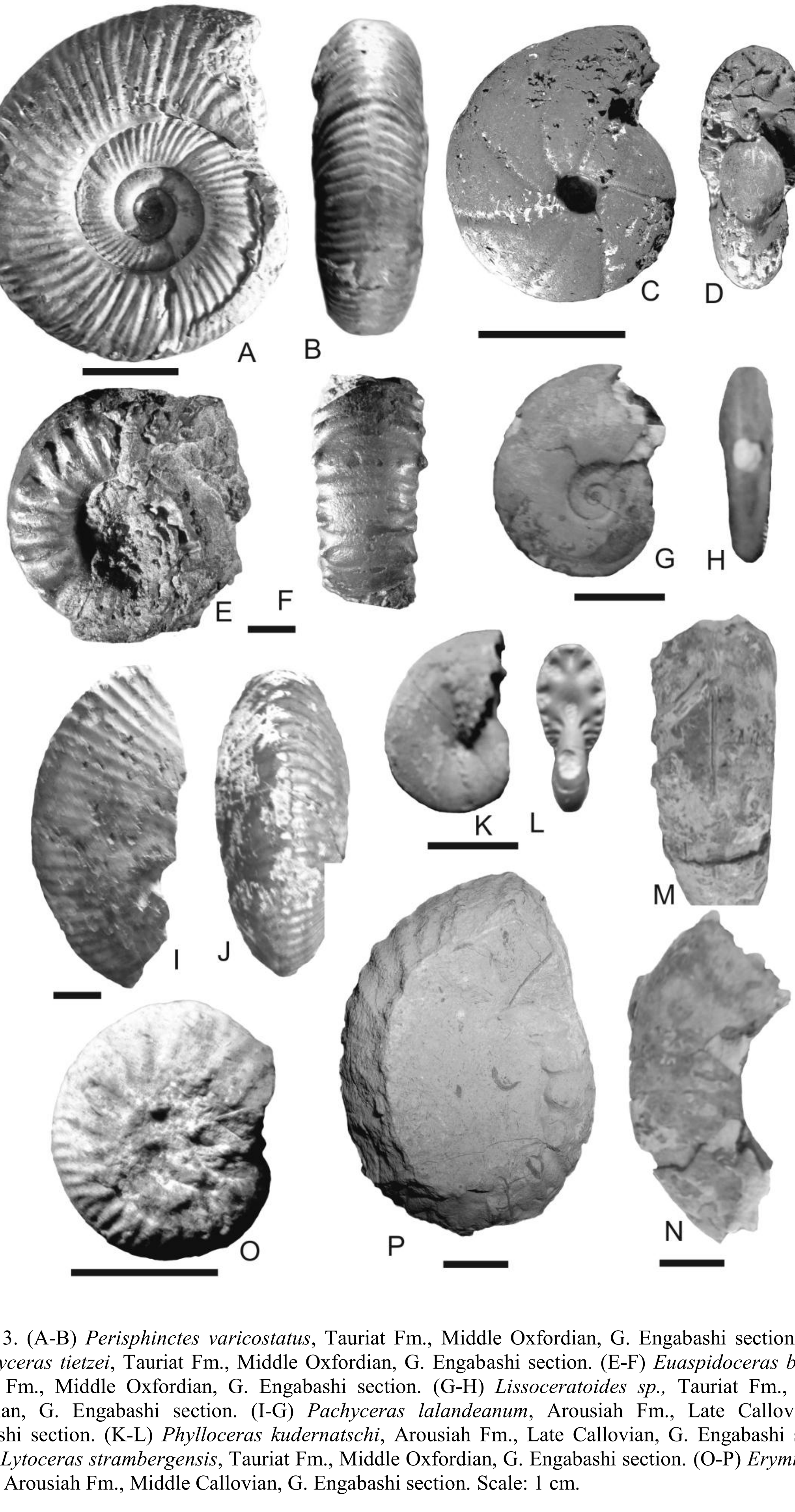

Fig. 2.13. (A-B) *Perisphinctes varicostatus*, Tauriat Fm., Middle Oxfordian, G. Engabashi section. (C-D) *Sowerbyceras tietzei*, Tauriat Fm., Middle Oxfordian, G. Engabashi section. (E-F) *Euaspidoceras babeaui*, Tauriat Fm., Middle Oxfordian, G. Engabashi section. (G-H) *Lissoceratoides sp.,* Tauriat Fm., Middle Oxfordian, G. Engabashi section. (I-G) *Pachyceras lalandeanum*, Arousiah Fm., Late Callovian, G. Engabashi section. (K-L) *Phylloceras kudernatschi*, Arousiah Fm., Late Callovian, G. Engabashi section. (M-N). *Lytoceras strambergensis*, Tauriat Fm., Middle Oxfordian, G. Engabashi section. (O-P) *Erymnoceras philbyi*, Arousiah Fm., Middle Callovian, G. Engabashi section. Scale: 1 cm.

3 Facies analysis

3.1 Facies description

3.1.1 Inner ramp

Wavy interbedded siliciclastics

This facies consists of thin interbedded layers of fine- to medium-grained sandstone and silty clay which are characterized by ripple or wavy lamination (Fig. 3.1A-B). The clay layers contain wood fragments and plant remains. Tidal processes such as the alternation of bed-load and suspension-load deposition cause rapid alternations of grain sizes (Dalrymple, 1992). Deposits of tidal flats have been found repeatedly in the upper part of the Shusha Formation and in the topmost part of the Bir Maghara Formation. In the latter, these siliciclastics enclose some gypsum interbeds, indicating arid conditions at the Bajocian-Bathonian boundary. The facies represent proximal areas of the intertidal zone.

Dolomitic silty wackestone

The white laminated silty wackestones are partially dolomitized. The lower bedding plane is sharp, while the upper one is slightly bioturbated. Some lensoidal gypsum beds less than 3 cm thick are common, the gypsum having a fibrous nature. A few siliciclastic particles, including quartz grains, occur as does dispersed organic matter. Mica and feldspar grains occur in very small quantities. Intergrain areas are occupied by micrite or neomorphic microspar and dolomite. The dolomitic grains are often dark under crossed nicols. In hand specimens this lithology is light brown with dark spots of dolomite (Fig. 3.1C). In thin-sections, it is characterised by clotted peloidal micrite mixed with silt (Fig. 3.1D).

Laminated micrite and rare fossils in addition to a mud-supported fabric suggest a very low energy tidal environment. The preservation of lamination is attributed to the scarcity of benthic organisms and consequently lack of bioturbation. The gypsum results from oxidation of sedimentary sulphide minerals such as pyrite during diagenesis or weathering. This facies has been encountered in the lower part of the Mahl Formation. This facies is interpreted as having formed in the lower part of the intertidal zone.

Calcareous sandstone

Brown, well sorted fine- to medium-grained, low-angle planar cross-bedded sandstone (Fig. 3.1E-F). Rare, small bivalve fragments could be observed. Well preserved trace fossils include *Thalassinoides* and *Diplocraterion.*

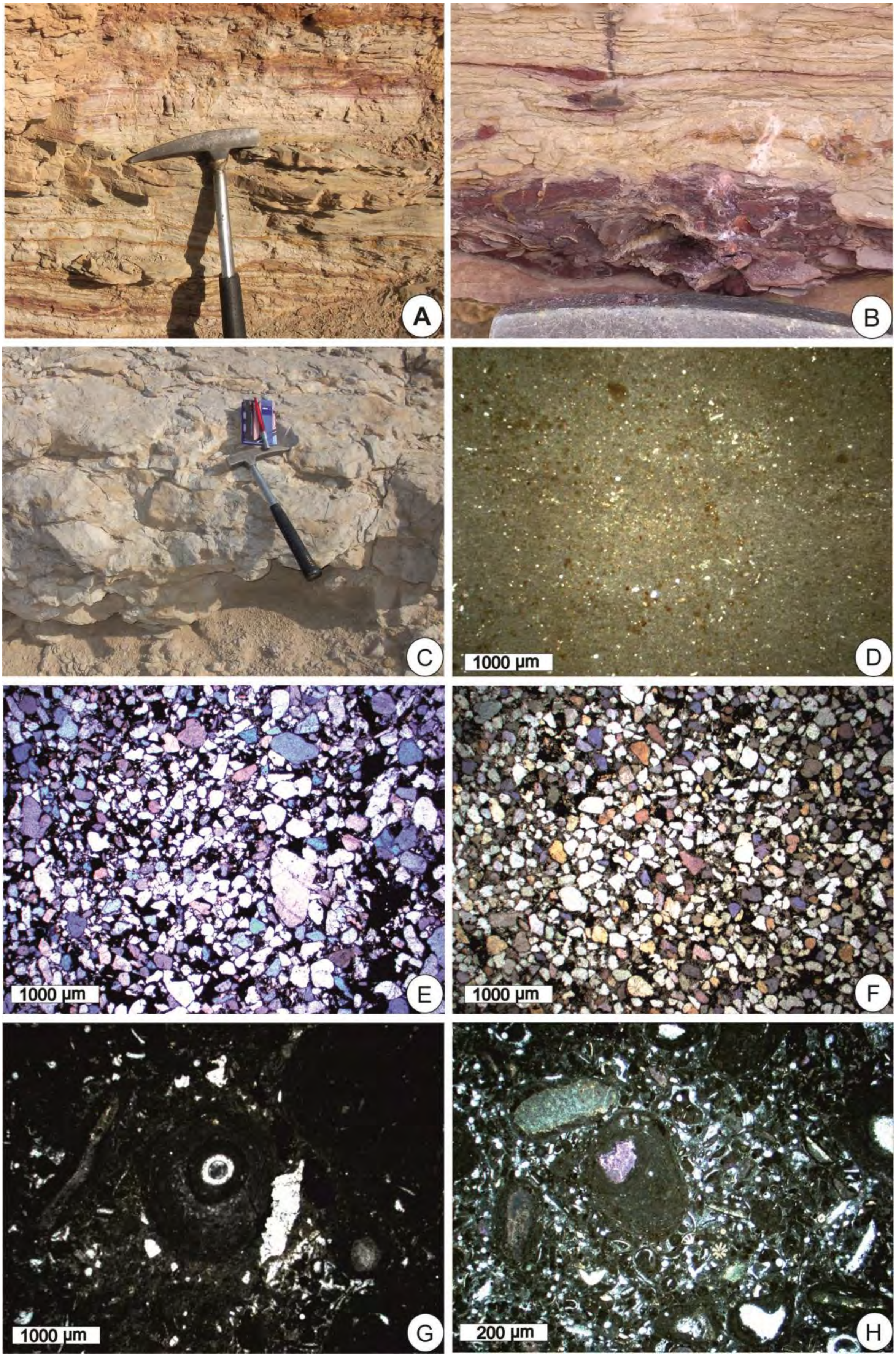

Fig. 3.1. Outcrop photos and photomicrographs of the proximal inner ramp facies. (A) Wavy interbedded siliciclastics of tidal origin, top of the Shusha Fm. (B) Flaser bedding sandstone, top of the Bir Maghara Fm. (C) Dolomitic wackestone, Mahl Fm. (D) Intraclastic wackestone, Mahl Fm. (E) Arkosic sandstone of shoreface origin, Bir Maghara Fm. (F) the same facies, Kehailia Fm. (G-H) Onco-bio pack- to grainstone from the lower part of the Mahl Fm.

This facies indicates a high-energy nearshore environment, possibly a beach and upper shoreface. The brown or red colours result from impregnation with iron oxide minerals. A well oxygenated shoreface environment with normal marine salinity is proposed.

Algal onco-bio-grain- to packstone

Medium-grained, medium-bedded, well sorted grain-/packstone. The grains include bioclasts, oncoids, and a few intraclasts (Figs. 3.1G-H, 3.2A-B). The most common skeletal grains are algae, sponge spicules, coated gastropod fragments, and corals. The sediment is highly bioturbated. A few ooids are also present. Most of the shell fragments are encrusted. The fine micritic matrix increases upward in abundance.

This facies is similar to RMF 21 described by Flügel (2004) from the shallow subtidal zone (around the FWWB) of a ramp system. Oncoids and very well-preserved gastropods are often interpreted as having been deposited in lagoonal environments (Brigaud et al., 2009). The facies was deposited in a comparatively high energy lower shoreface environment. It has been found in the lowermost parts of both the Mahl and the Bir Maghara Formation.

Bio-pel-wacke- to packstone

Medium- to thick-bedded grey limestone. Peloids are common to abundant (up to 80%; Fig. 3.2C-F), spherical or ellipsoidal and show weak sorting. In some beds, they form a densely packed, grain-supported fabric. Other grains include some bivalve shells, sponge spicules, ostracods, calcareous algae, and foraminifers. Pyritisation is common. A few oncoids and ooids are also present.

This facies is similar to SMF 16 and RMF 19 described by Flügel (2004) from sandy shoals above the FWWB. The palaeoenvironment can be interpreted as a shallow, low-energy, restricted lagoon (Wilson, 1975). The abundance of lime mud indicates quiet conditions. Oncoids and very well-preserved gastropods are often interpreted as having been deposited in protected lagoonal environments. Peloids associated with foraminifera, oncoids, ooids, and cyanobacteria are also common in lagoonal environments. According to Flügel (2004), a mud-dominated fabric rich in peloids may form under a semiarid climate and restricted water circulation and lead to hypersaline conditions with a restricted fauna. The low diversity of bioclasts and the dominance of peloids in this facies most likely represent a relatively restricted lagoon on an inner ramp with a poor connection to the middle ramp and with weak currents (e.g., Romero et al., 2002; Martini et al., 2007; Bádenas et al., 2010).

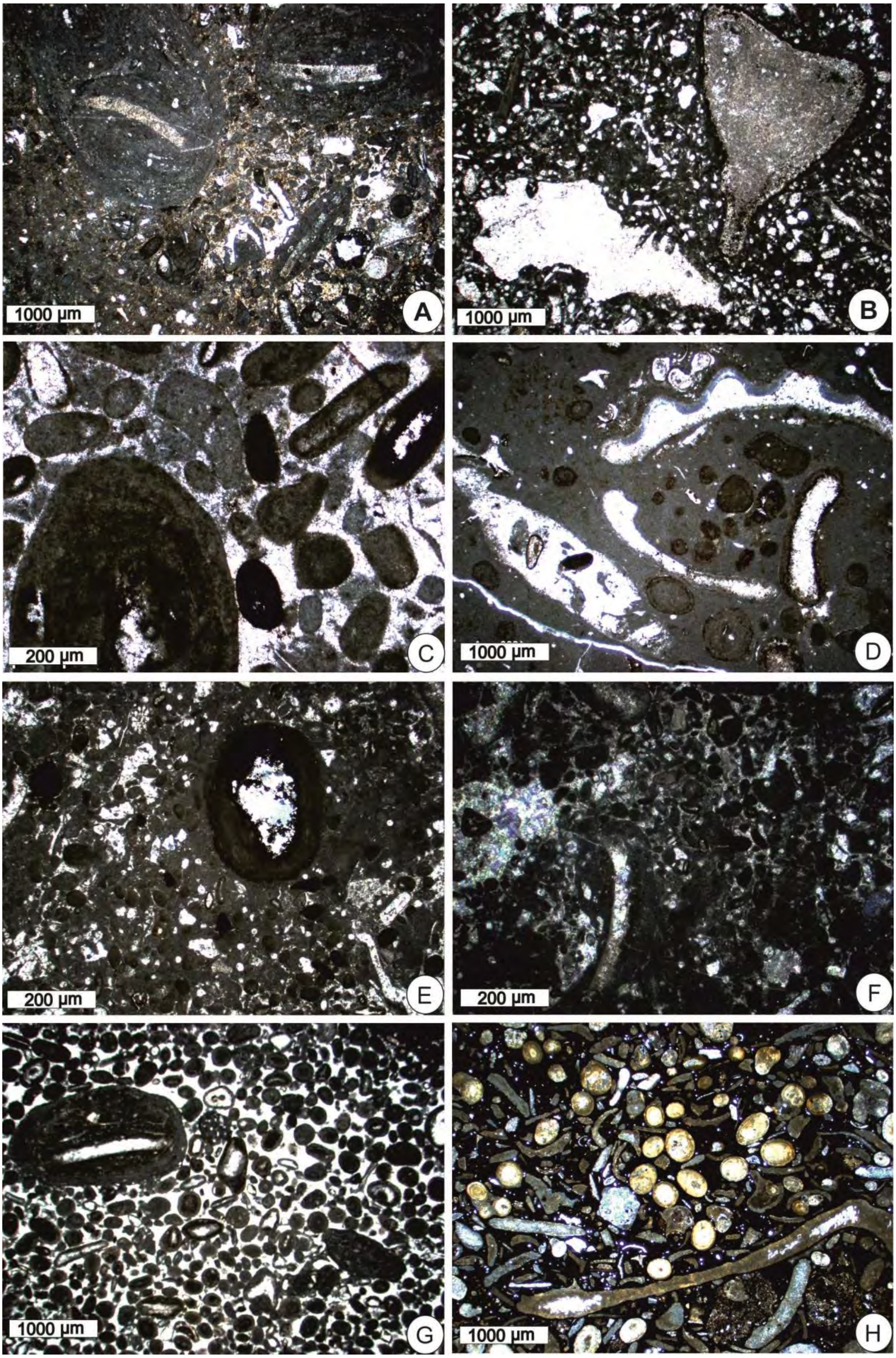

Fig. 3.2. Photomicrographs of the main lithofacies types of the distal inner ramp facies. (A) Onco-grainstone, Mahl Fm. (B-F) Restricted to open lagoonal peloidal facies, Bir Maghara Fm. (B) Pel-bio-grainstone. (C) Pel-grainstone. (D) Bio-pel-floatstone. (E-F) Pel-bio-packstone. (G) Pel-oo-grainstone, Upper Bathonian Kehailia Fm. (H) Bio-oo-packstone, lower part of the Kehailia Fm.

Bio-oo-pack- to grainstone

Thin, graded beds of grainstone with common chamositic ooids and abundant poorly sorted bioclasts. The major non-biogenic components are brownish, spherical ooids, 0.5-1 mm in diameter, partly recrystallized, with quartz grains or bioclasts as nuclei and multiple concentric layers. Some of the ooids are broken. Brownish micrite is also present. Bioclasts are also abundant. The texture is grain-supported with moderately sorted grains (Fig. 3.2G-H). Stratification is absent in thin-sections as well as in the outcrop.

This facies is similar to SMF 15-C and RMF 29 described by Flügel (2004) from sandy shoals above the fair-weather wave-base (FWWB). The moderate to high degree of winnowing and sorting of particles indicates deposition under moderate to high-energy conditions, which is also supported by the occurrence of some micrite. Most likely this facies represents oolitic shoals. Deposition took place under conditions that allowed some carbonate mud to settle into the intergranular space in somewhat protected settings among oolite shoals and bars. The co-occurrence of ooids with marine fauna likely supports a high-energy shoal setting above the FWWB (Strasser, 1986). Oolitic and bioclastic shoals commonly separate restricted lagoons from deeper ramp environments (Flügel, 2004) and act as extensive barriers to currents and waves. The presence of echinoderms, brachiopods, and bryozoans suggests well-oxygenated waters with normal salinity. This facies has been found in the lower and upper parts of the Kehailia Formation.

3.1.2 Middle ramp

Bio-onco-wacke- to floatstone

Components are large rhodoliths consist mainly of coralline red algae, dasycladalean algae, and porostromate algae, mainly *Girvanella* (Fig. 3.3D) with some chaetetid coralline sponges. The oncoids are commonly bored. The oncoids are elliptical, spherical shapes being rare. The laminae are discontinuous and asymmetric with respect to both shape and width (Fig. 3.3A), and usually consist of two layers, an inner dark micritic layer formed by cyanobacteria and an outer lighter one formed by loosely packed thalli of encrusting coralline algae. The nucleus is usually a big bioclast that occasionally were completely disintegrated (Fig. 3.3C). The common bioclasts include molluscs, sponge spicules, bryozoan, and foraminifera (mainly *Trocholina*; Fig. 3.3A-D).

This facies is similar to RMF 8 and RMF 9 described by Flügel (2004) from deep middle to outer ramp settings around the SWB. A moderate to low-energy, quiet-water conditions are indicated by lack of evidence of rolling, by branched oncoids, and by the dominance of micrite. An oncolitic floatstone facies with complete fossils may indicate regressive conditions (e.g., Wright, 1983).

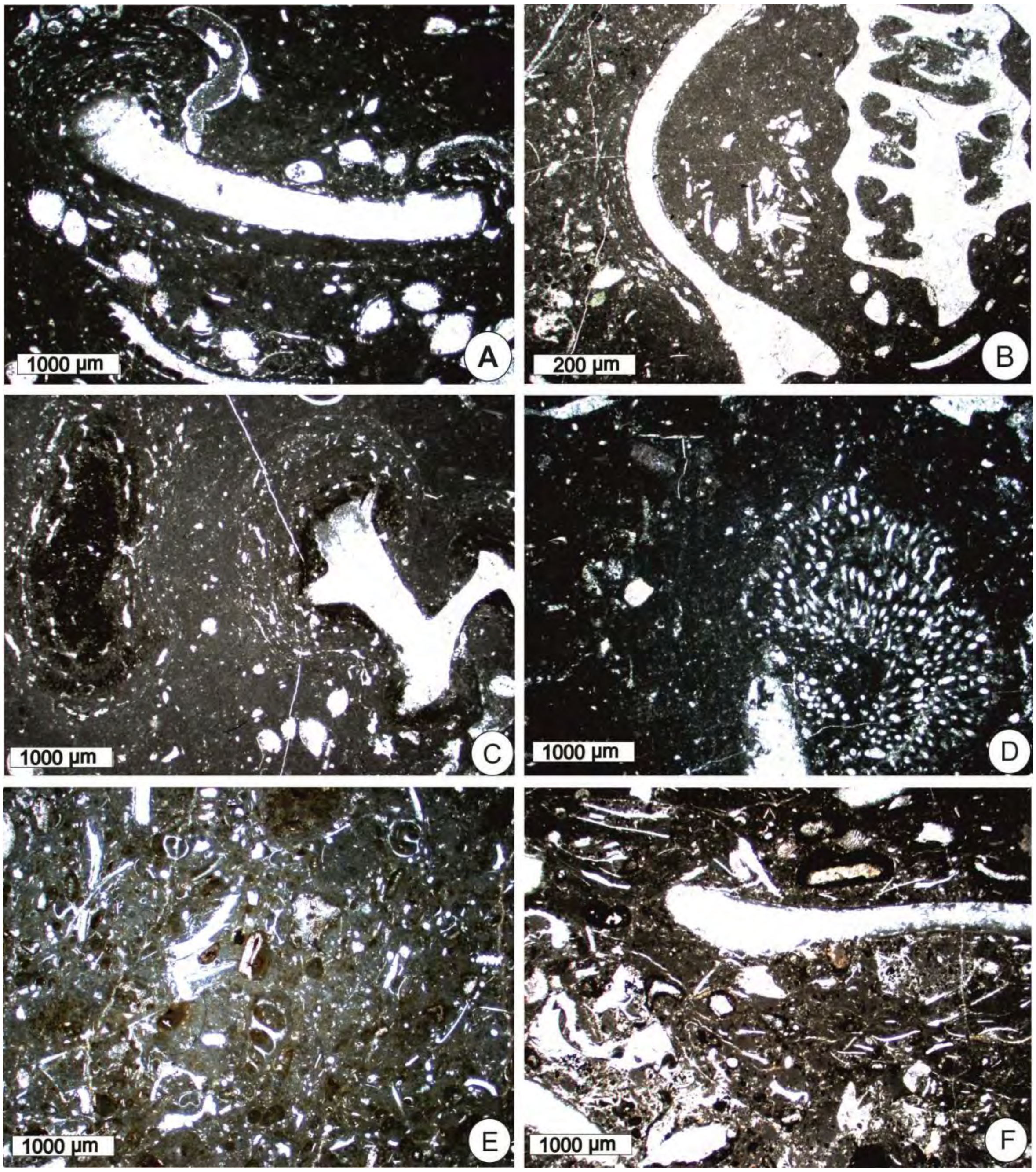

Fig. 3.3. Photomicrographs of the middle ramp facies.(A) Bio-onco-floatstone, Arousiah Fm., G. Engabshi section, the common bioclasts are of *Trocholina* (arrow) (B) The same facies, note the irregular grows pattern of the oncoid around a nerinid shells, tubular structures are of dasyclad green algae(arrow). (C) Ferruginous dark and light discontinuous laminae, nucleus is completely dissolved to the left. (D) Prostrate growth of the thin-walled *Girvanella* tubes. (E-F) Pel-bio-packstone, Arousiah Fm., G. Engabashi section.

Dominance of dasycladalean algae indicates euphotic conditions. This facies also occurs in open platform settings (Flügel, 2004). Deeper-water settings are often dominated by macroids (e.g., in the Recent outer Florida shelf; Prager and Ginsburg, 1989). The abundance of porostromate (microbial) oncoids and discoidal forms reveal a low-energy subtidal environment (e.g., Piller and Rasser, 1996). The upward decrease of the red algae (rhodoliths) and the increase in dacycladalean green algae indicate a change from oligophotic to euphotic conditions. A stable substrate is indicated by the abundance of bryozoans (Hageman et al., 1998). The majority of bryozoan habitats are found in areas of low sedimentation (Flügel, 2004). This facies occurs repeatedly in the Kehailia and Arousiah formations.

Pel-bio-packstone

Grey medium-grained, medium-bedded calcarenites. The grains include bioclasts (20%), and peloids (15%). Bioclasts are composed of crinoids, bivalves, gastropods, sponges, ammonites, brachiopods, and echinoid spines (Fig. 3.3D). Lenticular coral patches varying from 5 to 50 cm in diameter are also abundant.

This facies is similar to SMF 15-C and RMF 29 described by Flügel (2004) from the upper middle ramp above the SWB. The facies formed in a well-oxygenated, warm waters of normal salinity (see also Hips and Haas, 2009). Under such conditions crinoids flourished (Martini et al., 2007). The fine-grained mud may have been transported offshore by storm-induced currents and winnowing. This facies occurs in the lower and upper parts of both the Arousiah and Tauriat formations.

3.1.3 Outer ramp

Spiculite mud- to wackestone

This facies is composed of thin-bedded or poorly laminated, fine-grained, relatively homogeneous, dark-grey burrowed mudstone with scattered skeletal fragments (Fig. 3.4A-B). Very fine skeletal debris and sponge spicules are common. The fine-grained matrix is micrite and calcisiltite. This facies contains a well-preserved infauna in life position.

The facies is similar to SMF 1 and RMF 1 described by Flügel (2004) from a deep outer ramp setting below the SWB. Micrite is common in deeper outer ramps and in protected areas of inner ramps (Flügel, 2004). The absence of sedimentary structures suggests a nearly permanent low-energy environment probably located below the SWB. The water depth in this lower offshore position was probably greater than 50 m. Lamination is common in deep ramp settings with hemipelagic sedimentation. The fine-grained bioclastic mudstone and wackestone accumulated under episodic turbulence or the occasional influence of strong currents below the fair-weather wave-base (Buckovic et al., 2001; Jank et al., 2006), but sedimentary structures, which may be expected under such conditions, are lacking due to subsequent bioturbation. The mud-supported fabric of this facies suggests a mid to outer ramp setting in greater water depth. The presence of coated bioclasts with micrite envelopes indicates that skeletal and non-skeletal grains were transported from shallow environments to deeper water by offshore-directed bottom currents during waning storms (Martini et al., 2007). The presence of ammonites, brachiopods and the abundant bioturbation indicate an open and distal environment. This facies is widespread in the middle part of the Arousiah Formation.

Ammonite-bearing marl

Fossiliferous, light-grey, bioturbated marls with diverse skeletal components (bivalves, brachiopods, corals, gastropods, echinoids, and sponges; Fig. 3.4C). Beds of this facies are interbedded with open deep-marine mud- to wackestones. The marlstone units vary from 200 to 600 cm in thickness.

The presence of open-marine fossils (brachiopods, echinoderms, ammonites), of mud-supported facies, and the corresponding lack of high-energy facies, all show that these deposits formed in a relatively low-energy outer ramp environment (Pomar, 2001; Alsharhan and Kendall, 2003; Cosovic et al., 2004). The absence of storm- or wave-generated structures and the rarity of ooids and grain-supported fabric suggest low-energy environments below the storm wave-base (Burchette and Wright, 1992; Hips and Haas, 2009; Wilmsen et al., 2010). This facies has been repeatedly found in the middle part of the Kehailia Formation.

Shale

Poorly lithified, organic-rich, micro-laminated to fissile, yellow to dark green glauconitic shale (Fig. 3.4D) with minor argillaceous mudstone and laminated calcisiltstone interbeds. Authigenic minerals (glauconite and pyrite) are abundant. Benthic fauna is completely absent and only few ammonites and belemnites, which are of very small size and strongly pyritized, are present. No sedimentary structures were found.

The interbedded shale and calcisiltstone facies was deposited in an outer ramp setting. Shale was deposited by suspension settling whereas the calcisiltstone records distal storm-induced flows (e.g., Kreisa, 1981; Congilio and Dix, 1992). The abundance of fine-grained siliciclastics indicates transport from near-shore environments. Absence of sedimentary structures indicates deposition below the storm wave-base in an outer ramp setting (Kreisa, 1981). Very fine lamination is well preserved, resulting from suspension settling and documenting the absence of bioturbation. The latter indicates anoxia at the sediment-water interface, which inhibited colonization by benthic organisms. The abundance of authigenic minerals and co-occurrence of ammonites of different ages indicate high time-averaging (stratigraphic condensation). Deposition must have taken place during long-term terrigenous starvation. This facies is restricted to the Tauriat Formation.

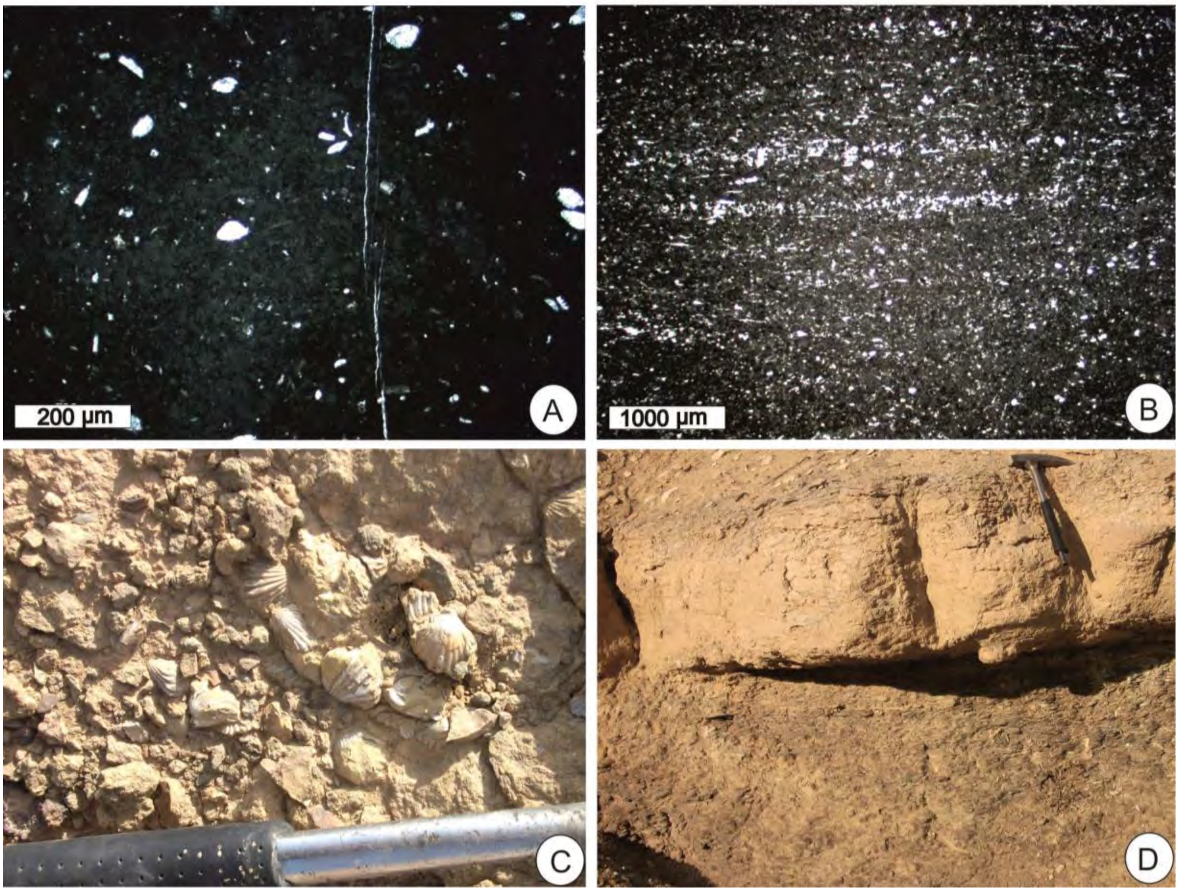

Fig. 3.4. Outcrop photographs and photomicrographs of the outer ramp facies. (A) Bio-wackestone, Kehailia Fm. (B) Bio-packstone, Arousiah Fm. (C) Fossiliferous marl, Kehailia Fm. (H) glauconitic shale, Oxfordian Tauriat Fm.

3.1.4 Slope

Oo-grainstone and crinoidal oo-bio-grainstone

Yellow thick-bedded (2-8 m), coarse-grained calcarenites. Bed contacts are usually sharp. Bioclasts vary from 20 to 90%. They include crinoids, echinoids (mainly cidaroid spines), corals, and molluscs (Fig. 3.5A-E). Apart from ooids, non-skeletal grains consist of oncoids (found occasionally in the lower parts of the facies). Intraclasts are also abundant. Some bioclasts exceed 2 mm in diameter. The ooids are well sorted but upward the grains are poorly sorted and have irregular outlines. The intraclasts are poorly sorted and angular to subrounded. The lower beds of this facies are full of ooids; subsequently alternations of ooids and bioclasts prevail. Up-section bioclasts increased in abundance and the uppermost beds are fully bioclastic.

This facies is similar to SMF 5 and RMF 10 described by Flügel (2004) from slope environments. Intraclasts are abundant in distally steepened ramps (Flügel, 2004). The sharp erosional base, the chaotic distribution of clasts, and the lack of a micritic matrix indicate an allochthonous nature. However, the lack of sedimentary structures indicative of transport suggests that transport was restricted to comparatively short distances. The latter is supported by the unbroken nature but chaotic arrangement of skeletal elements. The fauna of this lithofacies points to a middle ramp setting. Intraclasts may occur in all ramp settings, but are abundant in distally steepened ramps within debris flows accumulating near to the outer ramp slopes (Flügel, 2004). This facies has been recorded only in the Masajid Formation.

3.1.5 Delta

Prodelta shale

The prodelta comprises the lower part of the coarsening-upward delta cycle. This facies is composed of clay and/or siltstone. Silt grains increase in size up-section. The thickness of beds varies from 90 to 700 cm. Mostly there is a gradational boundary from this facies into the overlying beds, which are usually rippled sandstones. No sedimentary structures are preserved, and the beds have a massive or occasionally a bioturbated texture. The epifaunal rhynchonellid *Daghanirhynchia daghaniensis* and bivalves (e.g., *Protocardia africana, Grammatodon* and the oysters *Nanogyra nana* and *Africogryphaea costellata*) are common. Shells of *Ceratomya, Mactromya,* and *Bucardiomya* are occasionally present. Other marine taxa are absent.

The siliciclastic sediment indicates a nearshore setting with high terrigenous input. The fine-grained and homogeneous nature suggests deposition in a low-energy, quiet, relatively deep water environment. The occasionally black shales suggest a high content of organic material which is characteristic of a prodelta environment.

The low faunal diversity requires an explanation. As selective dissolution of aragonitic faunal elements apparently did not play a role, environmental parameters must have been responsible for it. The fine-grained sediment suggests a soft and possibly soupy substrate. Sediment-laden hyperpycnal flows might have led to a certain lowering of salinity near the bottom. The latter seems to be contradicted by the abundance of the rhynchonellid *Daghanirhynchia daghaniensis.* However, although articulate brachiopods for a long time have been considered as a stenotopic marine indicator, there might be exceptions to this (Fürsich and Hurst, 1980). Thus *Daghanirhynchia* might have been able to tolerate slightly reduced salinity values. *Nanogyra nana* represents an opportunistic species, which is found in many environments (e.g., Aberhan, 1994). The genus *Protocardia* also has a wide environmental distribution pattern throughout the Mesozoic (Hradecká et al., 2005). It is a common element in brackish-water assemblages (Fürsich, 1994), but also been recorded from black shales indicative of dysoxic conditions (e.g., Wignall, 1990). The bivalve is very common in fine-grained, soft to soupy substrates (e.g., Fürsich et al., 2012).

Ghandour and Maejima (2007) studied the foraminifera of the Safa Formation. Based on bio- and lithfacies analyses, they distinguished four different associations, from which two were mainly agglutinated, completely devoid of calcareous taxa (the *Ammobaculites* and the *Ammodiscus-Glomospirella* association) which they regarded as characterizing marginal marine, low salinity settings. The variation in the intensity of bioturbation most probably reflects fluctuating oxygen levels. In summary, it seems that a combination of somewhat reduced salinity and very soft substrates restricted colonization of the sea floor by macrobenthic organisms resulting in low species diversity. This facies is restricted to the Safa Formation and has been recorded from all of the measured sections.

Ripple-laminated sandstone of the delta front

The middle part of the upward-coarsening deltaic succession consists of ripple-bedded siltstone and fine-grained sandstone (see Fig. 3.5F and H). Individual beds range in thickness from 50 to 200 cm. Many of these sandstone beds have sharp undulating bases. These sharp-based sandstones discharged from the distributary channel mouth to the delta front. The ripple-laminated sandstones are more characteristic of the lower delta front (for details see Wright, 1985; Coleman and Wright, 1975).

Low-angle trough cross-bedded arkosic sandstone of distributary channel origin

This facies is composed of medium-grained to coarse-grained sandstones that exhibit low-angle trough cross-bedding (2-5 m thick; Fig. 3.5G) with many trace fossils including *Diplocraterion*, *Thalassinoides*, and *Rhizocorallium* at the surface of topmost bed*,* which may developed during a marine flooding interval of the next cycle. Laterally, these sandstones enclose economic coal deposits. Most beds in the three measured sections have erosional bases that extend downward into underlying strata. The quartz grains are angular to subangular and moderately well sorted. Inbetween ferruginous clay is present and constitutes the oxidized groundmass. The carbonaceous matter is also acting as cement. Reworked and fragmented clasts are commonly seen. These deposits are laterally discontinuous or laterally change in thickness.

Within a deltaic succession, delta-front deposits are commonly capped by terminal distributary channels (e.g., Olariu et al., 2012). The geometry, grain size, and sedimentary structures of the sand bodies indicate a distributary-channel system. Abundant quartz-rich sandstones are attributed to a very humid climate. The low-angle stratification and the presence of current ripples on top indicate a high energy environment.

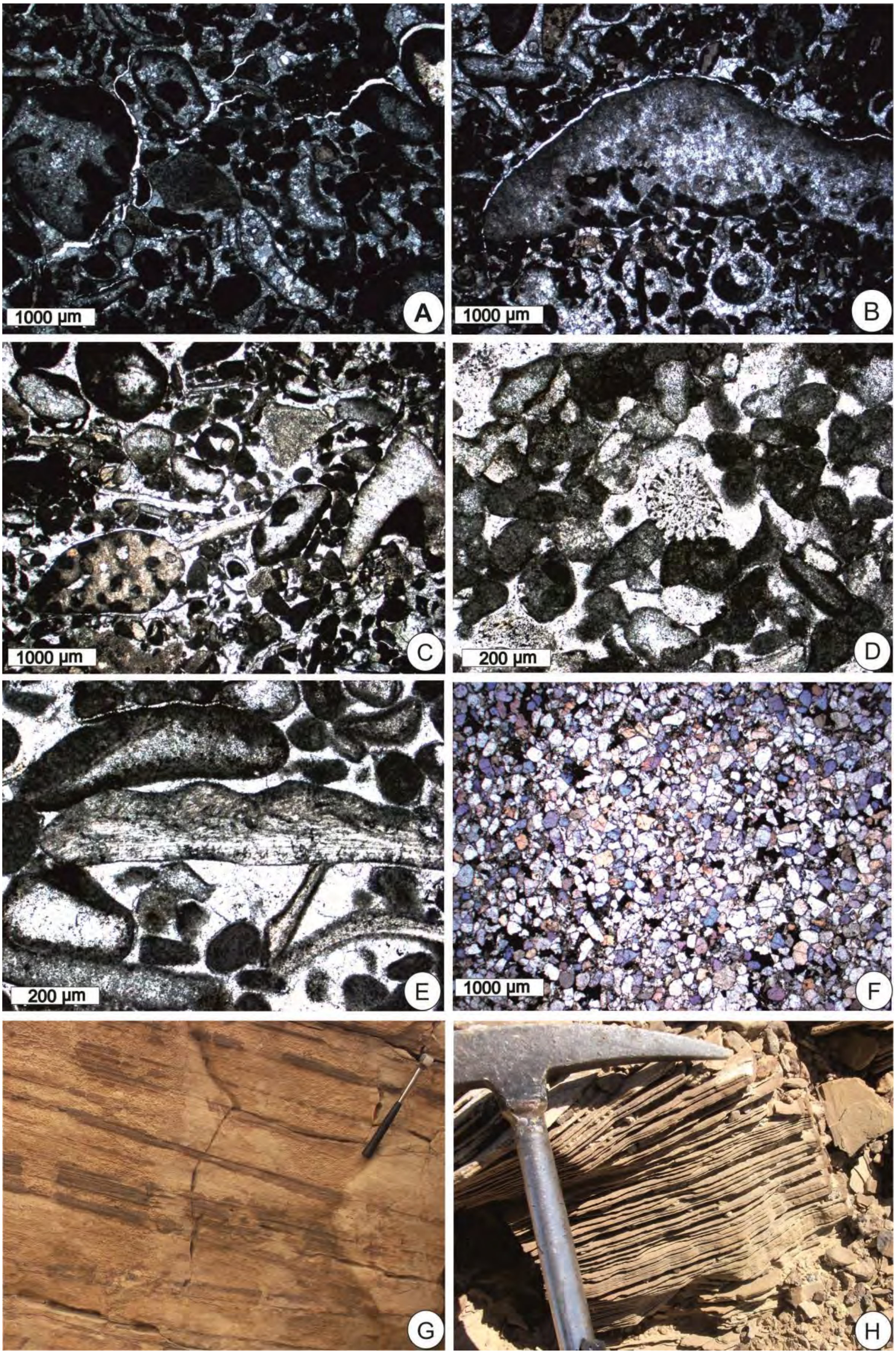

Fig. 3.5. (A-E). Photomicrographs of the slope facies, lower part of the Kimmeridgian Masajid Fm., composed mainly of chaotic-arranged crinoidal bio-grain- to rudstone. (F-H) Outcrop photographs and photomicrographs of the deltaic facies from the lower Bathonia Safa Fm. (F) Immature arkosic sandstone. (G) Low-angle trough cross-bedded ferruginous sandstone. (H) Ripple-laminated sandstone.

3.2 Facies associations

The distribution pattern of the microfacies in G. Maghara reflects transgression from tidal environments of the inner ramp at the base to relatively deep-water environments of the outer ramp at the top of the succession (Table 2.1). Thirty different microfacies types have been recognized and grouped into eight depositional environments ranging from deltaic, tidal, restricted lagoon, open lagoon, and shoal, to middle ramp, slope, and outer ramp. Sedimentation took place on a carbonate ramp which physiographically varied from homoclinal to distally steepened.

The inner ramp facies are widespread in both the Mahl and Bir Maghara formations. They include tidal deposits of sandy fine-grained mudstones and dolomitized algal wackestones with admixture of quartz grains. Phosphatic oo-grainstones, sandstones and bio-oo-packstones probably correspond to sandy shoals and banks of the inner ramp. Protected lagoonal settings of the inner ramp are characterized by peloidal packstones. Sediments formed in open-marine settings of the inner ramp are bio-packstones. Sediments of the mid-ramp are represented by bioturbated, glauconitic foraminifera-ostracod onco-wacke- to packstones. Echinoderm grainstones represent the slope facies and constitute the Masajid Formation. Outer ramp deposits are represented by spiculite wackestones and bio-mud- to wackestones. Mid-outer ramp sediments are typical of the Kehailia and Arousiah formations. The following descriptions provide a summary of these facies.

Table 2.1. Description and interpretation of the main facies associations.

Microfacies	**Components/features**	**Environment**
Bio-wackestone	Thin-bedded; bioclasts increase upward and include foraminifers, bivalves, sponge spicules, *Neuropora,* brachiopods, ferruginous nerineid gastropods, radiolarians, filaments, and algae. Brachiopod and gastropods shells common, well preserved. Lower and upper contacts sharp.	Low-energy outer ramp
Wacke-/mudstone	Poorly laminated dark grey bioturbated mudstone with dispersed sponge spicules and ammonite fragments. Concentrations of *Pholadomya* found in the lower part. Other fossils rare. Lower and upper contacts gradational.	
Shale	Fine-laminated to fissile, yellow to dark green glauconitic, organic-rich, with tiny pyritized ammonites. Authigenic minerals (glauconite and pyrite) abundant. Benthic fauna completely absent.	
Bio-grain- to rudstone	Yellow, thick-bedded (2-8 m), coarse-grained calcarenites. Ferruginous and siliceous concretions abundant. Bioclasts include crinoids, echinoids, and silicified molluscs. Intraclasts of minor importance. Cidaroid spines common. Lower bedding plane sharp, upper contact gradational.	High-energy upper slope
Oo-bio-grainstone	Graded, medium- to thick-bedded grainstones alternating with cidaroid-rich marls. Poorly sorted alternations of ooids and bioclasts; dominant bioclasts include foraminifers, echinoids, coral fragments, crinoid fragments, sponges; intraclasts. Lower bedding plane erosional.	
Oo-grainstone	Graded, medium- to thick-bedded. Well sorted ooids with minor oncoids and numerous cidaroid spines. Lower bedding plane erosional.	

Microfacies	Components/features	Environment
Bio-onco-floatstone	Highly bioturbated, medium-bedded; ferruginous and siliceous concretions abundant. Fossiliferous, light grey, alternating with marl. Oncoids large and irregular. Encrustation high, meiofaunal bioturbation and micritic envelopes occur. Bioclasts dominate and include algae, echinoids, gastropods, bivalves, foraminifers, corals, and sponges.	Low- to moderate - energy middle ramp
Onco-biofloatstone	Highly bioturbated, fossiliferous, light-grey, medium-bedded; ferruginous and siliceous concretions abundant, coral patches occur; poorly-sorted; meiofaunal bioturbation common; with nerineids, *Goniocylindrites,* bivalves, foraminifers, corals, ostracods, and some oncoids. Lower and upper contacts gradational.	
Onco-wackestone	Bioturbated, grey, medium-grained, medium-bedded. Apart from oncoids bioclasts dominate and include gastropods, foraminifers, sponge spicules, echinoids, codiacean green algae, "*Girvanella*", and some corals. Some grains are coated. The mollusc fragments are silicified and encrusted.	
Bio-onco-rudstone	Thin-bedded limestone alternating with sandstone. Oncoids are the most common components; followed by moderately sorted bioclasts (echinoids, gastropods, and sponge spicules). Lower contact sharp, upper one gradational.	Moderate - to high-energy inner ramp shoal
Bio-packstone	Thin-bedded; with molluscs, echinoid, crinoid, and coral fragments, sponge spicules, and calcispheres. Micritic envelopes common.	
Bio-grainstone	Thin-bedded, chamositic-phosphatic with shell concentrations; intraclasts, quartz grains, and grain aggregates occur. Oysters abundant. Shells encrusted and bored.	
Bio-oo-grainstone	Thin, graded, chamositic beds with well sorted concentric ooids. Peloids, microbial coated grains, oncoids and intraclasts also occur. Some bioclasts of bivalves and gastropods. Bioturbation abundant.	
Fossiliferous sandstone	Fossiliferous, well sorted, ferruginous. Bioclasts common. Echinoids and gastropods dominate.	
Pel-bio-packstone	Bioturbated, thick bedded packstone. Peloids common, bioclasts less common (brachiopods, bivalves, crinoids, sponges, ammonites, and echinoid spines. Pyrite grains occur.	Low to moderate - energy protected inner ramp
Pel-bio-wackestone	Bioturbated, greenish brown, medium- to thick-bedded, grey limestone, with poorly sorted peloids, few bioclasts, intraclasts, and oncoids. Bioclasts include corals, gastropods, miliolid foraminifers, serpulids, and sponges. Large terebratulid brachiopods abundant.	
Pel-packstone	Poorly sorted peloids, recrystallized bioclasts, sponge spicules. Few oncoids and ooids also present. Lower and upper contacts gradational. Encrusted corals debris common.	
Calcareous sandstone	Low-angle planar cross-bedded, poorly-sorted, ferruginous, arkosic with small bivalve fragments. Ichnotaxa include *Thalassinoides* and *Diplocraterion*. Lower and upper contacts erosional.	High-energy shoreface
Onco-pack- to rudstone	Well sorted oncoids, some bioclasts including sponge spicules, gastropod shell fragments, corals, and *Neuropora*. Micrite increases upward.	
Onco-grainstone	Medium-bedded with erosional base. Well sorted, with bioclasts, ooids, encrusted shells, algae, sponge spicules, and coated gastropod shell fragments.	
Intra-wackestone	Lower bedding plane sharp, upper one slightly bioturbated. With bands rich in silt grains and mud. Few fibrous gypsum lenses occur. A few siliciclastic particles, including quartz grains, occur as does dispersed organic matter.	Low-energy intertidal
Sand-silt-clay interbeds	Wavy to flaser laminated alternations of fine- to medium-grained sand, silt and clay; plant remains occur.	
Non-fossiliferous sandstone	Low-angle trough cross-bedded arkosic medium- to coarse-grained or moderately bioturbated and immature, yellowish brown, fine to medium-grained, subangular to subrounded with calcareous cement; moderately sorted with some rock fragments and silica overgrowth. Dolomitic in some parts. Wood fragments and plant remains occur.	High-energy distributary channel
Silt- to sandstone	Thin, ripple-bedded, siltstone and fine-grained sandstone with sharp undulating top. Plant remains and trace fossils occur. No fossils observed.	Moderate -energy delta front
Shale	Clay and/or siltstone, bed thickness varying from 0.9 to 7 m. Silt grains	Low-

Microfacies	Components/features	Environment
	increase in size upwards. Upper contacts gradational, lower ones sharp, undulating. Oysters, *Protocardia*, and *Grammatodon* occur.	energy prodelta

3.2.1 Inner ramp

The homoclinal ramp model (Burchette and Wright, 1992) distinguishes between inner, middle and outer ramp. Inner ramp sediments are deposited in an agitated environment above the fair-weather wave-base (FWWB). It ranges from the shallow subtidal to the intertidal zone. Lagoonal settings sheltered by barriers may develop (Tucker, 1985). In mixed siliciclastic-carbonate rocks of the inner ramp, sandy allochemic limestones (composed of ooids, bioclasts, and lithoclasts) are the most common rock types. Small patch reefs may also occur.

3.2.2 Middle ramp

Middle ramp deposits consist mainly of packstone or grainstones deposited above the storm wave-base (SWB). Sedimentation is therefore highly influenced by variable storm intensity (Burchette and Wright, 1992; Flügel, 2004). Autochthonous and allochthonous shells occur.

3.2.3 Outer ramp

The outer ramp is dominated by thin, laminated beds of terrigenous mud, with parautochthonous and autochthonous shells. Skeletal wackestones dominate, some lime mud formed in situ (Tucker, 1985). The presence of ammonites and belemnites indicates a comparatively distal environment. The absence of primary sedimentary structures produced by currents or waves suggests a low-energy environment probably located below the SWB.

3.2.4 Slope

The distally steepened ramp of G. Maghara tectonically developed from a previous homoclinal ramp. The sediments of the slope are largely autochthonous to para-autochthonous. Slumping and breccia deposits are of minor importance. Bio-oo-grainstones and rudstones characterize the slope. It resembles the ramp model proposed for the Upper Triassic shelf and platform margins in the Northern Calcareous Alps by Stanton and Flügel (1995).

3.2.5 Delta

The Early Bathonian Safa Formation represents an upward-coarsening siliciclastic succession typical of a deltaic setting (Fig. 3.4D-F). It comprises prodelta (shale, silt, and clay), delta front (rippled sandstone) and distributary channel (low-angle trough cross-bedded sandstone) subenvironments. The total thickness of these deltaic sediments is 200 m. The occurrence of elongated tidal bars and periodic abandonment surfaces in addition to numerous channels indicate the tide-dominated delta type (the action of tidal currents significantly overprints that of channel flow; see Renaud and Kuenzer, 2012). Tide-dominated deltas are directly connected to the sea via a series of distributary channels that are typically flanked by low-lying vegetated floodplains and swamp areas (the source of coal deposits at Gebel Maghara).

3.3 Depositional model

The facies analysis of the succession at G. Maghara indicates that sedimentation occurred in a mixed carbonate-siliciclastic system that developed within a half-graben (Yousef et al., 2010). The facies succession varied from shallow intertidal to deep outer ramp environments. Instead of barrier reefs, the crest of the horsts separated the half-graben basin from marine environments during the Early Jurassic and until Late Bajocian times from open marine environments.

As a result, an extensive restricted lagoon developed, in which storm events were both weak and only sporadic. A slope developed during the Kimmeridgian, but this slope differed from a distally steepened ramp of shelf-margin settings. It evolved from a homoclinal ramp and the sediments of the distal slope are autochthonous, as no slump deposits were seen in the field and turbidites are absent. In proximal parts of the slope crinoidal grain- and rudstones dominated. All these points indicate a high similarity to the Upper Triassic „Steinplatte reef" of the Northern Calcareous Alp of Austria (Stanton and Flügel, 1995).

The studied sections indicate that there was a sharp transition from a siliciclastic-dominated inner ramp during the Aalenian – Early Bathonian passing into an outer ramp from the Mid Bathonian onward. Another sharp transition occurs between the marl-calcilutite dominated facies (Bathonian-Oxfordian) and a calcarenite and calcirudite dominated slope facies (Kimmeridgian), resulting from the evolution of the homoclinal ramp into a distally steepened ramp (Fig. 3.5).

4.5 Basin evolution

During opening of the Neo-Tethys, an extensional tectonic cycle originated. By the Late Triassic/Early Jurassic, the extensional rift setting produced the half graben basin of G.

Maghara. This basin was filled initially with fluvial and deltaic siliciclastic sediments (Fig. 3.5). Subsequently, during a phase of tectonic quiescence, a homoclinal ramp developed on which shallow marine carbonates were deposited. During the Early Bathonian a slowdown in extension-related subsidence led to accumulation of fluvial and deltaic siliciclastic facies over the previously formed marine one. The comparatively uniform carbonate successions of the Middle Bathonian-Callovian represent a phase of tectonic quiescence. However, general tilting and faulting of the basin during the Oxfordian shifted the areas of maximum subsidence northwestward and effectively split the facies of G. Maghara into an upper (SE) and lower (NW) slope facies. Rejuvenation of the rift stage during the early Kimmeridgian shifted the ramp topography to a distally steepened one (Fig. 3.5). Compressional forces at the around the Jurassic-Cretaceous boundary resulting from convergence between Africa and Eurasia (Abd El-Motaal and Kusky, 2003) finally closed the basin.

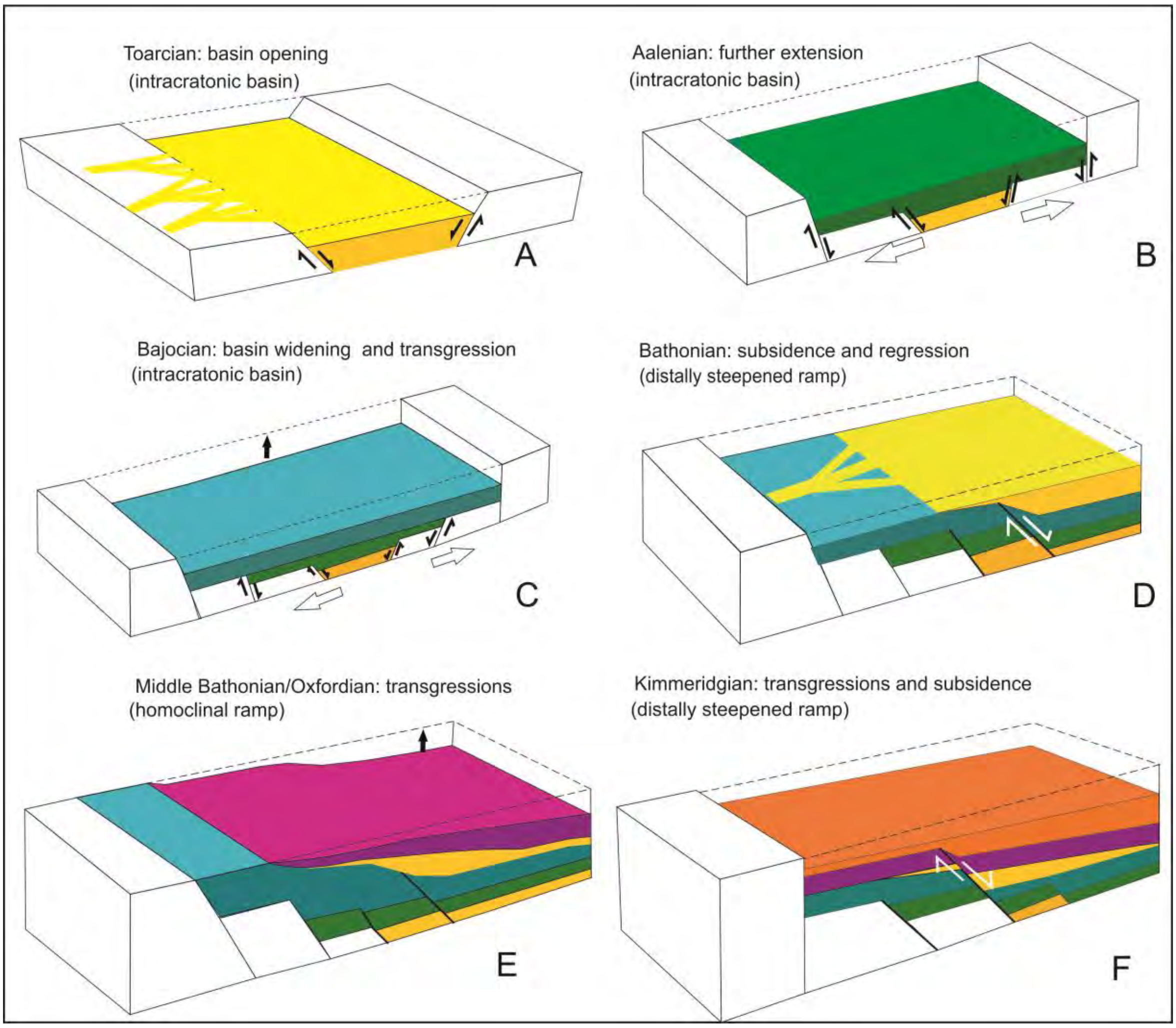

Fig. 3.5. Model of the main stages of the evolution of G. Maghara with schematic time slices depicting the subsidence and depositional history and sea level changes.

4 Sequence stratigraphy

4.1 General issues

The smallest cycles are meter-scale marl–limestone successions, interpreted as parasequences (sensu Van Wagoner et al., 1988). The nature of the different parasequences is summarized in Figs. 4.1 to 4-3. Larger depositional sequences are decameter-scale (5 to 15 m thick). They record a few hundred thousand years, comparable to 4th order cycles of Vail et al. (1991). Still larger scale sequences have thicknesses of several tens of meters and inferred durations of about 1–3 million years (3rd order sequences; Vail et al., 1991). Boundaries of large sequences are marked in most cases by an erosional surface, while those of smaller ones are marked by sharp contacts.

A significant criterion of lowstand systems tract (LST) sediments is the basinward shift of facies belts resulting from a relative sea-level fall and an abrupt upward transition to a significantly more proximal facies. In shallower areas sub-aerial erosion may develop. Lowstand deposits are generally lacking in G. Maghara except in the Safa Formation (Early Bathonian; Fig. 4.1). Continental sedimentation of the Safa Formation took place under humid, tropical conditions, with a steady supply of run-off material. Peat formed in hinterland swamps and lakes and was deposited as paralic coal in marginal marine areas. The shore-line was tide-dominated as is indicated by the occurrence of elongated tidal bars and periodic abandonment surfaces in addition to numerous channels. The action of the tidal currents significantly overprinted that of channel flow (see Renaud and Kuenzer, 2012).

Transgressive systems tracts (TST) of shallow water areas are marked by oo- to bio-pack-/grainstone (Fig. 4.1). The carbonate nature of the TST reflects dilution of siliciclastic material during sea-level rise. The TST sediments show mineralized hardgrounds and an increasing content of reworked nodules, and of phosphatic, glauconitic and chamositic grains, indicating increased sediment starvation. In distal parts, the TST consists of bioclastic skeletal pack- to floatstone with an erosional base as in the Arousiah Formation.

Maximum flooding zones (MFZ) are marked by finer-grained deeper water and hardground surfaces. Sediment starvation may result from deepening and resulting lack of siliciclastic input. The MFZ consequently commonly represent condensed horizons. In addition, deposits containing chemically and mechanically resistant particles such as pyrite or glauconite are common (Baird and Brett, 1986, 1991). The corrosion surface on top of limestones represents a considerable amount of time with non-sedimentation.

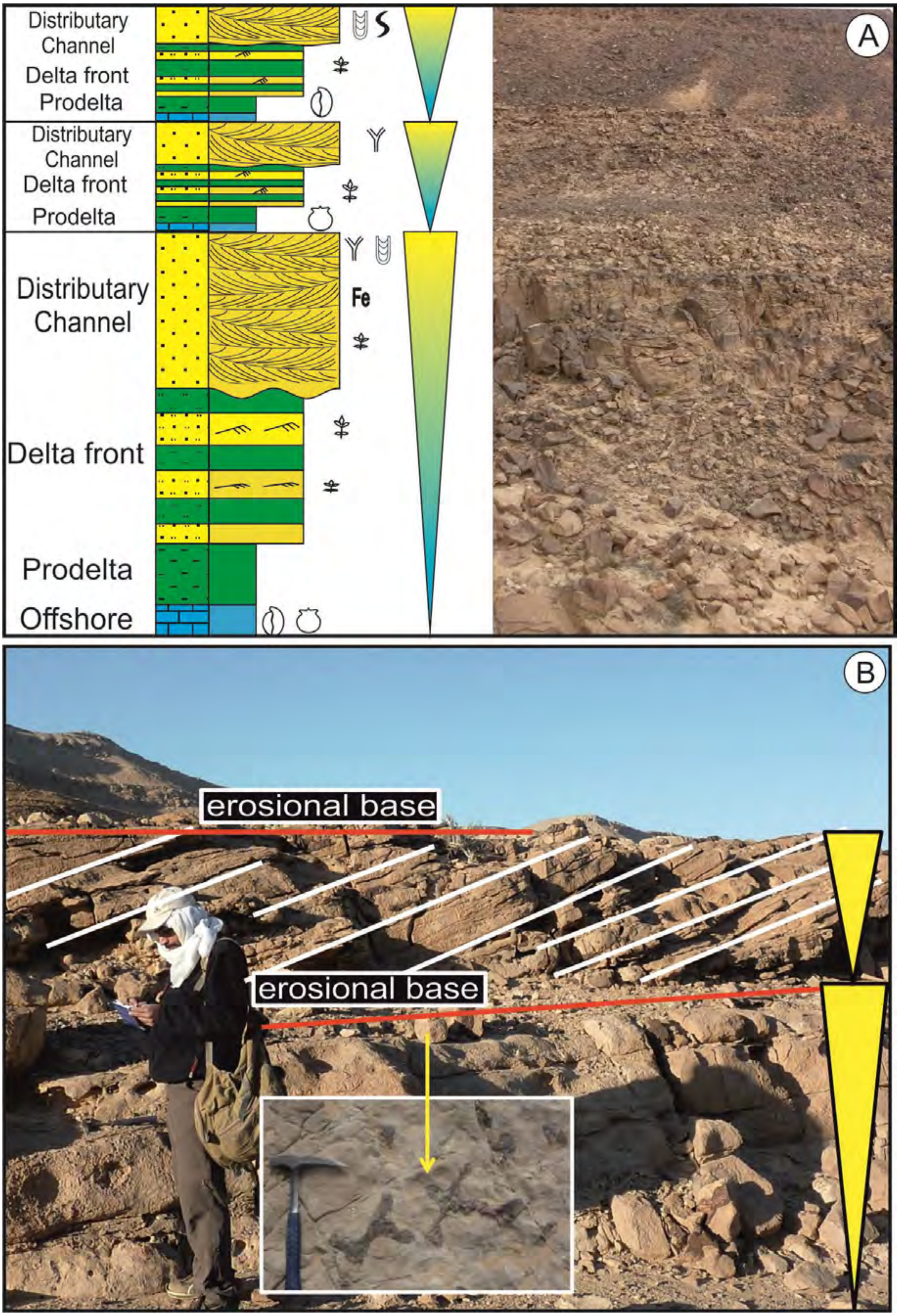

Fig. 4.1. Parasequences. (A) Coarsening-upward parasequences from the lowstand systems tract of the Safa Formation. (B) Sandbar at the top of the Safa Formation.

Highstand sediments in proximal areas are characterized by thin, wavy bedded pack- to grainstones or calcareous sandstone. In distal parts they consist of wackestones and marls, or dark, organic-rich clay or shales. Highstand Systems tracts (HST) show coarsening-upwards trends in most cases (Fig. 4.2). Increase of coarser siliciclastics in addition to the erosional contact associated with a rapid drop in sea level indicates a falling stage systems tract (FSST; Plint and Nummedal, 2000). Based on fossil content, thin-sections, and bed-by-bed description of outcrops and correlation of significant surfaces, the Middle to Upper Jurassic strata of G. Maghara are subdivided into seven distinct, correlative sequences (DS1to DS7). The following is a descriptive summary of theses sequences.

4.2 Depositional sequences

4.2.1 DS1 (Early Jurassic)

The Shusha Formation is part of an Early Jurassic cycle, which lies beyond the aim of the present study.

4.2.2 DS2 (Aalenian)

The Shusha-Mahl contact is marked by an irregular corrosion surface. This unconformity represents the lower SB of DS2. The absence of age-diagnostic fossils in the sediments above and below the unconformity makes an age determination very difficult, but Ash (1972) had assigned an Early Jurassic age to the Shusha Formation based on the fossil plant *Piazopteris branneri*, collected from the Ain Sukhana section, 150 km south of G. Maghara. This sequence is comparable to the second Jurassic cycle of Perelis-Grossowicz et al. (2000), the lower part of the J30 of Haq and Al-Qahtani (2005), and to the Aalenian – Lower Bajocian cycle of Gardosh et al. (2008). The sediments are generally very shallow-marine, inner-shelf carbonates (intertidal to shoreface).

The transgressive sediments above the sequence boundary (SB) are oncoid grainstones with a sharp erosional base and gradational bioturbated top followed by marl. The TST sediments continue with sparitic rudstones. The sharp bases, the coarse-grained nature in addition to grading are diagnostic criteria of TST sediments. Absence of fauna and occurrence of some plant fossils indicate very shallow, possibly restricted conditions. The thickness of TST obviously varies among the studied sections. The MFZ is marked by fine-grained marl with a 2-m-thick bedded dolomitic wackestone intercalation with few small gastropods (mainly algae-grazing Trochidae). The HST is characterized by algal wackestone beds, the clay and silt content becomes abundant up-section, and finally the Mahl Formation ends with a ferruginous sandy packstone, the top SB coinciding with the Mahl-Bir Maghara contact. The thickest HST deposits were recorded towards the East, in the Mowerib section. This cycle was deposited mainly in very shallow tidal environments. The Aalenian-Lower Bajocian sequence was deposited during an active extensional rifting phase in an intracratonic setting. The cycle is 150 m thick and its duration was approximately 3 m.y.

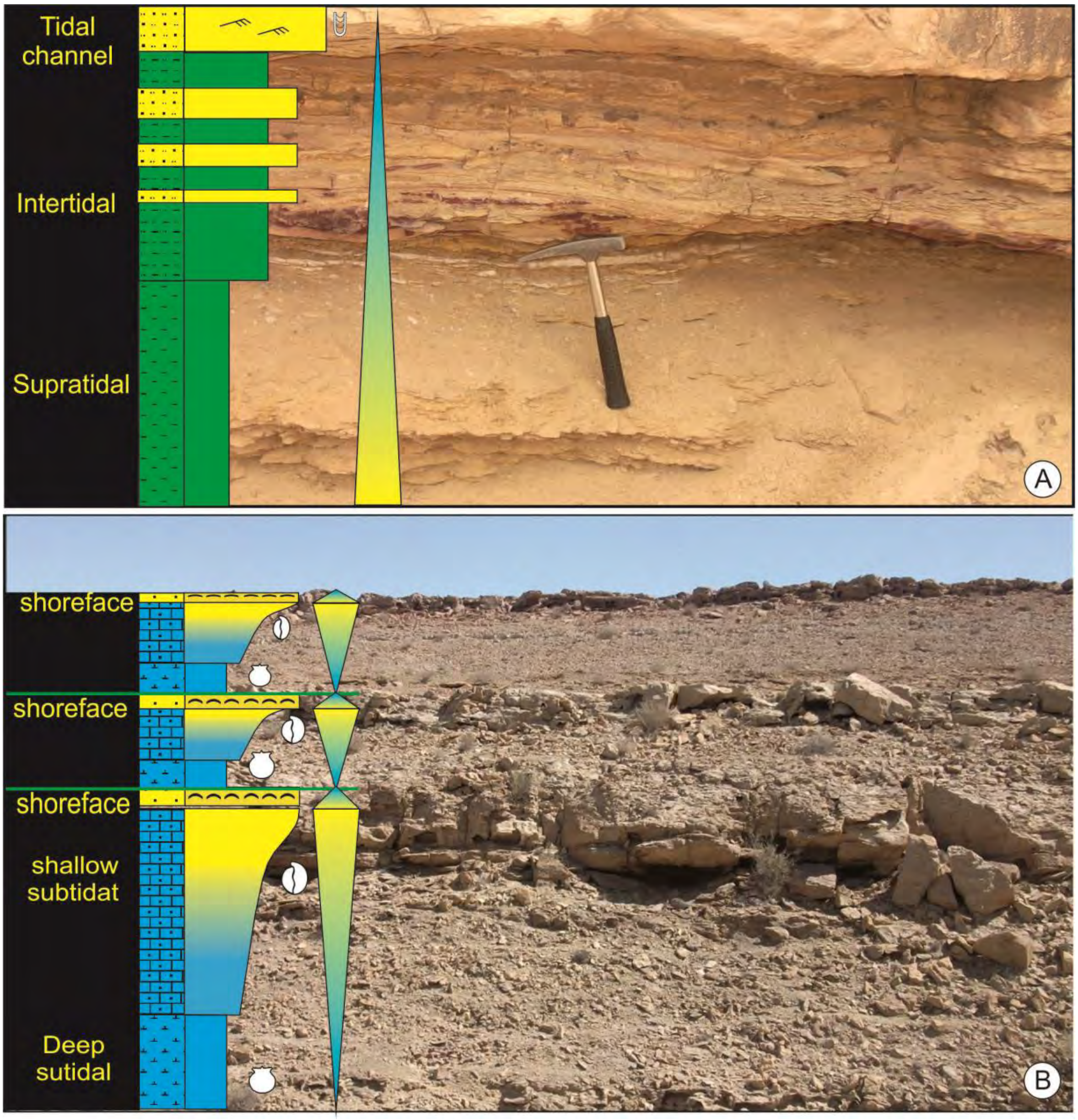

Fig. 4.2. Parasequences. (A) Deepening-upward parasequence from the base of the LST of Depositional Sequence 4, Safa Fm., G. Arousiah section. (B) transgression-regression parasequences from the HST of the Bir Maghara Fm., G. Engabashi section.

4.2.3 DS3 (Bajocian)

The Bir Maghara Formation is characterized by high siliciclastic content. The limestones vary from wackestones to grainstones. Algae and peloids are the dominant grains. The fossil content is high but patchy and of limited lateral continuity. DS3 is equivalent to the third Jurassic cycle of Gardosh et al. (2008) and to the upper part of the J30 of Haq and Al-Qahtani (2005). The TST begins with transgressive onco-pack- to grainstones of the shoreface. The maximum flooding deposits comprise pel-bio-wackestones with brachiopods and sponges. These wackestones are followed by marly silt rich in tiny pyritized ammonites. A 5-m-thick *Bositra* rich shale bed occurs twice and is interpreted to represent oxygen-poor restricted inner ramp conditions, as these shales are fissile, with no sign of bioturbation and contain neither benthic nor nectonic fossils except the epifaunal bivalve *Bositra*. HST deposits form coarsening-upward cycles that start with marl and/or wackestone followed by packstone, the concentration of sand grains increasing up-section. The sequence is capped by ferruginous well sorted calcareous sandstone. This cycle was deposited mainly in a inner ramp setting varying from open to restricted under a continuous supply of terrigenous sediments. The Late Bajocian cycle is 150 to 250 m thick. The duration of the cycle is ~1 m.y.

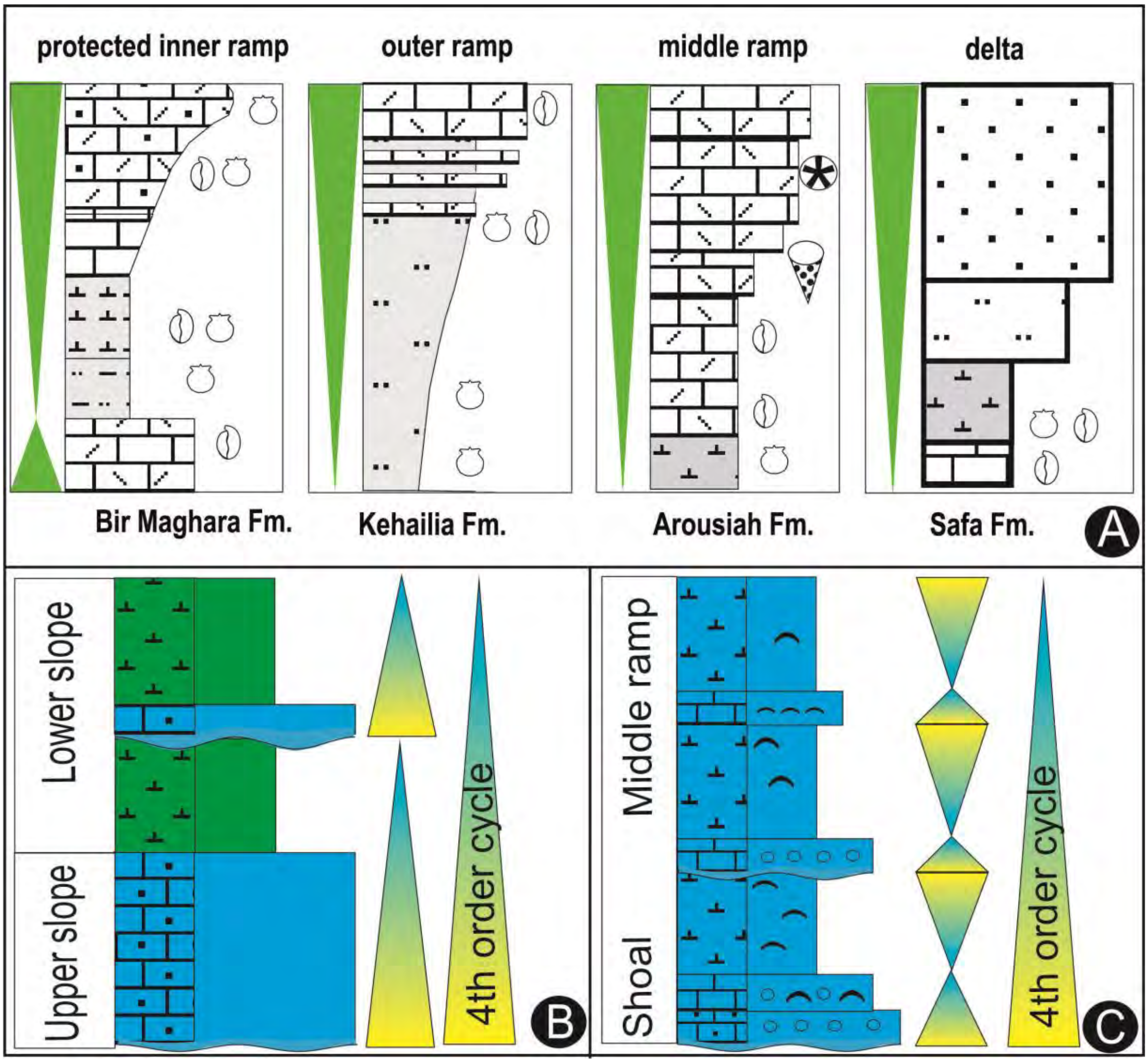

Fig. 4.3. Nature of different parasequences (A) and 4th order cycles (B) of the Masajid Fm. and the Kehailia Fm. (C).

4.2.4 DS4 (Bathonian)

The contact between the Bir Maghara and the Safa Formation represents the sequence boundary. The deltaic deposits of the Lower Bathonian Safa Formation, composed of sandstones with intercalated siltstones and limestones, are interpreted to represent the LST of DS4. The transgressive sediments start with thin beds of chamositic oo-grainstone and/or oo-bio-packstone. A *Pholadomya*-rich glauconitic dark mudstone bed representing the MFZ was recorded from the section at G. Arousiah. In the other sections the MFZ is represented by very fossiliferous marly siltstone with occasional infauna. Ammonites have been also collected from this horizon. The HST consists mainly of marl. A 6-m-thick sandstone bed with intercalated biopackstone and onco-oo-grainstone marks the top of the Bathonian sequence (FSST). This cycle was deposited in middle and outer ramp environments, except for the early TST and FSST, which were deposited in a shoal setting. The thickness of the Bathonian cycle is ~400 m. The duration of the cycle is ~2 m.y.

4.2.5 DS5 (Callovian)

The Callovian sequence consists of a thinly bedded carbonate unit. Marls are of minor importance. Flint layers and nodules are common. The input of siliciclastics is nearly zero. The sequence represents offshore environments of the lower middle to outer ramp. The TST sediments are generally obscured by debris; probably they are fine-grained skeletal shales or marl. The first measured beds are coral-bearing floatstones. Debris of corals, stromatoporoids, and red algal fragments dominate. The most common fossils are nerineid gastropods. The MFZ is marked by a spiculite mudstone. The MFZ does not correspond to a single bed and the boundaries between the system tracts are not easy to define. The MFS was placed at the base of a bed exhibiting condensation criteria (i.e., fine lamination, authigenic minerals, corrosion, intense bioturbation and/or encrustation, and skeletal concentrations). This cycle was deposited mainly in an outer ramp setting. The thickness of the Callovian cycle is ~200 m. The duration of the cycle is 2 m.y.

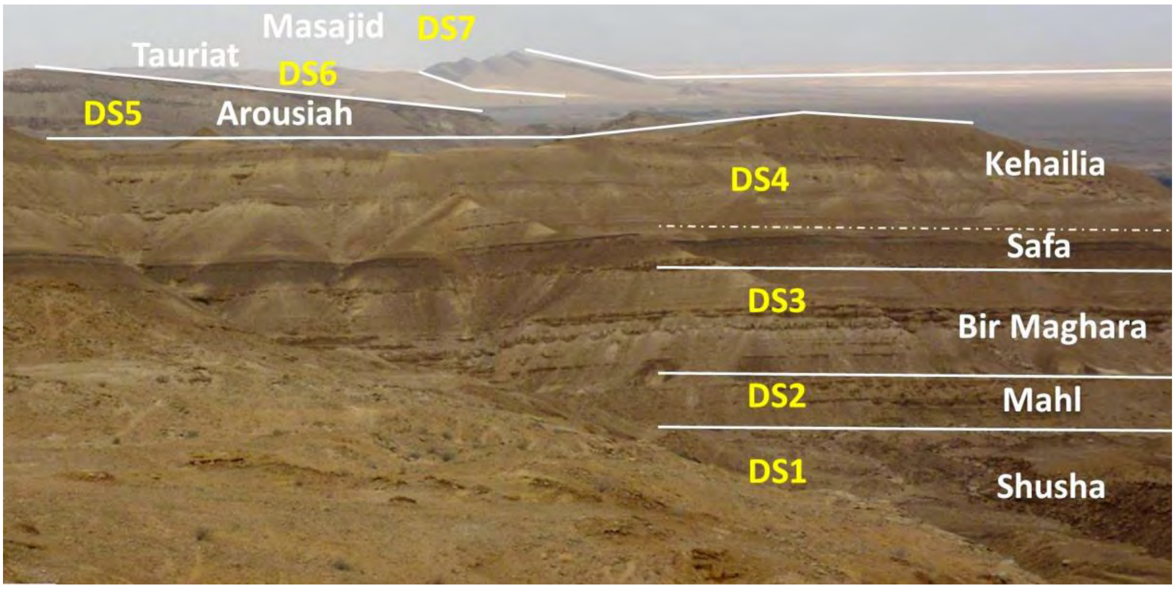

Fig. 4.4. Depositional sequences of the Middle to Upper Jurassic succession at G. Arousiah, western saddle of the anticline of G. Maghara.

4.2.6 DS6 (Oxfordian)

The Tauriat Formation (Fig. 2.19) represents the whole Oxfordian. Although the time interval represented by the Oxfordian sequence is the longest one among all determined sequences (the duration of the cycle is ~7 m.y.) it is only 70 m thick, resulting from a certain degree of condensation. Early and Middle Oxfordian ammonites occur at the same stratigraphic level. Condensation is also indicated by abundant autigenic minerals within this sequence. The TST is represented by bio-oncofloat- to rudstone. The MFZ is a glauconitic fissile shale with pyritized ammonites. Upward the shales turn much darker and ammonites disappear. In contrast, the HST deposits are lighter and contain a few bivalves and coral colonies. The Oxfordian sequence ends with a peloidal packstone bed.

Derin (1974) related the absence of the Kidod Shale (equivalent to the Tauriat Shale) in some areas of Israel to interfingering with carbonates. Gardosh et al. (2008) attributed the absence of the Kidod Formation to submarine erosion or non-deposition along an upper slope setting. In G. Maghara, the Tauriat Shale is absent only in the Mowerib section (Fig. 2.20), where the Kimmeridgian Masajid Formation rests directly on the Callovian Arousiah Formation without sign of erosion. The latter does not support the idea of Gardosh et al. (2008). Open marine conditions are supported by the rich ammonite fauna and the glauconitic nature of the sediments. Open marine conditions of Oxfordian shales in the Middle East were previously discussed by Gardosh et al. (2008). This cycle was deposited in an outer ramp setting below the storm wave-base. The maximum thickness of the Oxfordian cycle is 75 m.

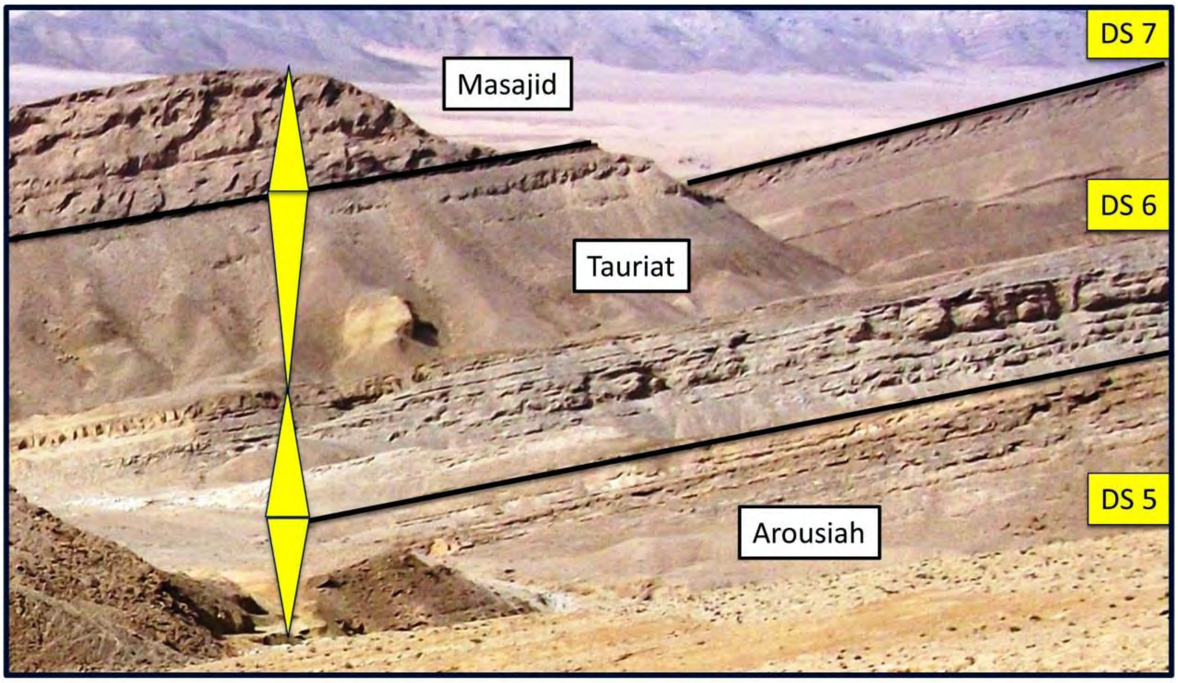

Fig. 4.5. The upper three depositional sequences exposed at G. Engabashi.

4.2.7 DS7 (Lower Kimmeridgian)

The DS7 is equivalent to the J60 and J70 of Haq and Al-Qahtani (2005) and the Oxfordian to Tithonian sequence of Gardosh et al. (2008). The TST consists of oo-grainstones, which change up-section into oo-bio-grainstone and finally into bio-grain- to rudstone with minor fine to coarse lithoclasts. In general, the TST of the Kimmeridgian is composed of 5- to 10-m-thick fining-upward cycles. Marl rich in cidaroid spines represents the top of these parasequences.

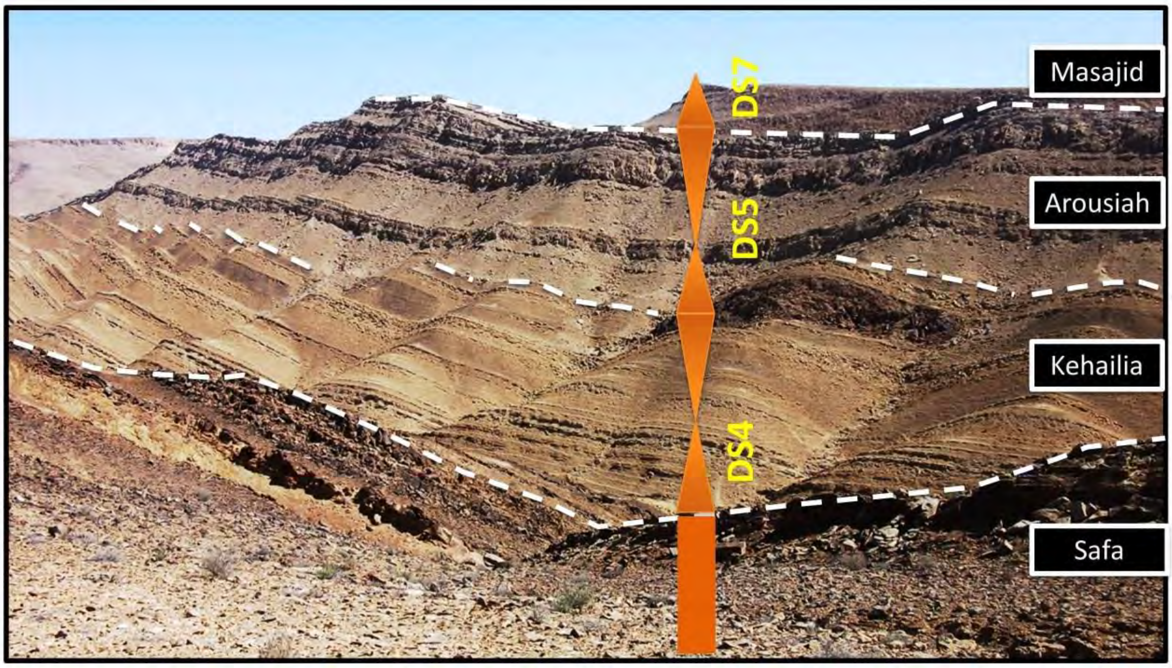

Fig. 4.6. Architecture of the depositional sequences of G. Mowerib. Note the absence of the Tauriat Fm. (DS6) in the section.

Friedman et al. (1971) interpreted a depositional slope and basinal environment for the Delta and Yam formations of Israel, respectively, which are correlated to the Masajid Formation. The occurrences of allochthonous rocks associated with mass transport are well recorded from offshore wells of the Levant Basin, e.g., the microconglomerate of the Yam West 1 well of Middle Jurassic age (Gardosh et al., 2008). The absence of the Masajid Formation south of G. Maghara may indicate non-deposition in upper slope areas. Kimmerdgian deposits have been also recorded north of G Maghara (e.g., Umm Mafruth and Risan Aneiza) with the same litho-and biofacies (Picard and Hirsch, 1987). The area of G. Maghara probably was uplifted earlier in the Middle Kimmeridgian or may have undergone erosion during the Cimmerian Orogeny. The thickness of the Lower Kimmeridgian cycle is 100 m. The duration of the cycle is ~2 m.y. This cycle formed in upper to lower slope environments (Fig. 4.7).

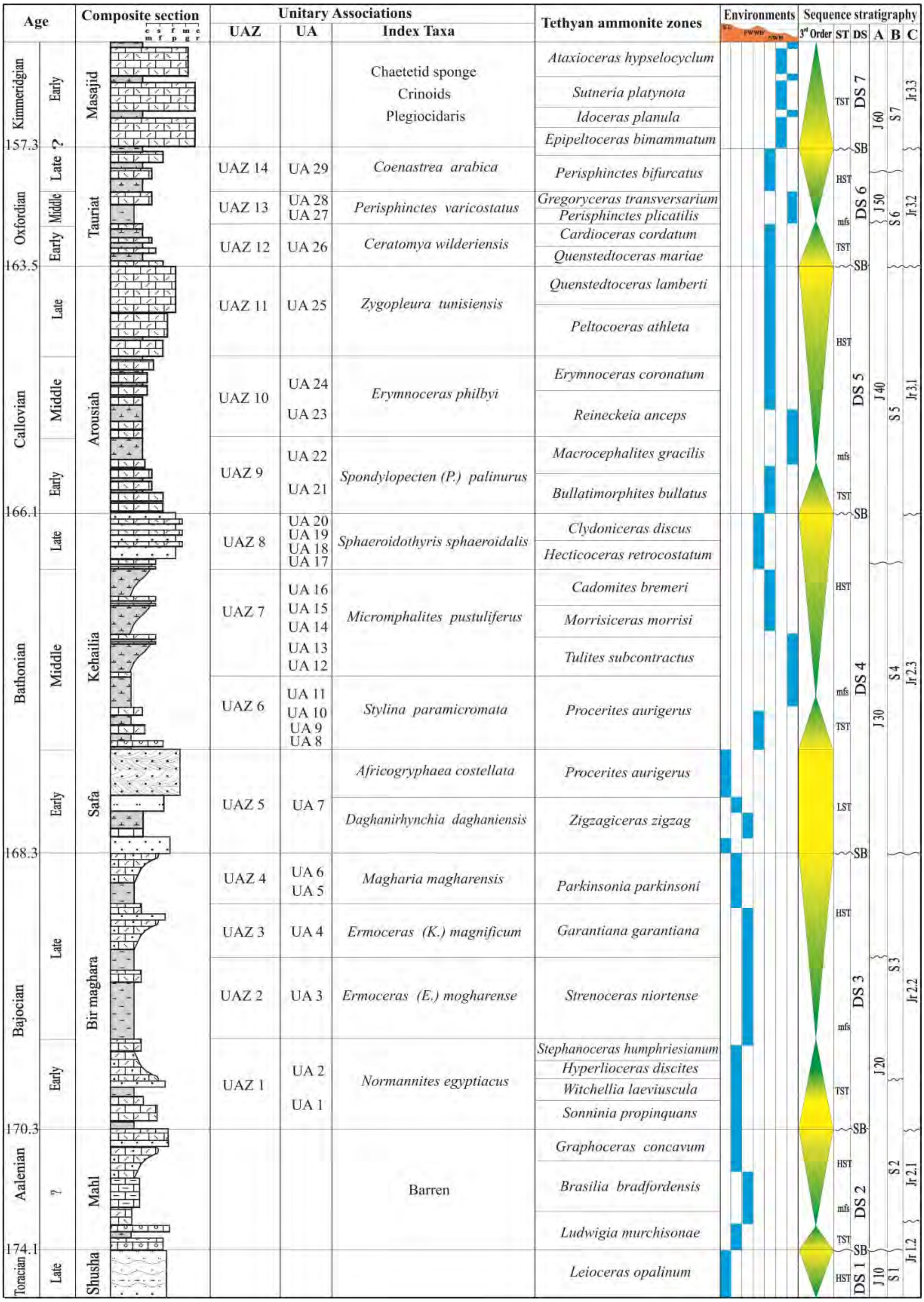

Fig. 4.7. Composite stratigraphic section of the Jurassic sedimentary succession exposed at G. Maghara. Biostratigraphy based on UA method, Tethyan ammonite zones after Gradstein et al. (2012). The 3rd order sequences were compared to their equivalent sequences in Saudi Arabia (A; Haq and Qahtani, 2005) and the Levant margin (B; Gardosh et al., 2008; C; Gardosh et al., 2011). TST: transgressive systems tract; HST: highstand systems tract; SB: sequence boundary; mfs: maximum flooding surface.

4.3 Eustatic versus tectonic control of sea-level fluctuations

Although the coastal onlap of the Jurassic sediments of G. Maghara coincides with the worldwide sea-level curve (Haq et al., 1987, 1988), the genetic sequences of the Jurassic succession of G. Maghara were controlled partly by tectonics. Detailed litho- and biostratigraphic correlations (Fig. 4.7) show that local fault activity controlled not only the thickness of the deposits but also the depositional environments and thus controlled the sedimentary cycles. It is not an easy task to separate eustatically controlled sea-level fluctuations from tectonic-controlled ones.

The genetic sequences of the Mahl and Bir Maghara formations, essentially composed of shallow-marine carbonates and locally and at certain levels rich in siliciclastics, which can be correlated throughout all measured sections, result from eustatic sea-level changes. In contrast, the occurrence of the 200-m-thick deltaic clastic wedge of the Early Bathonian Safa Formation, sandwiched between the carbonate ramp facies, more likely results from tectonic reactivation of an old fault. Also, the calcicirudite and calcarenite facies of the Early Kimmeridgian depositional sequence (DS7), which overlies the Oxfordian (DS6) calcitutite and marl facies and suddenly disappears in the G. Mowerib section (Fig. 4.6-4.8), might also be related to tectonics.

The stratigraphic boundaries in G. Maghara (i.e., the ripple-laminated ferruginous sandstone surface on top of the Aalenian Shusha Formation, the caliche horizon at the Bajocian–Bathonian boundary, the *Thalassinoides*-rich bar sandstone (Middle Bathonian), the Bathonian–Callovian ferrigenous shoal sandstone on top of the Kehailia Formation, and the hardground at the top of the Callovian Arousiah Formation) all reflect eustatic changes, while the sharp contacts between the Bajocian carbonates and the Bathonian siliciclastic sediments and between the marl and the crinoidal rudstone at the Oxfordian–Kimmeridgian boundary are related to tectonic activity affecting the ramp topography and hence the depositional environments.

However, the pattern of the genetic sequences, which originated primarily by eustatic sea-level fluctuations, might have been enhanced by tectonic movements. A good example is the upper shoreface facies of the Mahl Formation, which originated by the transgression of the sea over the tidal flat area of a recently developed basin. The extensional forces and the resulting subsidence enhanced the facies differentiation by expanding the basin both vertically and laterally and increasing accommodation so that new, deeper facies became established.

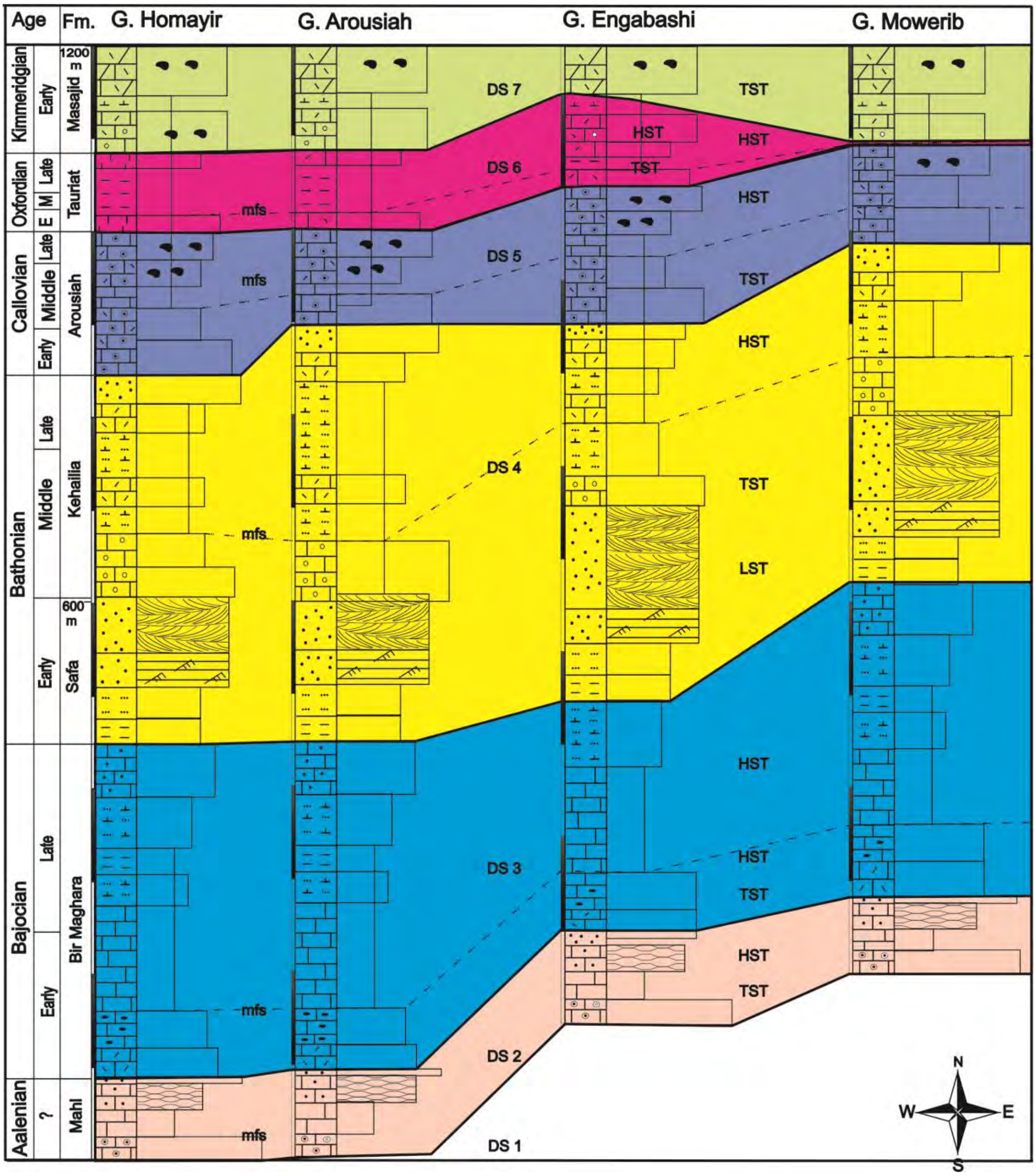

Fig. 4.8. Sequence stratigraphic correlation of the measured sections. Key in Fig. 2.1.

5 Palaeoecology

5.1 Overview

Macrobenthos is a powerful tool in interpreting palaeo-environments; it reflects the physical habitat, as its abundance and distribution is largely controlled by abiotic factors (i.e. physical parameters within a given environment). Thus, under stress conditions (e.g., limited oxygen supply, unstable substrate, salinity fluctuations), benthic communities may disintegrate, major taxa may vanish or be replaced, diversity may be lowered, and numerical dominance by opportunistic species may increase. In addition, changes in presence/absence of rare species may take place (e.g., Werner, 1986; Oschmann, 1988; Aberhan, 1992; Brett, 1995; Zuschin and Stanton, 2002; Aberhan et al., 2006; Federal Geographic Data Committee „FGDC", 2012, Fürsich et al., 2012; Hofmann et al., 2013). There are two main groups of environmental factors controlling the distribution of macrobenthos; physical (e.g., temperature, sediment type, grain size, rate of sedimentation, and water energy) and (bio)chemical (e.g., oxygen, salinity, pH value, and photosynthesis; FGDC, 2012).

5.2 Multivariate analysis

5.2.1 Benthic communities

The cluster analysis produced twelve clusters, interpreted to represent the remnants of former communities, termed here associations (recurring) and assemblages (non-recurring or distorted; Fürsich, 1984). These clusters have been named after the most dominant species, only one association has been named after two abundant species to avoid name duplication. These are the *Eudesia cardioides* association (A), *Nicaniella pisiformis* association (B), *Daghanihynchia angulocostata* association (C), *Pholadomya inornata* assemblage (D), *Chomatoseris epithecalis* association (E), *Daghanirhynchia/Africogryphaea* association (F), *Eligmus rollandi* assemblage (G), *Amydroptichus formosus* association (H), *Coenastrea arabica* assemblage (I), *Cymatorhynchia quadriplicata* association (J), *Daghanirhynchia daghaniensis* association (K), and the *Africogryphaea costellata* association (L) (Fig. 5.1).

The dendrogram obtained from hierarchical clustering has been checked many times until meaningful „clusters" were generated. The major characters differing among the associations are; epifaunal/infaunal ratio, substrate lithology and consistency, dominating macrobenthic group, and diversity (Fig. 5.1). Based on species richness, the clustered associations and assemblages were grouped into two major groups; polyspecifc and paucispecific (Fig. 5.2).

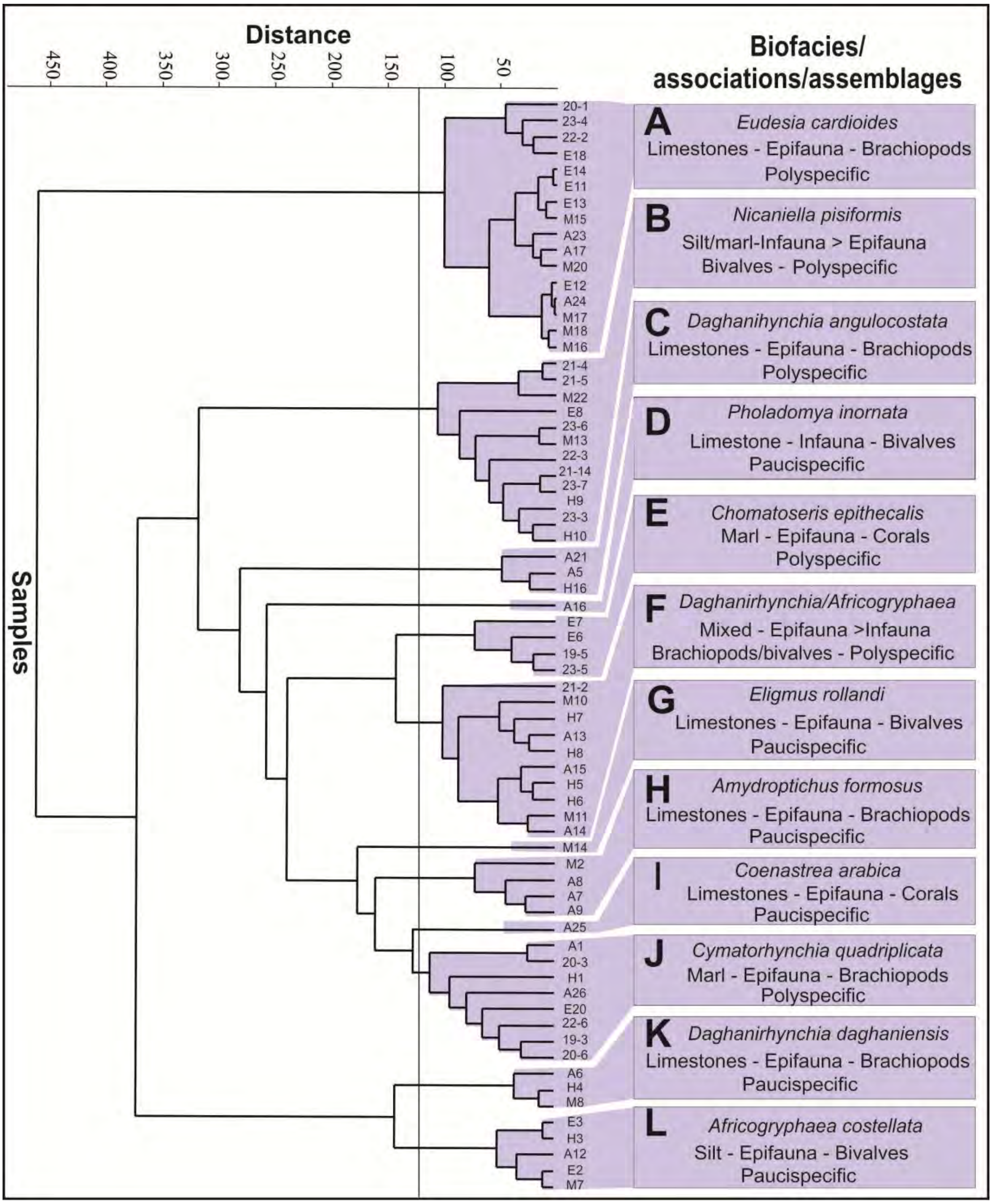

Fig. 5.1. Q-mode cluster analysis using Ward‟s method. This analysis produced twelve clusters of sample groups based on relative abundances. A-L: associations and assemblages. The vertical line is the cut-off line for defining the various associations and assemblages.

The rarefaction curve was utilized to examine the diversity indices. Although the Shannon index was low for associations C and A (Fig. 5.2A), the rarefaction curve shows that both associations are comparatively diverse (Fig. 5.2D). The habitat differentiation among associations is highly variable. Although associations C and E were classified as polyspecific with a high alpha Shannon Index diversity (Fig. 5.2A), their beta diversity is low (Fig. 5.2B), which implies that taxa within these associations shared the same habitats with low competition for resources. In contrast, the other polyspecific associations (A, B, F, and J) have high beta diversity, which indicates successful habitat partitioning among taxa (e.g., epifauna, shallow- and deep-infauna) due to increasing competition.

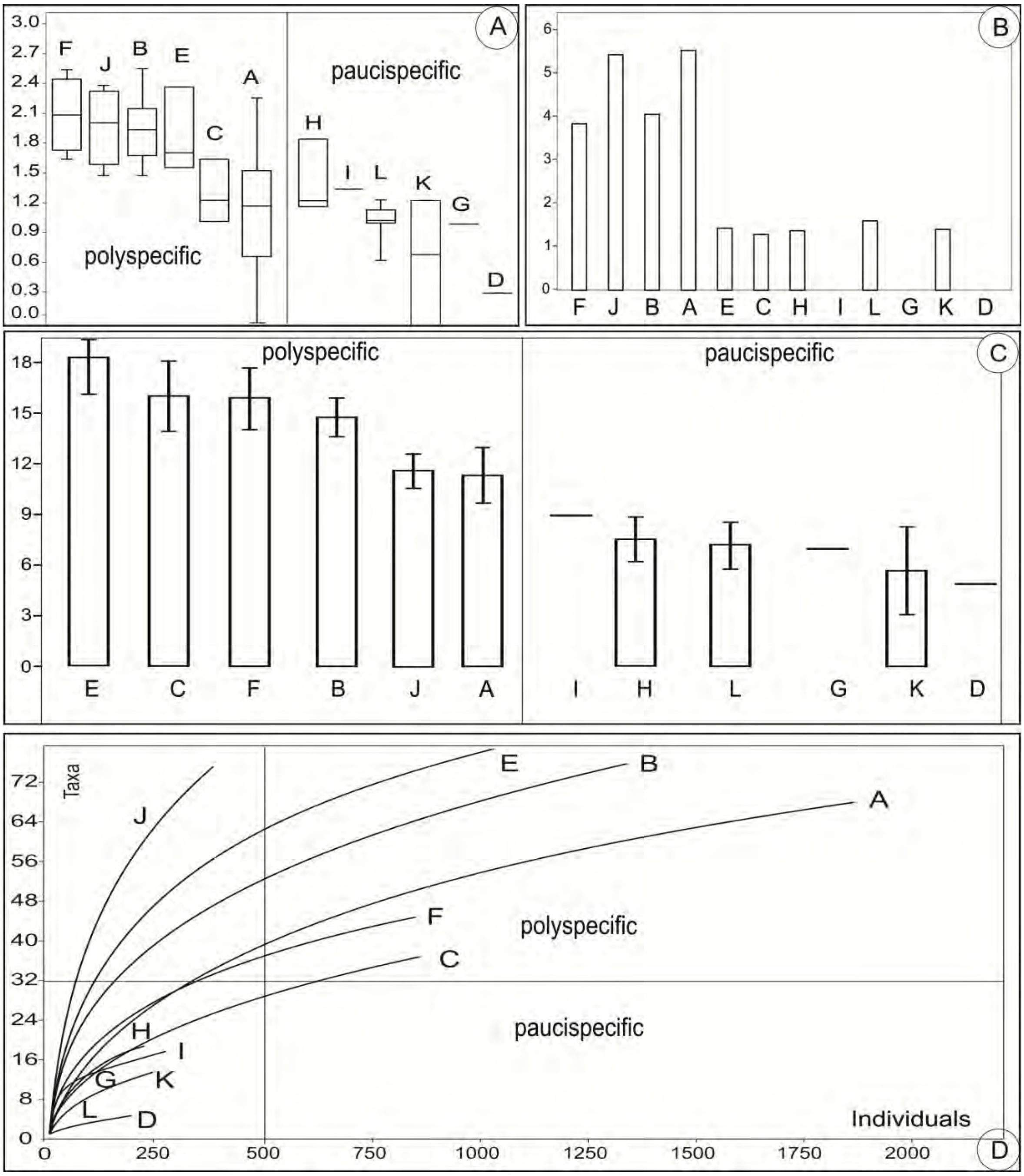

Fig. 5.2. A, Box plots of the Shannon Index of samples of the various associations. B, Beta diversity. C, Box plots of the species richness. D, Rarefaction curves (Hurlbert, 1971). A-L: benthic associations and assemblages (Key in Fig. 5.1).

5.2.2 Ordination of associations/assemblages

The results of the NMDS (Fig. 5.3A) delineated the same degree of habitat partitioning as hierarchical clusters with very little overlap among association samples. However, association J is highly scattered along axis 2 of NMDS (Fig. 5.3A). From the trophic nucleus of this association (Table 1), none of the dominant taxa are present in all samples. According to Bush and Brame (2010), ordination results may have been obscured by opportunistic species that abundantly occur in multiple environments, which is the case in association J. Long-ranging taxa (e.g., *Plegiocidaris* sp., chaetetid sponge, *Millericrinus goubili*) probably are the main cause of the scattering seen in association J.

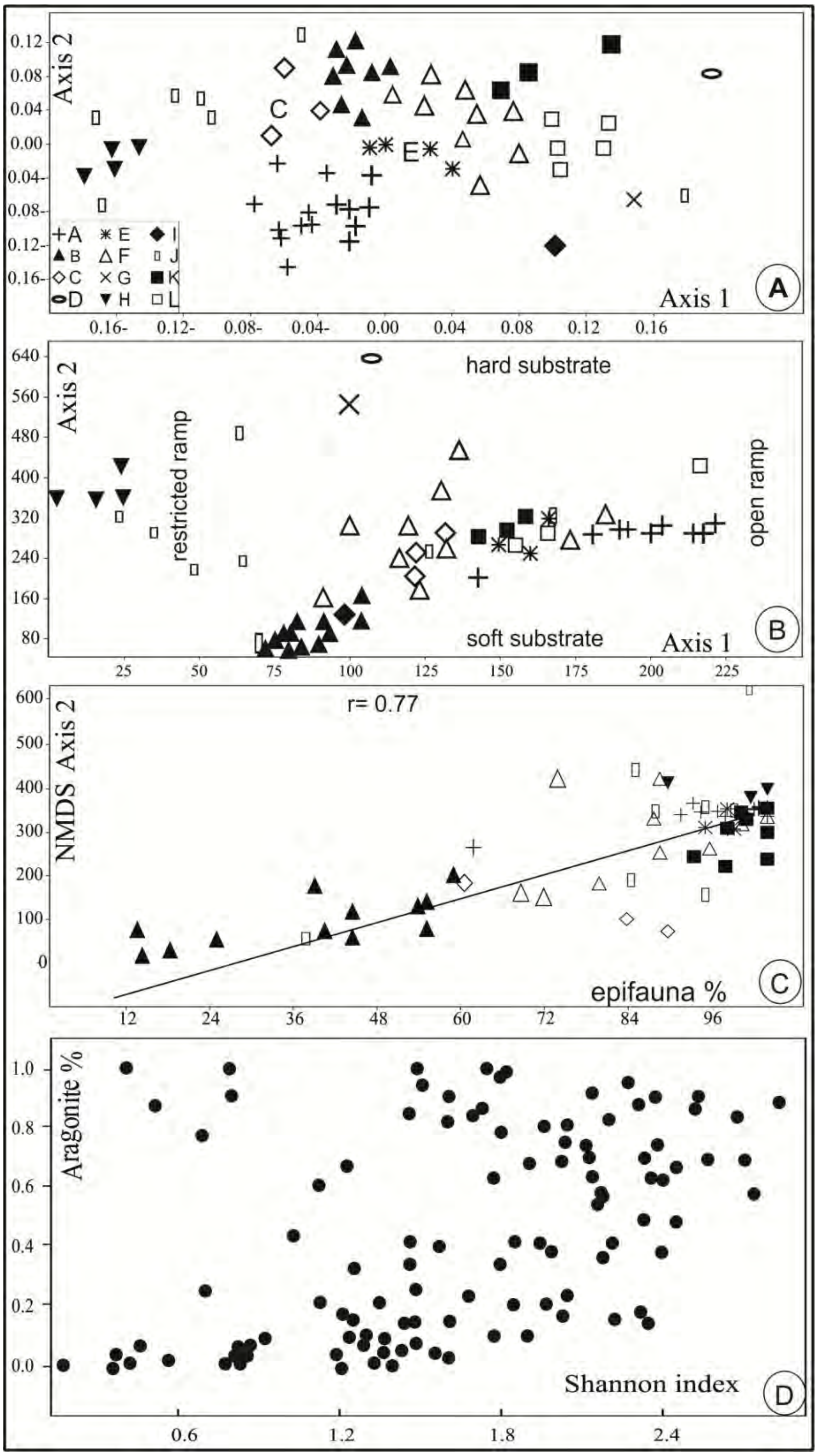

Fig. 5.3. A, 2-D Q-mode NMDS plot, based on Bray-Curtis similarity. Groups are identified from clusters (Key in Fig. 5.1). B, DCA plot based on Bray-Curtis similarity, Axis 1 corresponds to a depth gradient, while Axis 2 ordered the samples according to substrate consistency. C, Regression fit of axis 2 of NMDS versus epifaunal percentage. r = 0.77, which indicates a moderately positive linear relationship (assemblages not included). D, Scatter diagram showing no correlation between percentage of aragonitic shells and diversity. A-L: benthic associations and assemblages (Key in Fig. 5.1).

From DCA the primary environmental gradient controlling the distribution of the fauna was the water depth. DCA axis scores indicate relative shifts in water depth, which distributed along Axis 1 ranges from restricted inner ramp to more than 50 m at the outer ramp setting (Fig. 5.3B). Axis 2 separates taxa according to differences in substrate consistency. Samples with high Axis 2 scores are dominated by epifaunal suspension-feeders, most notably by brachiopods, oysters, and corals, which prefer hard substrates, while low Axis 2 scores incorporate samples with mainly infaunal deposit-feeders, usually nuculid bivalves, which prefer soft substrates. The linear regression model of the epifauna/infauna ratio against Axis 2 indicates a good positive relationship with the percentage of epifauna (r=0.77; Fig. 5.3C).

The packing of samples at a specific point within the DCA plot of our data is not a coincidence, but samples may be arranged in another dimension that is not shown in such a 2-d plot. Our results agrees with Bush and Brame (2010) that the NMDS generally produces less distorted results (but without meaningful gradient) than the DCA. The identified associations hardly exhibit any stratigraphic pattern, which is due to the presence of long-ranging taxa.

5.3 Faunal associations

5.3.1 Taphonomic aspects

More than 99% of the brachiopods are articulated, and only 40% of the bivalves occur as single valves, which implies a relatively low degree of reworking. Originally aragonitic shells are also preserved, indicating no major distortion by selective chemical dissolution. This is corroborated by the lack of correlation between species diversity and percentage of aragonitic shells (Fig. 5.3D). The loose-packed biofabric, lack of sorting and abrasion in shell concentrations, in addition to lack of faunal amalgamation, all point to no or only weak signatures of physical agents such as currents and/or waves (see also Fürsich et al., 2012). Hence, the fauna is regarded as autochthonous to parautochthonous, in the latter case including at most within-habitat transport, and thus can be used as palaeoenvironmental indicator.

5.3.2 Polyspecific associations

Daghanirhynchia/Africogryphaea association (F)

This association includes ten samples with 1043 individuals and 79 species (the highest species number among all identified associations). It is present in all measured sections. Brachiopods and bivalves dominate with the rhynchonellid *Daghanirhynchia daghaniensis* (22.6%), the large oyster *Africogryphaea costellata* (16%), and the infaunal bivalve

Nicaniella (N.) pisiformis (4.5%) being the most abundant taxa. All major benthic groups are found here (i.e., brachiopods, bivalves, gastropods, corals, echinoids, and crinoids) and all type of life habits are represented (epifaunal, semi-infaunal and infaunal). Epifaunal species dominate (77%), of which 37% are pedicle-attached, whereas infauna accounts for 18% of the individuals. Seventy-one percent of the individuals were suspension-feeders. Herbivores represent 15% and microcarnivores (corals) 6%. The samples are either from marl or from argillaceous wackestone.

Table 5.1. Trophic nuclei of the benthic associations. Taxonomic group: Br; brachiopod; B: bivalve; G: gastropod; Cor; coral; E; echinoid; S: serpulid; Spo; sponges; Cri: crinoid; Cru: crustacean. Mode of life: E: epifaunal; EB: epifaunal byssate; EC: epifaunal-cemented; ER: epifaunal recliner; I: infaunal; IS: shallow infaunal; ID: deep infaunal; SI: semi-infaunal. Feeding mode: S: suspension-feeder; D: deposit-feeder; H: herbivore; C: carnivore; O: omnivore; MC: microcarnivore. Shell composition: C: calcite; A: aragonite. Mobility; M: mobile, S: sessile.

Association and Assemblages	taxonomic group	Mode of life	Feeding mode	Shell composition	Mobility	Relative abundance	Presence %
A. Eudesia cardioides association							
Eudesia (Sphriganaria) cardioides (Douvillé, 1916)	BR	EB	S	C	S	70.49	100
Burmirhynchya (H.) cavagnari (Diaz-Romero, 1931)	BR	EB	S	C	S	6.80	50
Ectyphoria sinaiensis Feldmann et al. 2012	BR	EB	S	C	S	2.30	19
Nanogyra nana (J. Sowerby, 1822)	B	EC	S	C	S	1.68	44
B. Nicaniella pisiformis association							
Nicaniella (N.) pisiformis J. de C. Sowerby, 1840	B	IS	S	A	S	31.47	92
Nuculoma variabilis (Sowerby, 1825)	B	IS	D	A	M	10.92	33
Ryderia decorata (Douvillé, 1916)	B	IS	D	A	M	8.28	83
Nanogyra nana (J. Sowerby, 1822)	B	EC	S	C	S	4.52	50
Daghanirhynchia angulocostata Cooper, 1989	BR	EB	S	C	S	3.85	42
Collignonastrea jumarensis (Gregory, 1900)	Cor	E	MC	A	S	3.79	25
Palaeonucula lateralis (Terquem and Jourdy, 1869)	B	IS	D	A	M	3.67	50
Pronoella (Pronella) loweana (Morris & Lycett, 18)	B	IS	S	A	S	3.23	17
Bothryopneustes lamberti Fourtau, 1924	E	I	O	HMC	M	2.87	17
Amphitrochus magharensis Douvillé, 1916	G	E	O	A	M	2.74	50
Gervillella orientalis (Douvillé, 1916)	B	SIB	S	A	S	2.64	33
Palaeonucula tenuistriata (J. de C. Sowerby, 1837)	B	IS	D	A	M	2.52	25
C. Daghanirhynchia angulocostata association							
Daghanirhynchia angulocostata Cooper, 1989	BR	EB	S	C	S	56.28	100
"Nerinea" praespeciosa Cossmann, 1885	G	SI	O	A	M	18.97	67
Amphitrochus magharensis Douvillé, 1916	G	E	O	A	M	7.90	33
D. Pholadomya inornata assemblage							
Pholadomya (Ph.) inornata (J. de C. Sowerby, 1837)	B	ID	S	A	S	96.17	100
E. Chomatoseris epithecalis association							
Chomatoseris epithecalis Alloiteau and Farag, 1964	Cor	E	MC	A	S	26.97	100
Kutchithyris parnesi Feldmann et al., 1991	BR	EB	S	C	S	15.16	25
Nanogyra nana (J. Sowerby, 1822)	B	EC	S	C	S	12.38	75
Gryphaeligmus jobbokensis (Cox, 1925)	B	ER	S	C	S	10.35	75
Microsolena areshensis Alloiteau and Farag 1964	Cor	E	MC	A	S	7.11	100
Africogryphaea costellata (Douvillé, 1916)	B	ER	S	C	S	4.05	50
Sphriganaria cardioides (Douvillé, 1916)	BR	EB	S	C	S	3.36	100
Collignonastrea jumarensis (Gregory, 1900)	Cor	E	MC	A	S	2.81	100
F. Daghanirhynchia / Africogryphaea association							
Daghanirhynchia daghaniensis Muir-Wood, 1935	BR	EB	S	C	S	21.60	90

Africogryphaea costellata (Douvillé, 1916)	B	ER	S	C	S	15.87	70
Nicaniella (N.) pisiformis Sowerby, 1840	B	IS	S	A	S	4.94	60
Crinoid sp. 1	Cri	E	O	HMC	M	4.49	10
Gervillella orientalis (Douvillé, 1916)	B	SIB	S	A	S	3.67	40
Bihenithyris sp. A	BR	EB	S	C	S	3.16	40
Ryderia decorata (Douvillé, 1916)	B	IS	D	A	M	2.93	50
Chomatoseris epithecalis Alloiteau and Farag 1964	Cor	E	MC	A	S	2.83	30
Cererithyris sp.	BR	EB	S	C	S	2.52	40
Palaeonucula lateralis (Terquem and Jourdy, 1869)	B	IS	D	A	M	2.52	40
Amphitrochus magharensis Douvillé, 1916	G	E	O	A	M	2.26	30
Nuculoma variabilis (J. de C. Sowerby, 1825)	B	IS	D	A	M	1.91	20
Protocardia (P.) africana (Cox, 1965)	B	EB	S	A	S	1.84	30
Nanogyra nana (J. Sowerby, 1822)	B	EC	S	C	S	1.67	30
Montlivaltia engebashi Alloiteau and Farag 1964	Cor	E	MC	A	S	1.42	10
Plegiocidaris sp.	E	E	O	HMC	M	1.36	20
Chaetetid sponge	Spo	EC	S	C	S	1.33	10
Ectyphoria sinaiensis Feldmann et al., 2012	BR	EB	S	C	S	1.27	20
Eligmus rollandi (Douvillé, 1907)	B	EB	S	C	S	1.27	20
Nerinea praespecicosa Cossmann, 1885	G	SI	O	A	M	1.19	50
G. Eligmus rollandi assemblage							
Eligmus rollandi (Douvillé, 1907)	B	EB	S	C	S	72.73	100
Bothryopneustes sp.	E	I	O	HMC	M	12.12	100
H. Amydroptichus formosus association							
Amydroptichus formosus Cooper, 1989	B	EB	S	C	S	24.37	75
Conarosia rotundata Cooper, 1989	BR	EB	S	C	S	20.67	75
Staphrothyris sp.	BR	EB	S	C	S	15.75	75
Montlivaltia magharicum Alloiteau and Farag 1964	Cor	E	MC	A	S	9.17	50
Cererithyris sp.	BR	EB	S	C	S	8.35	25
Plegiocidaris sp.	E	E	O	HMC	M	4.98	100
I. Coenastrea arabica assemblage							
Coenastrea arabica El-Sa'ad, 1991	Cor	E	MC	A	S	59.18	100
Gyrodendron sp.	Cor	E	MC	A	S	16.33	100
Stylina knetchi Alloiteau and Farag 1964	Cor	E	MC	A	S	8.16	100
J. Cymatorhynchia quadriplicata association							
Cymatorhynchia quadriplicata (Zieten, 1830)	BR	EB	S	C	S	10.35	50
Ataphrus (Ataphrus) asiaticus Douvillé, 1916	G	E	O	A	M	8.04	25
Palaeonucula lateralis (Terquem and Jourdy, 1869)	B	IS	D	A	M	5.44	25
Montlivaltia magharicum Alloiteau and Farag 1964	Cor	E	MC	A	S	5.18	25
Cirripeds	Cru	EC	S	C	S	4.25	13
Heterosalenia sp.	E	E	O	HMC	M	4.03	13
Amphitrochus magharensis Douvillé, 1916	G	E	O	A	M	3.87	25
Plegiocidaris sp.	E	E	O	HMC	M	3.29	38
Eudesia multicostata Tintant, 1963	BR	EB	S	C	S	3.20	25
Peronidella	Spo	EC	S	C	S	2.93	25
Gyrodendron sp.	Cor	E	MC	A	S	2.84	13
Chaetetid sponge	Spo	EC	S	C	S	2.83	13
Awadia lepidomorpha Abdallah and Fahmy, 1969	B	SI	S	A	S	2.31	13
Trigoniia costata Parkinson, 1811	B	IS	S	A	S	2.08	13
Coronella sp.	Spo	EC	S	C	S	1.99	13
Delphinula sp.	G	E	O	A	M	1.88	13
Millericrinus goubili d'Orbigny, 1839	Cri	EC	S	HMC	S	1.61	13
Procerithium (Cosmocerithium) tenerum Parnes, 1981	G	E	O	A	M	1.57	25
Isastrea parva Gregory, 1900	Cor	E	MC	A	S	1.42	13
Eligmus rollandi (Douvillé, 1907)	B	EB	S	C	S	1.42	13
Cladophylliopsis alternicosta (Koby, 1906)	Cor	E	MC	A	S	1.33	25
Ampullospira sp.	G	IS	O	A	M	1.21	13
Millericrinus echinatus Schlotheim, 1820	Cri	EC	O	HMC	S	1.21	13
Crinoid sp. 2	Cri	E	O	HMC	M	1.18	13
Prorokia sp	B	EB	S	A	S	1.16	13
Acteonina (Strioacteonina) sp.	G	IS	O	A	M	1.15	25
Amydroptichus formosus Cooper, 1989	B	EB	S	C	S	8.19	31

Stylina knetchi Alloiteau and Farag 1964	Cor	E	MC	A	S	1.14	13
K. Daghanirhynchia daghaniensis association							
Daghanirhynchia daghaniensis Muir-Wood, 1935	BR	EB	S	C	S	80.07	100
L. Africogryphaea costellata association							
Africogryphaea costellata (Douvillé, 1916)	B	ER	S	C	S	63.6	63
Daghanirhynchia daghaniensis Muir-Wood, 1935	BR	EB	S	C	S	12.5	75
Nanogyra nana (J. Sowerby, 1822)	B	EC	S	C	S	5.2	13

A muddy see floor with abundant secondary hard substrates is inferred, which is supported by the abundance of mobile taxa (23%). Secondary hard substrates were the result of high production of shell material, which provided a stable place for fixosessile faunal elements (e.g., Zuschin and Stachowitsch, 2009). The high percentage of suspension-feeders suggests a turbulence level sufficiently high to keep food particles suspended in the water column. The presence of herbivores implies that this association lived within the photic zone.

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All samples are from the Middle Bathonian, the middle TST of DS4. All brachiopods are articulated, but disarticulation of bivalves is high (76%), suggesting that reworking events were short-lived. The sediment was deposited above the storm wave-base (SWB) in a middle ramp setting. This agrees with the observation of Aberhan (1994) that brachiopod-dominated associations in the Early Jurassic of Chile were restricted to the middle part of carbonate ramps. Species diversity and evenness is high, while the dominance is very low (Table 5.2), pointing to normal-marine, fully oxygenated conditions and a high nutrient supply (mesotrophic to eutrophic conditions). The environment inferred for this association is a middle ramp, characterized by episodic high-energy events

***Cymatorhynchia quadriplicata* association (J)**

The *Cymatorhynchia quadriplicata* association is represented by eight samples with 392 individuals and 76 species, but most of the samples are dominated by only one or few species. It is characterized by the epifaunal terebratulid *Cymatorhynchia quadriplicata* (10.3%), the small gastropod *Ataphrus (A.) asiaticus* (8%), the shallow infaunal bivalve *Palaeonucula lateralis* (5.4%), and the conical solitary coral *Montlivaltia magharica* (5.2%). Brachiopods, infaunal bivalves, and corals are common faunal elements, each representing 15% of the association. Suspension-feeders dominate (54.2%), while deposit-feeders are comparatively rare (4.5%). Mobile taxa are common (39.1%). Epifauna dominates (80%), the infauna represents 17%, and the semi-infauna only 3% of the association. The lithofacies varied from siliciclastics to carbonates and was probably firm.

The degree of fragmentation is low, graded bedding rare, and species overlap among samples is high (Table 5.1). These features point to negligible reworking by storms and suggest that this association records an autochthonous to parautochthonous community relict (Kidwell, 1991; Fürsich et al., 2009; Hofmann et al., 2013).

The association is highly variable as seen from the NMDS (Fig. 5.2). None of the dominating taxa of the trophic nucleus (Table 5.1) is present in all samples. Long-ranging taxa (e.g., *Plegiocidaris* sp., chaetetid sponges, *Millericrinus goubili*) are probably the main reasons that these samples are grouped in a single association. Both alpha and beta diversity are high (Table 5.2). Probably, this association has lived in a low stress environment.

Based on age differences (which is the origin of this variation) the association was split into three sub-associations; Early Bajocian, Early Oxfordian, and Early Kimmeridgian. All lived in a quiet to moderately agitated environment below the SWB. The Early Bajocian sub-association occurs in the Bir Maghara Formation, and occasionally in the late TST of DS3. The Early Oxfordian sub-association is from the late TST of DS6. The Early Kimmeridgian sub-association is from the late TST of DS7.

Nicaniella pisiformis association (B)

This association includes 12 samples with 1353 individuals in 76 species. Shallow-infaunal bivalves such as *Nicaniella (N.) pisiformis* (31.5%), *Nuculoma variabilis* (10.9%), and *Ryderia decorata* (8.3%) are the dominating group. A few brachiopods, corals, and echinoids also occur. Infaunal species dominate (67.8%), epifaunal ones represent 28.3% of the association, the rest lived semi-infaunally. Most of the species are related to soft substrates, such as the shallow-infaunal deposit-feeders.

Table 5.2. Summary of the biotic characteristics of associations and assemblages.

Association	*Daghanirhynchia /Africogryphaea*	*Cymatorhynchia quadriplicata*	*Nicaniella pisiformis*	*Eudesia cardioides*	*Chomatoseris epithecalis*	*Daghanirhynchia angulocostata*	*Amydroptyhus formosus*	*Coenastrea arabica*	*Africogryphaea costellata*	*Eligmus rollandi*	*Daghanirhynchia daghaniensis*	*Pholadomya inornata*
	Polyspecific						paucispecific					
	F	J	B	A	E	C	H	I	L	G	K	D
N samples	10	8	12	16	4	3	4	1	5	1	3	1

Total N species (Ts)	79	76	76	74	45	37	18	9	19	7	14	5
Mean N species (Ms)	15.9	11.6	14.8	11.3	18.3	16	7.5	9	7.2	7	5.7	5
Total N individuals	1043	392	1353	2352	862	871	282	49	462	33	259	209
Mean Shannon (H)	2.1	2.0	1.9	1.1	1.9	1.3	1.5	1.4	1.0	1.0	0.7	0.2
β diversity (Ts/Ms-1)	3.9	5.5	4.1	5.63	1.5	1.3	1.4	0	1.6	0	1.4	0
Evenness (e^H/Ts)	0.6	0.7	0.5	0.4	0.4	0.2	0.7	0.4	0.5	0.4	0.6	0.3
Dominance (D)	0.2	0.2	0.2	0.5	0.3	0.4	0.3	0.4	0.5	0.6	0.7	0.9
Epifauna	77.2	79.8	28.2	93.7	95.1	92.0	96.5	95.9	99.0	78.8	95.7	3.8
Infauna	17.9	17.2	67.8	5.3	4.1	7.2	3.5	4.1	1	21.2	4.0	96.2
Semi-infauna	4.9	3.0	4.0	1.0	0.7	0.1	0.0	0.0	0.0	0.0	0.0	0.0
Epibyssate	37.1	20.5	9.1	84.3	21.9	57.1	79.6	0.0	22.0	72.7	84.7	0.5
Cemented	5.6	17.7	5.6	3.5	14.5	2.0	2.4	4.0	11.3	0.0	0.0	0.0
Reclining	16.3	0.0	0.9	1.7	14.4	0.4	0.0	0.0	62.5	0.0	6.7	2.4
Deep-infaunal	1.4	0.2	0.2	0.6	0.0	0.2	3.2	2.0	0.3	3.0	0.0	96.2
Shallow-infaunal	15.4	17.0	63.1	4.1	4.1	7.0	0.3	2.0	6.0	3.0	4.3	0.0
Bivalves	43.7	21.6	75.4	8.1	33.5	8.0	29.2	4.0	70.8	78.8	10.8	99.0
Epifaunal bivalves	24.1	6.4	7.1	3.9	29.7	1.3	25.8	0.0	69.5	72.7	6.7	2.9
Infaunal bivalves	15.8	12.8	68.3	4.2	3.8	6.7	0.3	4.0	1.3	6.1	4.1	96.1
Brachiopods	32.1	15.5	5.7	83.8	19.4	57.0	54.5	0.0	20.8	0.0	84.7	0.0
Corals	6.1	14.9	5.0	2.9	41.0	4.6	9.2	89.8	1.0	3.0	2.9	0.5
Suspension-feeders	71	44	54.2	90.6	52.8	60.7	85	8	96	78.8	92	99.0
Deposit-feeders	9	2	28.11	2.62	1.87	5.58	0	0	1	0.00	3.5	0.00
Microcarnivores	6	15	4.9	2.90	41.04	4.44	9	90	1	3.0	3	0.48
Omnivores/Herbivores	15	33.5	12.72	3.72	4.2	28.75	5	2	2	18.18	1.5	0.48
Mobile	23	39	40.75	6.15	6	34.63	6	2	2	18.18	5	0.48
Stationary	77	61	59.25	93.85	94	75.37	94	98	98	81.82	95	99.52

Mobile taxa account for 40.7%. Due to their activities, they increased the softness of the substrate, which thus became less attractive for epifauna. More than half of the individuals are suspension-feeders (54.2%), 28.1% are deposit-feeders, which indicates that food particles were concentrated in both the water column and in the sediment. The absence of herbivores suggests that sedimentation took place below the photic zone, which also explains the absence of algal microborings. The species diversity and evenness of the association is high (Table 5.2). Both indicate a stable environment suitable for the colonization by several guilds. Samples in this association belong to the Middle Bathonian Kehailia Formation.

The thin-bedded fine-grained sediment (mainly marl or silt) and the dominance of infauna indicate an environment characterised by soft substrate, low energy conditions, and a distinct decrease of carbonate production due to its position below the euphotic zone (Loutit et al., 1988). Sedimentary structures are lacking probably due to bioturbation. The sedimentation rate was low, resulting in some encrustation and bioerosion (e.g., *Gastrochaenolites;* Fig. 5.6A).

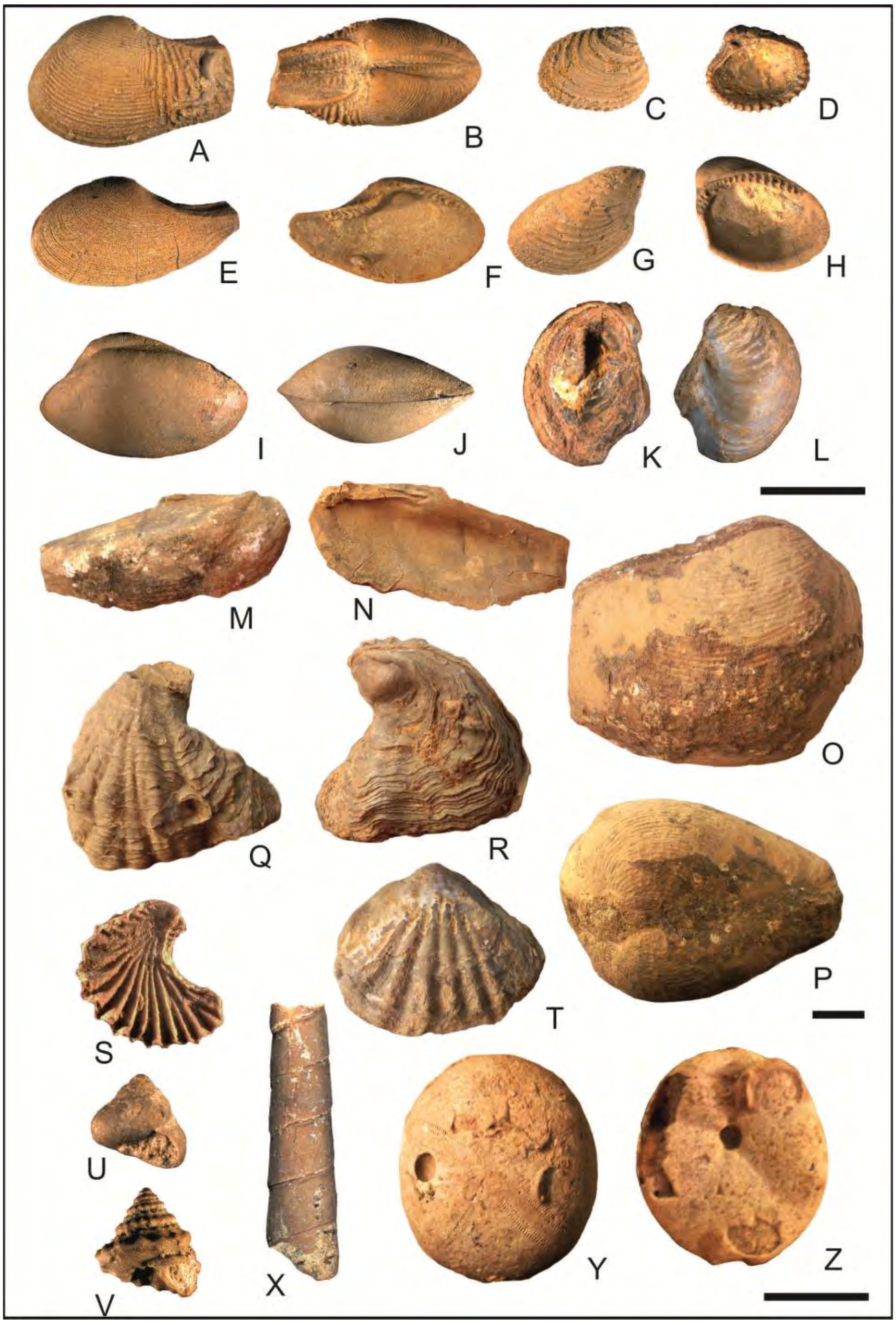

Fig. 5.4. Some characteristic molluscs and echinoids of the associations. A-B, Nuculoidea n.sp., Kehailia Fm., Middle Bathonian, G. Homayir section, BSPG 2014V 1. C-D, *Nicaniella (N.) pisiformis* J. de C. Sowerby, 1840*,* Kehailia Fm., Middle Bathonian, G. Arousiah section, BSPG 2014V 2. E-F, *Ryderia decorata* (Douvillé, 1916)*,* Kehailia Fm., Middle Bathonian, G. Engabashi, BSPG 2014V 3. G-H, *Nuculoma variabilis* (J. de C. Sowerby, 1825)*,* Kehailia Fm., Middle Bathonian, G. Arousiah section, BSPG 2014V 4. I-J, *Palaeonucula lateralis* (Terquem & Jourdy, 1869)*,* Arousiah Fm., Middle Callovian, G. Engabashi section, BSPG 2014V 5. K-L, *Nanogyra nana* (J. Sowerby, 1822)*,* Arousiah Fm., Middle Callovian, G. Engabashi section, BSPG 2014V 6. M-N, *Gervillella orientalis* (Douvillé, 1916)*,* Bir Maghara Fm., Upper Bajocian, G. Engabashi section, BSPG 2014V 7. O-P, *Pholadomya (Ph.) inornata* (J. de C. Sowerby, 1837)*,* Arousiah Fm., Middle Callovian, G. Arousiah section, BSPG 2014V 8. Q-R, *Africogryphaea costellata* (J. de C. Sowerby, 1837)*,* Safa Fm., Lower Bathonian, G. Mowerib section, BSPG 2014V 9. S, *Gryphaeligmus jobbokensis* (Cox, 1925)*,* Arousiah Fm., Middle Callovian, G. Arousiah section*,* BSPG 2014V 10. T, *Eligmus rollandi* (Douvillé, 1907), Kehailia Fm., Upper Bathonian, G. Homayir section, BSPG 2014V 11. U, *Ataphrus (A.) asiaticus* Douvillé, 1916*,* Bir Maghara Fm., Lower Bajocian, G. Engabashi section, BSPG 2014V 12. V, *Amphitrochus magharensis* Douvillé, 1916*,* Bir Maghara Fm., Lower Bajocian, G. Engabashi section, BSPG 2014V 13. X, *"Nerinea" praespeciosa* Cossmann, 1885*,* Arousiah Fm., Middle Callovian, G. Arousiah section, BSPG 2014V 14. Y-Z, *Bothryopneustes* sp., Kehailiah Fm., Upper Bathonian, G. Homayir section, BSPG 2014V15. Scales: 1 cm, referring to the rows above.

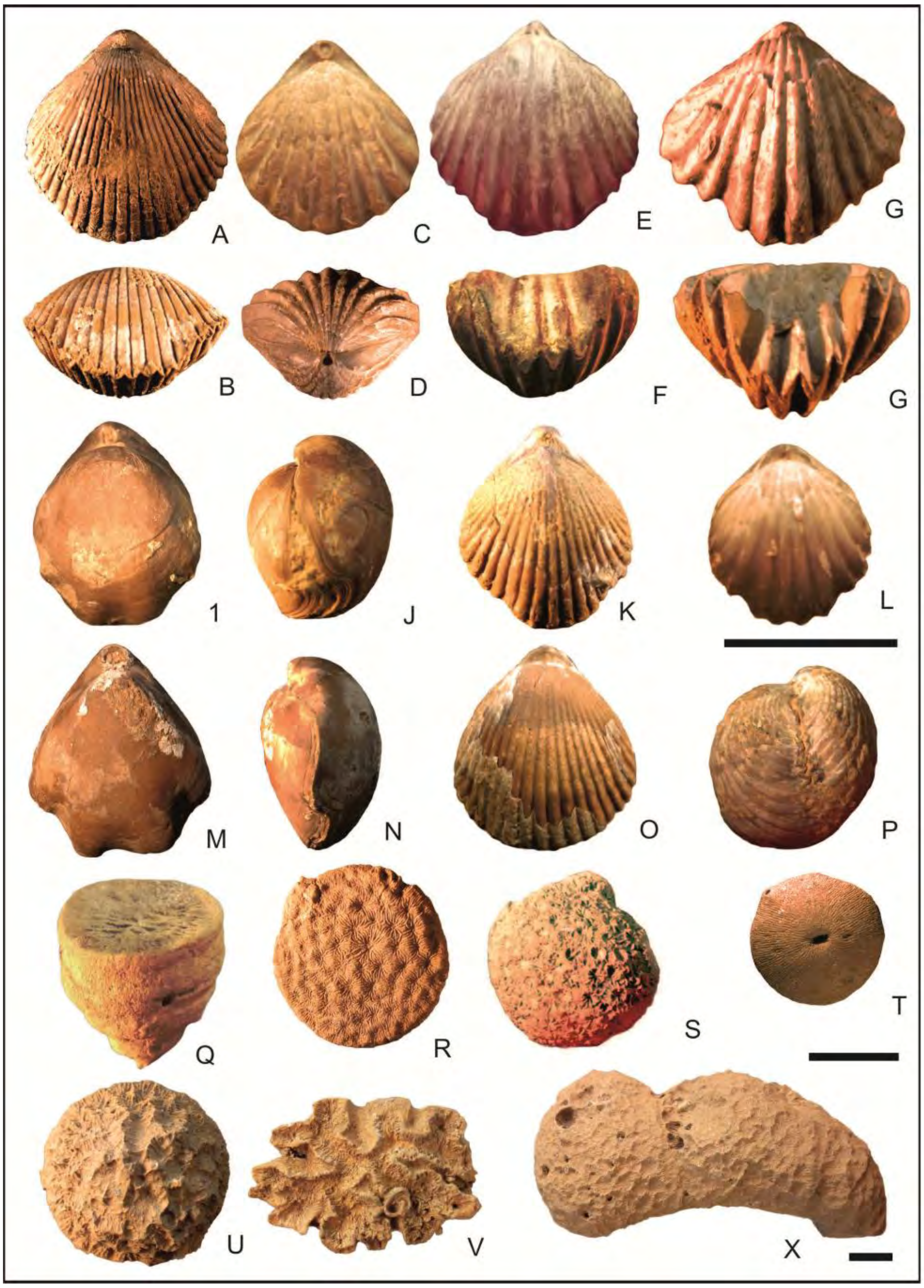

Fig. 5.5. Some characteristic brachiopods and corals of the associations. A-B, *Cymatorhynchia quadriplicata* (Zieten, 1830), Bir Maghara Fm., Upper Bajocian, G. Engabashi section, BSPG 2014V 16. C-D, *Eudesia (Sphriganaria) cardioides* (Douvillé, 1916), Kehailiah Fm., Middle Bathonian, G. Engabashi section, BSPG 2014V 17. E-F, *Daghanirhynchia daghaniensis* Muir-Wood, 1935, Safa Fm., Lower Bathonian, G. Arousiah section, BSPG 2014V 18. G-H, *Daghanirhynchia angulocostata* Cooper, 1989, Arousiah Fm., Lower Callovian, G. Arousiah section, BSPG 2014V 19. I-J, *Ectyphoria sinaiensis* Feldmann et al., 2012, Kehailiah Fm., Upper Bathonian, G. Engabashi section, BSPG 2014V 20. K, *Amydroptichus formosus* Cooper, 1989, Bir Maghara Fm., Upper Bajocian, G. Engabashi section, BSPG 2014V 21. L, *Burmirhynchia (Hopkinsirhynchia) cavagnari* (Diaz-Romero, 1931), Arousiah Fm., Lower Callovian, G. Mowerib section, BSPG 2014V 22. M-N, *Kutchithyris parnesi* Feldmann et al., 1991, Kehailiah Fm., Middle Bathonian, G. Arousiah section, BSPG 2014V 23. O-P, *Conarosia rotundata* Cooper, 1989, Bir Maghara Fm., Upper Bajocian, G. Engabashi section, BSPG 2014V 24. Q, *Montlivaltia magharicum* Alloiteau & Farag, 1964, Bir Maghara Fm., Upper Bajocian, G. Engabashi section, BSPG 2014V 25. R, *Microsolena areshensis* Alloiteau & Farag, 1964 , Kehailiah Fm., Middle Bathonian, G. Arousiah section, BSPG 2014V 26. S, *Stylina knetchi* Alloiteau & Farag, 1964, Tauriat Fm., Middle Oxfordian, G. Homayir section, BSPG 2014V 27. T, *Chomatoseris epithecalis* Alloiteau & Farag, 1964, Kehailiah Fm., Middle Bathonian, G. Arousiah section, BSPG 2014V 28. U, *Collignonastrea jumarensis* (Gregory, 1900), Kehailiah Fm., Middle Bathonian, G. Arousiah section, BSPG 2014V 29. V, *Gyrodendron* sp., Tauriat Fm., Middle Oxfordian, G. Arousiah section, BSPG 2014V 30. X, *Coenastrea Arabica* El-Sa'ad, 1991, Tauriat Fm., Middle Oxfordian, G. Arousiah section BSPG 2014V 31.

The shells experienced a long residence time on the sea floor before becoming buried (Loutit et al., 1988), and thus provided secondary hard substrates for the few epifaunal taxa. The dense networks of *Thalassinoides* in the sediments of this association (Fig. 5.6B) were produced by decapod crustaceans similar to those living in muddy bottoms of the modern seas. The degree of bioerosion is lower than expected and affected only few shells, which is a consequence of the fact that infaunal shells are less affected than epifaunal ones (Lazo, 2004). In addition, thin shells (< 0.5 mm), regardless of life habit or mineralogy, are damaged less commonly than thicker ones, probably because of selective colonization of the latter by fouling organisms (Best and Kidwell, 2000).

In conclusion, the *Nicaniella (N.) pisiformis* association reflects low-energy conditions, in which physical breakage was lower than in early transgressive deposits. This, together with low rates of sedimentation (starvation), is a typical feature of the maximum flooding (Brett, 1995; Fürsich and Aberhan, 1990; Fürsich and Pandey, 2003; Wilmsen, 2008, 2012). Diversity probably was enhanced not only by time-averaging, but also by the stable low-stress conditions (fully oxygenated and euhaline) with low to moderate food supply (oligo- to mesotrophic). As a result, deep- and shallow-infaunal, epifaunal organisms, as well as nektonic ammonites occur (high beta diversity).

***Chomatoseris epithecalis* association (E)**

This association includes four samples with 862 individuals and 45 species. It is present in all measured sections. Corals, bivalves, and brachiopods dominate; they represent 41%, 33.5%, and 19.5%, respectively. The dominant species are the solitary discoid coral *Chomatoseris epithecalis* (27%), the terebratulid *Kutchithyris parnesi* (15%), the oyster *Nanogyra* nana (12.4%)*,*the malleid *Gryphaeligmus jobbokensis* (10.4%), and the coral *Microsolena areshensis* (7%). All mega-guilds are found here. In addition, all types of life habit are represented. Facies varies from marl to packstone.

Epifaunal individuals dominate (95%), 22% of which were pedicle-attached. Consequently, a firm substrate is inferred. The latter is supported by the scarcity of mobile taxa (6%). Fifty-three percent of the individuals were suspension-feeders; the turbulence level must have been sufficiently high to keep food particles suspended in the water column. The species diversity is high (Table 5.2), but dominance increased and evenness decreased compared to the previously discussed associations. The increase in dominance may be explained by the elevated water-energy, and by eutrophication. However, as corals provide habitats for fixo-sessile taxa, the overall diversity was still high. All samples are from the early Middle Bathonian (Kehailia Formation).

The environment inferred for this association is a well oxygenated, shallow middle ramp above the SWB, characterized by high energy events, low rate of sedimentation, and a high productivity.

Daghanirhynchia angulocostata **association (C)**

This association includes three samples, one from the Upper Bajocian (packstone) and two from the Lower Callovian (onco-wackestone). These samples comprise 871 individuals and 37 species. Brachiopods and gastropods are the main components in this association, while bivalves, corals, and other macroinvertebrates are minor elements. The dominant taxa are, in order of decreasing abundance, *Daghanirhynchia angulocostata* (56.3%), "*Nerinea*" *praespeciosa* (19%), *Amphitrochus magharensis* (7.9%), and *Palaeonucula lateralis* (3.8%). Epifaunal species dominate (92%). Concentrations of sponges also occur (Fig. 5.6D). The fossils are commonly silicified.

Corals, sponges, and herbivorous taxa occur, indicating the photic zone. Both species richness and beta diversity are high (Table 5.2). Dominance of carbonate sediments instead of siliciclastics indicates low terrigenous supply. The latter may be the reason for the low abundance of the infaunal guild (7.2%), which may also be due to a firm substrate during early transgression. Such a substrate might have developed from by-passing of fine sediment. Consequently, food supply for infaunal deposit-feeders may have been limited.

Brachiopods are abundant (57%), while bivalves represent only 8%. The consistency of the substrate may have excluded infaunal bivalves (Grădinaru and Bărbulescu, 1994) and hence decreased bulldozing and increased the chances for survival of the lecithotrophic larvae of brachiopods. At the same time, the planktotrophic larvae of bivalves may have suffered high mortality being digested by the abundant sponges and microcarnivores.

The dominance of nerineoid gastropods agrees with Waite et al. (2008), who suggested that nerineoids were epifaunal, living in suspension-rich, high-energy environments with a low sedimentation rate and a stable substrate. Concentrations of nerineids may have acted as a grid, trapping the sediment in between. In this way, nutrients could have become concentrated (Wieczorek, 1979). An additional modification of heterobranchs is the development of new respiratory structures such as secondary gills, which enhance the respiration process under dysoxic conditions (Ponder and Lindberg, 1997). In heterobranchs, the eggs are connected by chalazae (two spiral bands in the egg that extend from the yolk and attach to opposite ends of the lining membrane), surrounded by albumen (supplement to yolk) and in separate capsules encased in jelly (Ponder and

Lindberg, 1997). This complex structure enhances the ability of larvae to overcome food dilution and/or oxygen depletion (see also Oschmann, 1993).

The *Daghanirhynchia angulocostata* association lived on a deep middle ramp above the SWB with low terrigenous input.

***Eudesia cardioides* association (A)**

This association includes 16 samples with 2352 individuals spread across 74 species. The dominating brachiopods (Table 5.2) are the rhynchonellids *Eudesia* (*Sphriganaria) cardioides* (70.5%) and *Burmirhynchia (Hopkinsirhynchia) cavagnari* (6.8%), followed by the spherical-shaped terebratulid *Ectyphoria sinaiensis* (2.3%). The small opportunistic oyster *Nanogyra nana* (1.6%) encrusted, together with some serpulids, *Eudesia* shells. Rock types are mainly wacke- to floatstone. Most of the species exhibit a relationship to hard substrates, being either pedically or byssally attached (epifaunal species account for 93.7%; Table 5.2). Infaunal taxa are comparatively rare (5.3%). The percentage of mobile taxa is also low (6.2%). The abundance of pedicle-attached epifauna (84.2%) indicates plenty of components (bioclasts) within the otherwise fine-grained sediment.

Although alpha diversity is moderate, beta diversity is high (Fig. 5.2 and Table 5.2), which most likely reflects low stress (Fürsich, 1981; Wilmsen, 2008, 2012; Fürsich et al., 2012). The presence of brachiopods and corals indicates euhaline conditions. Ninety percent of the individuals were suspension-feeders (brachiopods, bivalves, and serpulids), which points to elevated water energy whereby food particles are kept suspended in the water column. The rarity of deposit-feeding bivalves can be explained as consequence of this high water-energy and of by-passing of particulate organic matters. The brachiopod metabolism is three- to ten-times slower than that of bivalves (Peck, 1992, 1996; Rhodes and Thompson, 1993), which enables brachiopods to cope better with low food availability than bivalves.

The *Eudesia cardioides* association has been recognized in all measured sections. Most samples in this association are from the Middle Bathonian Kehailia Formation. Some are from the Early Callovian Arousiah Formation. The sediments have been deposited above the SWB in a middle ramp environment characterized by comparatively high-energy conditions.

5.3.3 Paucispecific associations

***Amydroptichus formosus* association (H)**

The moderately diverse association is represented by four samples with 282 individuals in 18 species. It is characterized by the terebratulid *Amydroptichus formosus* (24.4%), the rhynchonellids *Conarosia rotundata* (20.8%) and *Staphrothyris* sp. (15.7%), the conical solitary coral *Montlivaltia magharica* (9.2%), and by the rhynchonellid *Cererithyris* sp. (8.3%). Brachiopods are the most common faunal element (54.5%), bivalves (25.8%) occupying the second rank. The common corals and brachiopods indicate euhaline conditions in the photic zone. Suspension-feeders dominate (85%) as does the epifauna (96.5%).

The dominance of epifauna suggests a firm substrate (wacke- to packstone). All brachiopods and 83% of bivalves are articulated, which indicates low water-energy. The small size of many taxa such as the ammonites *Magharina, Straungia,* and *Lissoceras* in addition to corals probably was due to a limited food supply (Grădinaru and Bărbulescu, 1994; Tomašových, 2006), which may have resulted from restricted circulation. The low food supply may also explain the dominance of brachiopods (Tomašových, 2006).

Infauna is rare (3.5%), possibly due to the nutrient-poor carbonate regime or due to hypoxia below the sediment-water interface. The latter is supported by the abundance of ammonites and *Bositra*-rich shales within the stratigraphic interval of this association (Fig. 5.6C). The ammonites are mainly endemic taxa, always of very small size, and strongly pyritized.

The dominance of epifaunal suspension-feeders in soft substrates is commonly related to anoxic conditions below the sediment-water interface, which excludes the deep- and possibly also the shallow-infaunal guilds (Oschmann, 1988; Aberhan, 1992). Fluctuating climatic conditions in lagoonal environments may lead to a stratified water mass and hypoxia within the sediment (Fürsich et al., 2012). Under such conditions, elevation above the sediment-water interface has the advantage of feeding from higher-level tiers and helps these organisms to survive seasonal hypoxia.

The moderate diversity values (Table 5.2) within this association are interpreted to be a consequence of moderate time-averaging, whereas the original palaeo-community had suffered from restricted conditions. The *Amydroptichus formosus* association is thought to represent a restricted ramp (see also Al Far, 1966) under quiet conditions with low terrigenous input and a certain amount of oxygen deficiency. The association occurs in the Upper Bajocian Bir Maghara Formation.

***Coenastrea arabica* assemblage (I)**

The single sample (hence termed assemblage rather than association) comes from a marly onco-packstone of the G. Arousiah section. It consists of 392 individuals and nine species. The colonial phaceloid coral *Coenastrea arabica* represents 59.2% of the individuals, the flabello-meandroid coral *Gyrodendron* sp. 16.3%, and the globular, plocoid coral *Stylina knetchi* 8.2%. The high abundance of corals indicates euhaline conditions.

The fixosessile epifauna represents 96%, and corals alone 90%, whereas the infaunal biota accounts only for 4%. The moderate diversity values (Table 5.2), the high dominance (D: 0.4), and the paucispecific nature of the *Coenastrea arabica* assemblage may indicate a moderate stress environment. The assemblage occurs in the uppermost Arousiah Formation, which corresponds to a late regressive phase. It was deposited in a middle ramp environment above the SWB. As the sedimentation rate was probably high, only a few guilds are present.

***Africogryphaea costellata* association (L)**

The association includes five samples with 462 individuals and 19 species. It is a low diversity, paucispecific association, which is characterized by high abundances of only a single species, which is the epifaunal oyster *Africogryphaea costellata* (63.6%), followed by the epifaunal brachiopod *Daghanirhynchia daghaniensis* (12.5%). The small oyster *Nanogyra nana* represents 5.2%, usually encrusting hard substrates such as *Africogryphaea* shells as do some serpulids (8%; Fig. 5.6F). Nearly all individuals lived epifaunally (99%). Ichnotaxa such as *Rhizocorallium irregulare* occur at the base of the bed containing the oyster (Fig. 5.6G). All samples in this association are from the top of the Safa Formation comprising the late-Early Bathonian.

The low diversity values and the high dominance (Table 5.2) suggest a high stress environment. The sedimentological framework of this association and the position within the sections indicate that the beds were deposited in a quiet-water, distal prodelta environment. The stress in marginal marine environments is varied (e.g., salinity fluctuations, hyperpycnal flows, oxygen deficiency, etc.). Barnes (1989) suggested that a dominance of taxa, which are usually interpreted to be indicative of brackish-water, could also indicate an unusually soft or soupy substrate. The dominance of the stenohaline brachiopods excludes salinity as a stress factor.

The laminated nature of the sediments in addition to the scarcity of bioturbation may suggest some oxygen deficiency. According to Tyson and Pearson (1991), seasonal dysoxic conditions may occur in in salinity-stratified estuarine or pro-delta settings. When bottom circulation is limited, the oxygen stored in each layer may become periodically exhausted. The epifauna can overcome dysoxia at the sediment-water interface. The dominance of the reclining oyster *Africogryphaea* suggests a soft substrate. In conclusion, the *Africogryphaea costellata*_association colonised a low-energy prodelta environment influenced by dysoxia and/or a soft substrate during sea-level lowstand (Early Bathonian).

Daghanirhynchia daghaniensis **association (K)**

Three samples with 259 individuals and 14 species belong to this low diversity, paucispecific association. The epifaunal brachiopod *Daghanirhynchia daghaniensis* represents 80% of the individuals. The facies varies from marl to pure mudstone. Although the substrate probably was soft, epifauna dominates (95.7%), infauna being represented by only 4% of the individuals.

Concentrations of the epifaunal suspension-feeding brachiopod *Daghanirhynchia daghaniensis* do not point to high-energy conditions, since they occur in soft sediments (marl, mud- or wackestone). Brachiopods dominate, whereas mobile faunal elements account only for 5%. Absence of grazers may have favoured the colonization by brachiopods (Thayer, 1986). The brachial valve of *Daghanirhynchia daghaniensis* is highly convex (Fig. 5.5C), which may have facilitated a stable position of the shell in the soft sediment (i.e., in a way similar to the reclining oyster). Scarcity of infauna may have been due to dysoxia below the sediment-water interface.

Diversity in this association is very low and the dominance is very high (Table 5.2)., which points to high stress. The association comes from the same environment as the previously described *Africogryphaea costellata* association, but it occupies a lower stratigraphic position. The association lived in a low-energy, distal prodelta environment within the Safa Formation influenced by dysoxia during an Early Bathonian sea-level lowstand.

Are *Africogryphaea costellata* and *Daghanirhynchia daghaniensis* opportunistic species similarly to the well-known *Nanogyra nana* of the previous association (Fürsich, 1977)? Levinton (1970) provided seven criteria to recognize the opportunistic strategy of a species in the fossil record. Some of these criteria such as wide isochronous distribution in thin horizons, and abundance in several other associations as well seem to fit both species. However, the abundance of the two species (80% and 63%, respectively), which is less than what Levinton (1970) suggested for opportunists (i.e., 85-100%), their relatively large size, and their long life span, identifies them more likely as „periodic" taxa (Kawasaki, 1980; Winemiller, 1989, 2005; Winemiller and Rose, 1993). Periodic taxa occupy an intermediate position between opportunistic and equilibrium species (i.e., moderate to long generation time, moderate reproductive effort, delayed maturation, large body size, low investment per offspring, longevity, high fecundity, and high recruitment variation), and thus may be eurytopic (see also Sanders, 1968; Levinton, 1970).

Eligmus rollandi **assemblage (G)**

This assemblage is represented only by one sample with 33 individuals and 7 species. The sample is from the G. Engabshi section. The epifaunal bivalve *Eligmus rollandi* represents 72.7% of the individuals, the irregular echinoid *Bothryopneustes* sp. 12.1%, and five other species account for less than 3.1%,. They are two heterodont bivalves (*Integricardium* sp. and *Thracia viceliacensis*), another species of *Bothryopneustes* (*B. lamberti*), the small coral *Chomatoseris epithecalis,* and the epifaunal gastropod *Phyllocheilus pictaviensis*. The high abundance of the epibyssate *Eligmus* indicates the presence of sufficient components in the otherwise soft substrate, the latter inferred from the occurrence of common infaunal biota (21.2%). Suspension-feeders are the main trophic group (78.8%), whereas omni-/herbivores are far less common (18%).

The assemblage comes from interbedded oo-biopack-/grainstones, less than 40 cm thick. It represents the late stage of HST (FSST) of the depositional sequence 4, comprising the Late Bathonian Kehailia Formation. Absence of brachiopods may be related to increasing bulldozing and hence bioturbation (Thayer, 1979). Absence of identifiable ichnotaxa in these shallow-water sediments may be related to the high degree of bioturbation.

The low diversity values, the high dominance (Table 5.2), the paucispecific nature of the assemblage and the high physical damage (90% of the bivalve shells are disarticulated, and two-thirds of the specimens show some degree of abrasion and/or fragmentation), all could reflect a high stress environment. The assemblage is clearly the parautochthonous relict of a former community. The *Eligmus rollandi* assemblage lived above the fair-weather wave-base in a high-energy shoal environment of the inner ramp. Consequently, only few guilds were developed.

Pholadomya inornata **assemblage (D)**

The assemblage includes only one sample from the G. El-Mor section with 209 individuals and five species. The deep infaunal suspension-feeding bivalve *Pholadomya (Ph.) inornata* represents 96.2% of the paucispecific assemblage. *Africogryphaea costellata* represents 2.4% and three other species (*Protocardia (P.) africana, Bathrotomaria eudora*, and *Coenastrea arabica*) account for less than 0.5% each. The assemblage comes from a glauconitic mudstone bed, 2.20 m thick, in the Middle Callovian of the Arousiah Formation which represents a phase of maximum flooding.

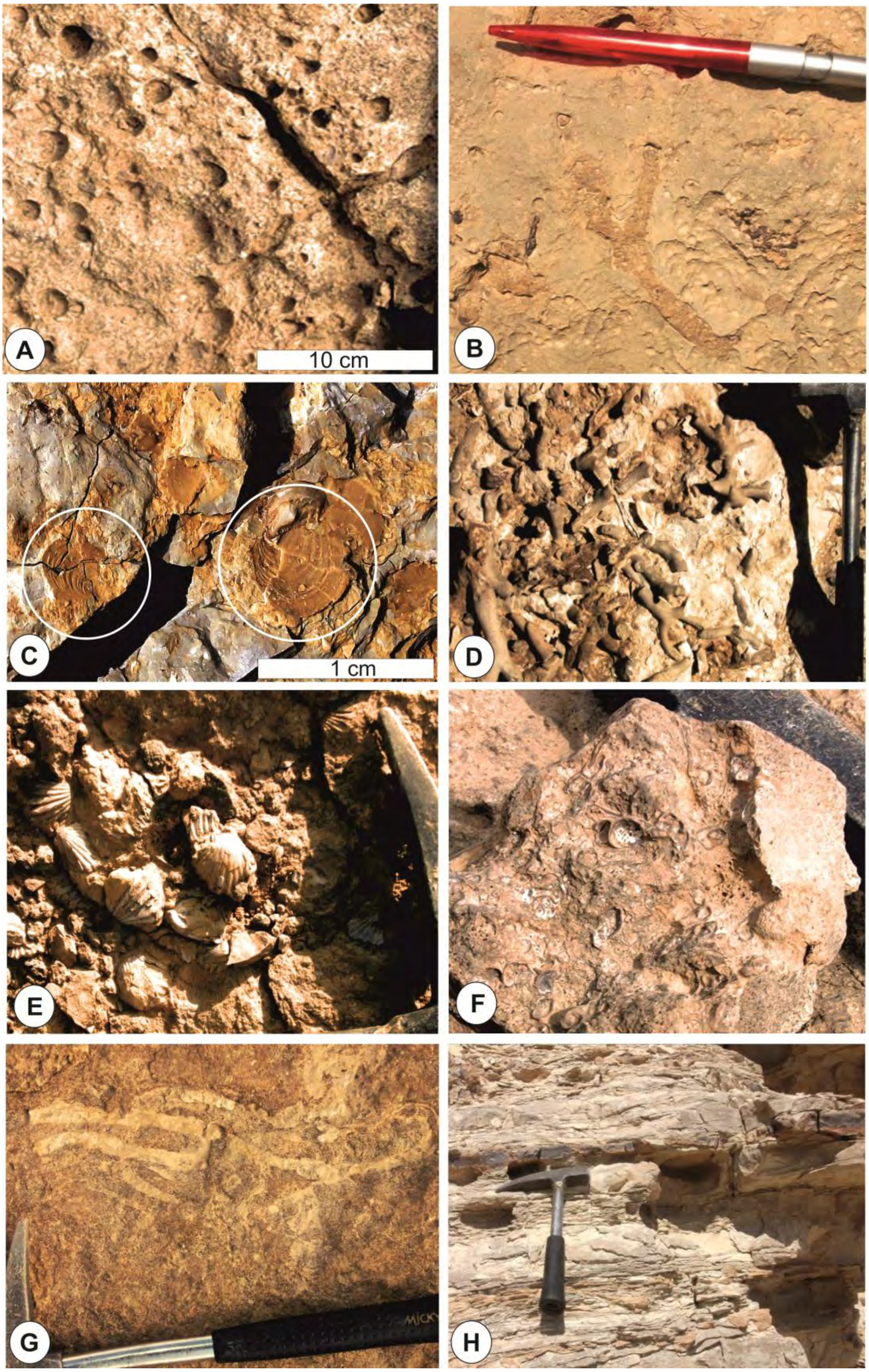

Fig. 5.6. A, Hardground with many *Gastrochaenolites* borings, Kehailia Fm., Middle Bathonian, G. El-Mor. B, *Thalassinoides* in the hardground shown in A. C, Shale rich in *Bositra*, overlying some beds in Association H, Bir Maghara Fm. Bajocian, G. Engabashi. D, Concentration of siliceous sponges, Arousiah Fm., Callovian, G. Engabashi. E, Biogenic concentration of *Daghanrihynchia angulocostata*, Arousiah Fm., Callovian, G. Engabashi. F, Hardground encrusted by *Nanogyra nana* and serpulids, Safa Fm., Lower Bathonian, G. Moweib. G, *Rhizocorallium irregulare* in sandstone of the Safa Fm., G. Engabashi. H, Nodular and layered silica concretions, Arousiah Fm., Callovian, G.Engabashi.

The presence of glauconite, formed during phases of strongly reduced sedimentation, supports the interpretation that the bed represents a long time span. The exclusively articulated *Pholadomya* suggests that the fauna is autochthonous. The fine-grained sediment and the low abundance of encrusting species point to a soft substrate.

Due to the long time span involved (extensive time-averaging) faunas of the maximum flooding zone usually are characterized by high species diversity. However, this assemblage has a very low diversity value which, together with the very high dominance, could be the consequence of a high stress environment. The latter is enigmatic as according to Fürsich et al. (1995) *Pholadomya* is a stenohaline taxon, not adapted to high stress conditions. Low diversity may also result from selective diagenetic dissolution of skeletal elements. The originally aragonitic *Pholadomya* shells are preserved as internal moulds, which suggests dissolution of aragonitic shell material. The bed containing the *Pholadomya* assemblage lived below the storm wave-base in a sediment-starved, oligotrophic outer ramp environment.

5.4 Distribution pattern of brachiopods versus bivalves

Brachiopods are more common than bivalves in the Jurassic rocks of G. Maghara (individual ratio 3883:2963). This coincides with previous observations about the abundance of brachiopods in the Mediterranean and East Europe provinces (Aberhan, 1994). Four of the twelve identified associations and assemblages are dominated by brachiopods, six by bivalves and in two associations corals dominate (Fig. 5.1). Brachiopods dominate in Associations A, C, H, and L because of the increasing number of secondary hard substrates and decreasing bulldozing activities. As immobile suspension-feeders living on soft substrate suffer from grazing and bulldozing activities more than other organisms (Thayer, 1979), brachiopods are absent in assemblage G (40% grazers) and in association B (18% grazers and deposit-feeders).

The abundance of brachiopods in associations A, C, and H, which lived during the early stages of transgression, supports the idea of Thayer (1986) that the energetically efficient articulate brachiopods have a competitive advantage over suspension-feeding bivalves when oxygen or food is limited. Brachiopods, in general, have a lower metabolic rate and thus lower nutrient demands than bivalves. Dominance of siliceous sponges in association C corroborates the oligotrophic conditions, as „hexactinellid" sponges are able to feed by osmotrophy, and „lithistid" sponges can feed efficiently on living organic matter by hosting a huge mass of bacteria (Barthel, 1992; Leinfelder et. al., 1999). Brachiopod dominance might also be enhanced by reduced oxygen levels, which limits grazers and bivalve competitors for space (Tomašových, 2006). Abundance of brachiopods in associations L may be related to dysoxia at the sediment-water interface.

Fürsich et al. (2001) and Gahr (2005) observed that brachiopods and epifaunal bivalves dominated and infaunal bivalves were relatively rare in habitats less affected by siliciclastic supply from land (as in case of associations A, C, and H). When terrigenous sediment influx increased, infaunal bivalves increased in abundance, while the substrate turned soupy (loose) and became unstable for brachiopods. As a result, infaunal bivalves outcompeted brachiopods. The latter is evident in Association B, in which infaunal bivalves represent 68.3% of the association.

In associations E, F, and J bivalves usually exceed brachiopods in abundance (ratio 4:3); this may reflect the environmental conditions on the middle ramp, where higher water energy and mesotrophic conditions prevail. Bivalves, which are characterized by 17 times higher pumping rates (amount of water processed by the gills to extract food particles) than brachiopods (LaBarbera, 1984), thus better cope with higher water energy than brachiopods.

Abundance of bivalves in high-stress associations and assemblages (assemblages D, G, and association K) may suggest superiority of bivalves over brachiopods. Adaptation strategies such as thick shells and a strong attachment organ (pedicle or byssus) successfully cope with agitated environments in both brachiopods and bivalves (Ager, 1965; Grădinaru and Bărbulesu, 1994). Both groups have also developed strategies to cope better with very soft substrates (e.g., mud stickers and reclining mode of life in the case of bivalves (Seilacher, 1984) and a semi-infaunal life-style in the case of brachiopods (Grădinaru and Bărbulescu, 1994)). The deep-sulcate pedicle valve is a successful adaptation of brachiopods to quiet deep-water environments with limited food supply; it increases the divergence between the inhalant and exhalant feeding currents and enhances the feeding process (Rudwick, 1970; Fürsich and Hurst, 1974). In addition, Steele-Petrović (1979) noticed that brachiopods are able to assimilate dissolved substances during times of low influx of particulate food. As a result, brachiopods are dominating the nutrient-poor carbonate environments (see also Gahr, 2005).

Bivalves developed various strategies to cope with predation (e.g., an infaunal mode of life, thick shells, spines, and swimming ability; Thayer, 1985; Rhoads and Thayer, 1991; Tomašových, 2006). In addition, the often long planktotrophic larval stage enhances the potential to disperse across long distances and helps to overcome temporary oxygen problems. Although brachiopods have also developed anti-predation strategies (such as chemical defenses; Mahon et al., 2003), the strategies of the bivalves are more comprehensive.

Our results support the restriction of brachiopod-dominated associations to environments with firm to hard substrates, low food supply, low grazing activity, and low rates of sedimentation (Aberhan, 1993b, 1994; Fürsich et al., 2001; Gahr, 2005). In general, the distribution patterns of brachiopods and bivalves can be explained by variations in abiotic factors (such as water energy and sedimentation rate; Fig. 5.7) but also by biotic factors (feeding strategies; Tomašových, 2006).

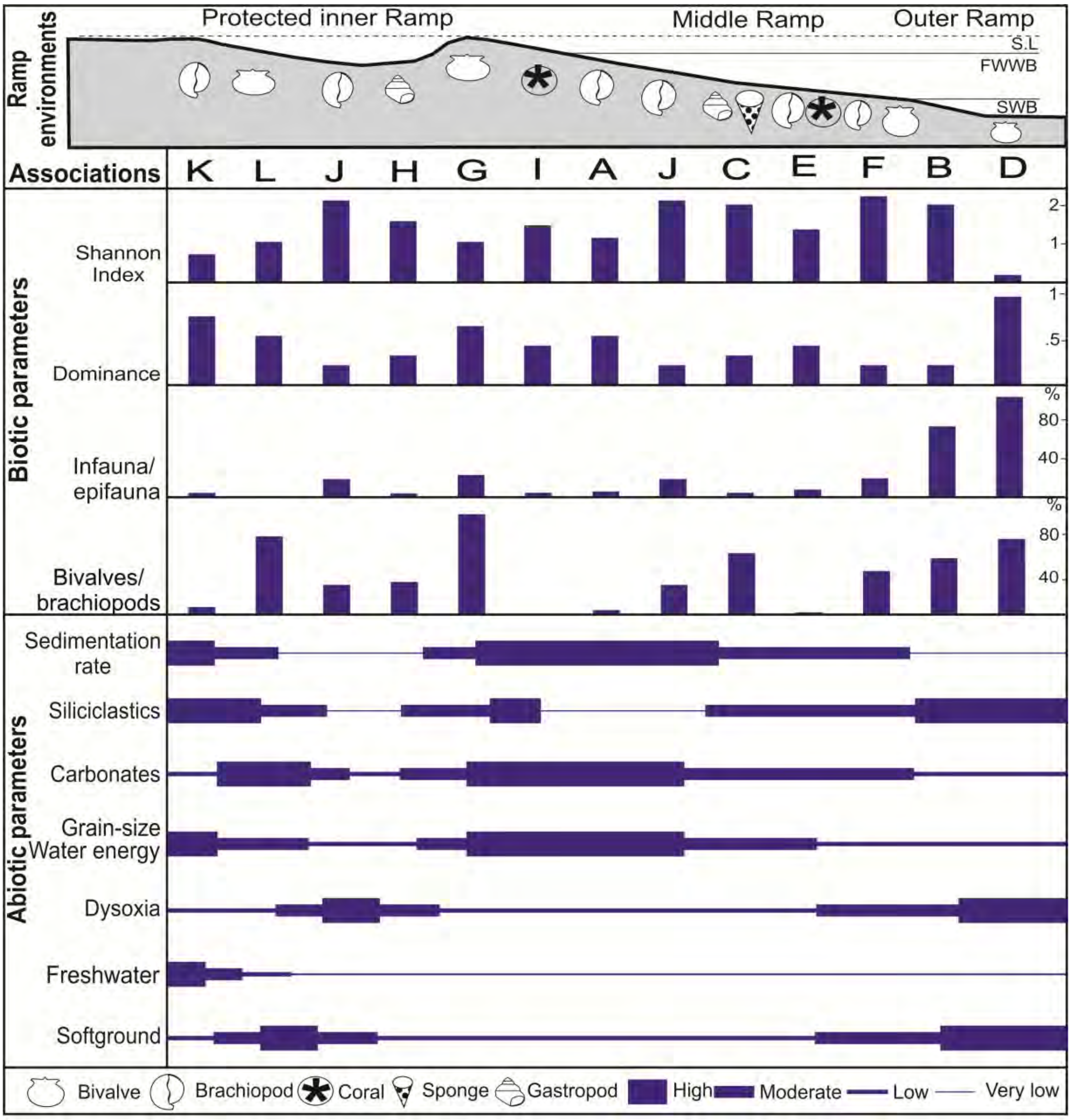

Fig. 5.7. Distribution of the benthic associations within the various depositional environments of the ramp and their biotic and abiotic characteristics. Shaded areas indicate the most suitable (high diversity) environments for macrobenthos. A-L: associations and assemblages; key in Fig. 5. 1.

5.5 Fauna-substrate relationships

The macroinvertebrate fauna exhibits a clear relationship with different types of substrates, especially when these are grouped into nutrient-rich siliciclastics and nutrient-poor carbonates. In modern environments, Sanders (1958) noticed that filter-feeders numerically dominate in sand, whereas deposit-feeders dominate in muddy sediments, correlated with the clay fraction. Infaunal susspension-feeders had their largest populations in well sorted fine sand, related to elevated water-energy. Driscoll (1967) examined epifaunal species in Buzzards Bay on the east coast of North America and demonstrated that attached and sedentary epifaunal taxa are more abundant on bottoms with low silt-clay content, as stronger currents associated with coarser sediments increases the food supply and provides firm surfaces for fixation. The same patterns were found when Fürsich (1976) investigated macrobenthic associations in Oxfordian strata of England and Normandy and Oschmann (1988) studied the facies relationship of Upper Kimmeridgian and Portlandian macrobenthos of southern England and northern France.

Most of the present samples are from fine-grained sediments. There, fossil diversity and densities are high in silt, marl, and carbonate mud- to wackestones. This agrees with Fürsich (1976), who found a negative correlation between grain size and macrobenthic diversity. The diversity in silt and pure carbonates is lower than in marl (Fig. 5.8), probably due to a decrease in epifauna, especially brachiopods. The diversity of the latter group positively correlates with silt (e.g., Rudwick, 1970; Fürsich et al., 2001; Gahr, 2005). In pure carbonates, the diversity is lower than in marl, probably the result of a decrease in infaunal bivalves, which require a comparatively high food supply, generally not provided in carbonate environments. In contrast, marly substrates contain less terrigenous siliciclastics than silt, but at the same time contain enough food for deposit-feeders.

Oschmann (1988) used the epifaunal-infaunal ratio as a standard for evaluating the suitability of the sea floor for benthic macrofauna. Here, the epifaunal-infaunal ratio is >1 in carbonates, <1 in silt, and nearly 1:1 in marl. In addition, the epifaunal-infaunal bivalve ratio retains a similar pattern (Fig. 5.8A). All these features indicate that marl was a suitable substrate for macrobenthos.

Although most studies of Recent communities and of palaeo-communities (e.g., Driscoll, 1967; Fürsich, 1976; Hofmann et al., 2013) mentioned a decrease of epifauna in soft sediments, epifauna dominated in all major substrate types (i.e. silt, marl and carbonate) at G. Maghara. However, the abundances increased with increasing carbonate content (Fig. 5.8A). Oschmann (1988), when investigating adaptations for soft bottoms of the epifauna from the Kimmeridgian of Western Europe, suggested that they played only a negligible role in determining the distribution pattern. However, the dominance of the reclining oyster *Africogryphaea* and of the large, comparatively compressed *Daghanirhynchia*, which is characterized by a very small foramen and deep sulcus, in soft substrate indicate that epifaunal adaptation to low-energy, soft bottoms played an important role. Moreover, secondary hard substrates consisting of shell fragments have to be taken into account (Zuschin and Stachowitsch, 2009).

The distribution of brachiopods versus bivalves in various types of substrate reveals a different pattern (Fig. 5.8A). Bivalves dominate in marl more than in limestone, whereas brachiopods dominate in limestone (see also Tomašových, 2006; Graziano al. et, 2006). The distribution pattern can be explained by the differing feeding strategies of the two groups. Compared to pure carbonate regimes, marly substrates were mesotrophic, with nutrients available both as suspended particles and on the bottom. As discussed above, bivalves are characterized by higher pumping rates than brachiopods, and thus prefer nutrient-rich habitats, while brachiopods can survive in nutrient-poor habitats (Fig. 5.8).

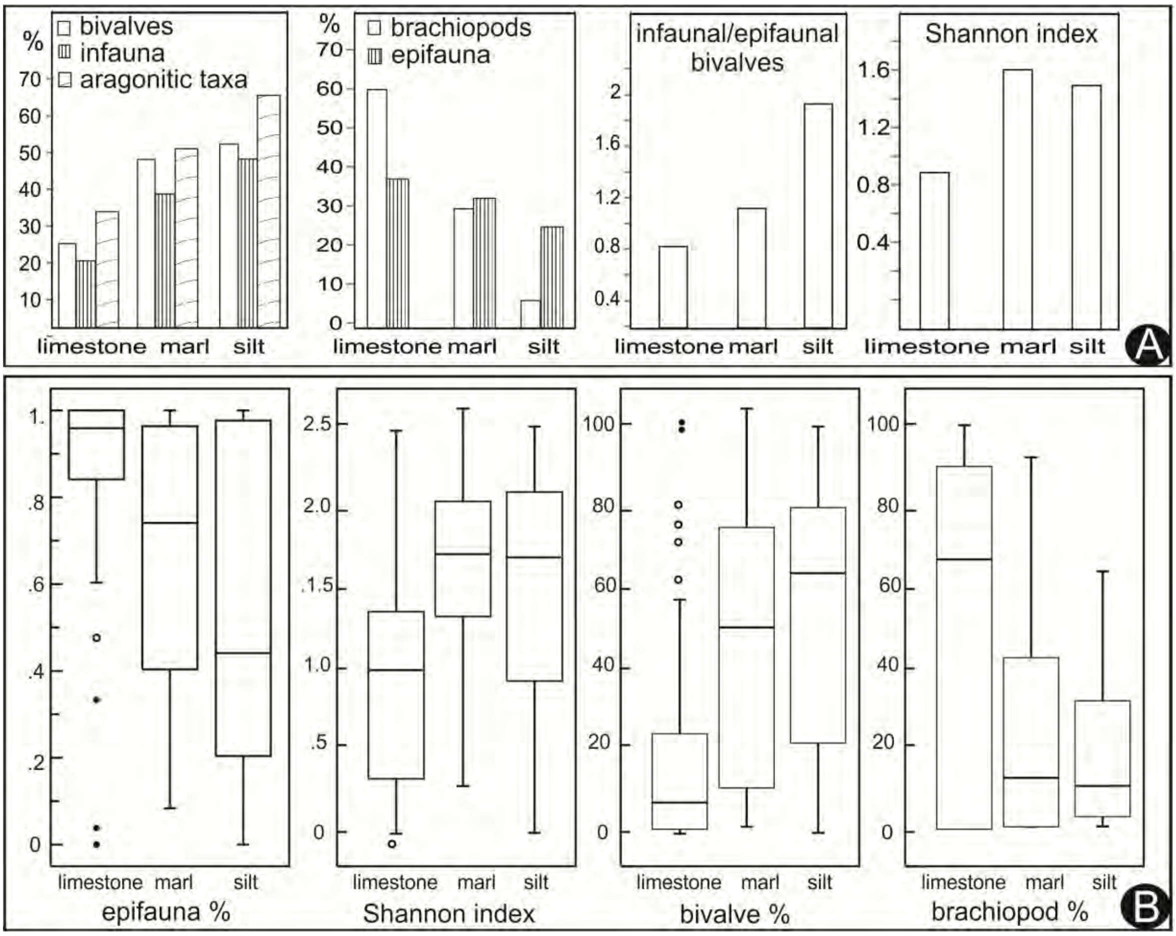

Fig. 5.8. A, Substrate preference of some taxa and guilds (percentage of bivalves, infauna, and aragonitic taxa, in addition to infaunal/epifaunal ratio decrease in carbonate, while brachiopods and infauna increase and diversity is high in marl). B, Box plots of some important ecological parameters in three major facies.

There is a distinct increase in the percentage of aragonitic shells in silt (Fig. 5.8) due to the preference of the mainly aragonitic infauna for this substrate (e.g., nuculid bivalves). The variations of faunal preferences (e.g., bivalves vs. brachiopods, epifauna vs. infauna, and diversity) among the major rock types are significant at the .001 confidence interval (Fig. 5.8B).

5.5 Relationship of macrobenthic associations to sequence stratigraphy

Skeletal concentrations occur in a predictable array in larger-scale cycles (parasequences to third-order sequences; e.g., Kidwell, 1991; Brett, 1995; Fürsich and Pandey, 2003; Wilmsen, 2012; Fürsich et al., 2012). Brett et al. (2007) suggested a dual relationship between palaeoecology and sequence stratigraphy, where fossils provide an important tool for reconstructing the environmental changes and sequence stratigraphy provides a predictive framework of biotic changes. Moreover, Fall and Olszewski (2010) argued that fossil communities provide useful information for the placement of sequence boundaries and the magnitude of disruption.

Scarponi and Kowalewski (2007) found that the late transgressive systems tract displays the highest equitability and richness, and that samples from the highstand systems tract display the lowest diversity, which reflects a combination of environmental factors (increasing heterogeneity of marginal habitats) and taphonomic processes (decreasing time averaging). Brett et al. (2007) suggested that in shallow-shelf and ramp settings, sea-level fluctuations may produce approximately symmetrical patterns of biotic replacement where biofacies are arrayed parallel to depositional strike, but asymmetries are common and may result from variations in sediment supply during sea-level fluctuations. Hence, the low siliciclastic input typical of transgressions predictably favours those organisms (e.g., brachiopods and corals) that require low sedimentation rates, non-turbid conditions, and generally stable substrates, whereas the regressive half cycle at analogous depths favours more eurytopic organisms that tolerate or prefer the higher rate of sedimentation and turbidity (e.g., bivalves and echinoids).

The quantitative analysis of the Jurassic benthic community relicts of G. Maghara reveals that both community structure and changes in the diversity pattern coincide with the third-order sequence stratigraphy architecture (Fig. 5.9). During the TST, carbonate production was high and epifaunal suspension-feeders in addition to corals dominated. Diversity values increased with increasing flooding. During the MFZ, the proportion of fine-grained siliciclastic sediments increased as carbonate production declined. This is accompanied by an increase in infaunal deposit-feeders. The faunal diversity was usually at maximum and dominance at a minimum. During late HST, the deposits show a decrease in carbonate production resulting from the high rate of terrigenous input. Consequently, both diversity values and bioturbation intensity decreased. Moreover, in many parasequences, bivalves and brachiopods show a different replacement pattern (see Fig. 4.3A in the previous chapter).

The diversity pattern within a depositional sequence cannot not be assigned to a single taphonomic or ecological mechanism. During FSST, LST, and early TST, low diversity associations (paucispecific) are developed. The low diversity is related to environmental stress due to (1) persistent wave influence when in the course of a sea-level fall the environment is above the FWWB (assemblage G); (2) dysoxia generated by decomposition of accumulated land-derived organic matter (associations L and K). In contrast, polyspecific associations most likely developed during times of mid TST to the MFZ of a sedimentary sequence, when the sedimentation rate in offshore areas will be at a minimum (Brett, 1995). The high diversity during the MFZ interval was commonly augmented by time-averaging (Fürsich and Aberhan, 1990; Kidwell, 1998). However, environmental stability, which increases with increased flooding, most likely contributed to the high diversity of MFZ associations. In addition, accumulation of biogenic hardparts in context with low rates of sedimentation may have increased substrate heterogeneity and thus increased beta diversity (association B).

In general, the macrobenthic communities can be grouped into two main categories. „Immature" communities (paucispecific) occurred when a given environment lost its stability. Such conditions may have developed during the LST or the FSST. In contrast, „mature" communities (polyspecific) developed during the middle to late stage of TST, MFZ, and during the early HST (Fig. 5.9). However, in deep settings, unfavourable conditions may also develop during the MFZ or early HST such as dysoxia generated by the establishment of stratified water masses. In addition, shells of these intervals may remain for a prolonged time interval in the diagenetic active zone and hence may have a high dominance and low diversity (assemblage D).

As the Jurassic associations at G. Maghara are autochthonous to parautochthonous, we should differentiate between these undistorted and the taphonomically distorted associations. As both are genetically different, concentrations of the two modes of preservation exhibit a completely different distribution pattern within the framework of sequence stratigraphy. The taphonomically distorted concentrations are usually dense, having been concentrated by waves or current and time-averaging, while the undistorted concentrations are usually dispersed. Physical concentrations occur during early TST and late HST (for details see Banerjee and Kidwell, 1991; Fürsich and Pandey, 2003; Wilmsen, 2012), whereas undistorted concentrations occur mainly in late TST and MFZ (Figs. 5.9 and 5.10). However, during MFZ, time-averaging may distort the primary communities by increasing diversity values (e.g., by faunal mixing).

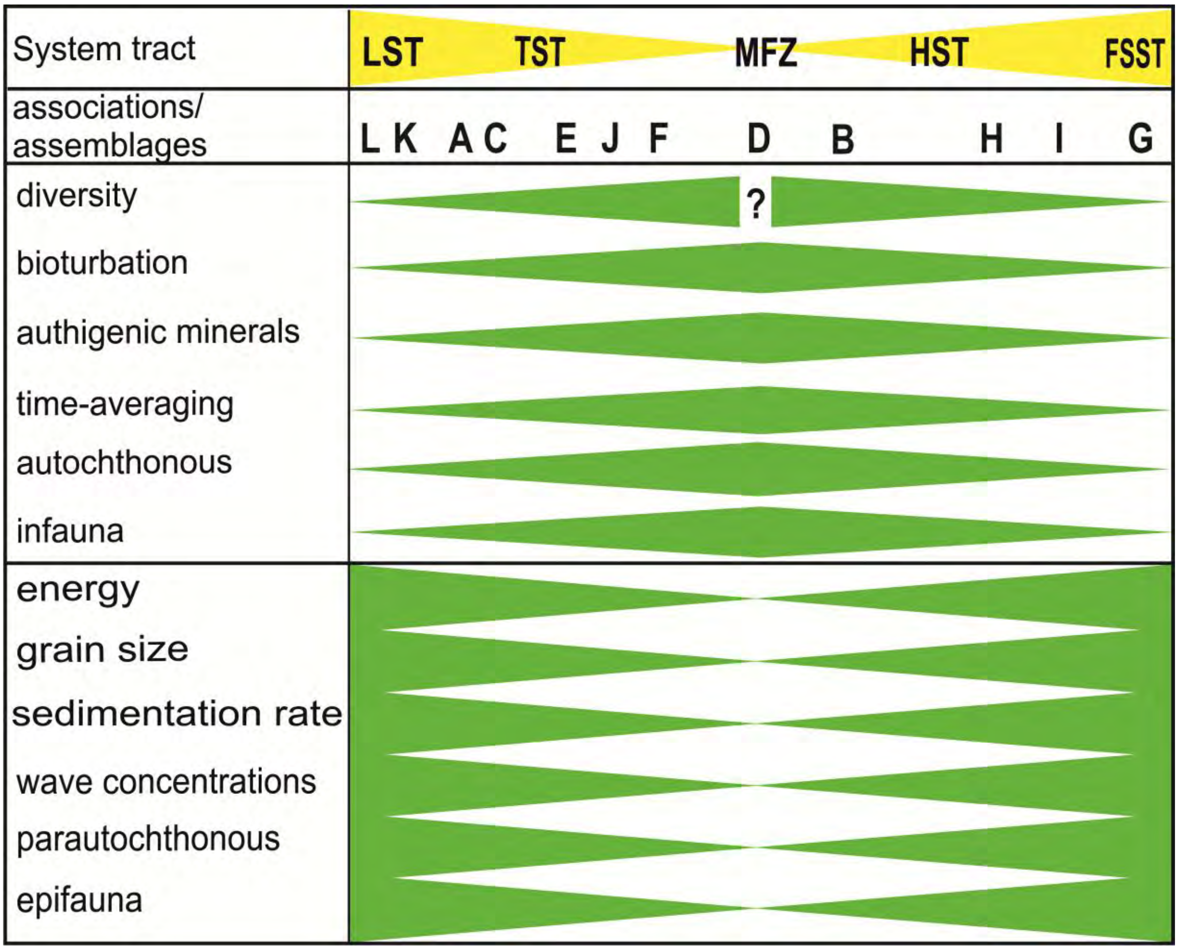

Fig. 5.9. Communities attributes and associations distribution within a 3rd order sequence stratigraphy. A-L: associations and assemblages; Key in Fig. 5.1.

5.6 Sea-level changes and hydrodynamic conditions

As discussed above, low diversities of some associations were chiefly caused by stress. There is no direct way in which sea-level fluctuations or the hydrodynamic conditions influence species diversity. Holland (2012) suggested that the response of diversity to sea-level changes is likely idiosyncratic. Sea-level change might produce a substantial diversity change at a specific place, whereas an identical sea-level fluctuation might produce little or no diversity change in another place. He also found no link between sea-level changes and diversity in the Phanerozoic fossil record as a whole. However, indirect relationships should be taken into account. Dysoxic and oligotrophic conditions may develop during early sea-level highstand, in connection with a stratified water mass resulting from low circulation in a deep or restricted inner ramp setting. In addition, soupy substrates develop only in low-energy environments, in which fine particles settle down from suspension.

Sea-level fluctuations influence the environmental stability and hence they must have influenced the structure of palaeo-communities (Fig. 5.10).

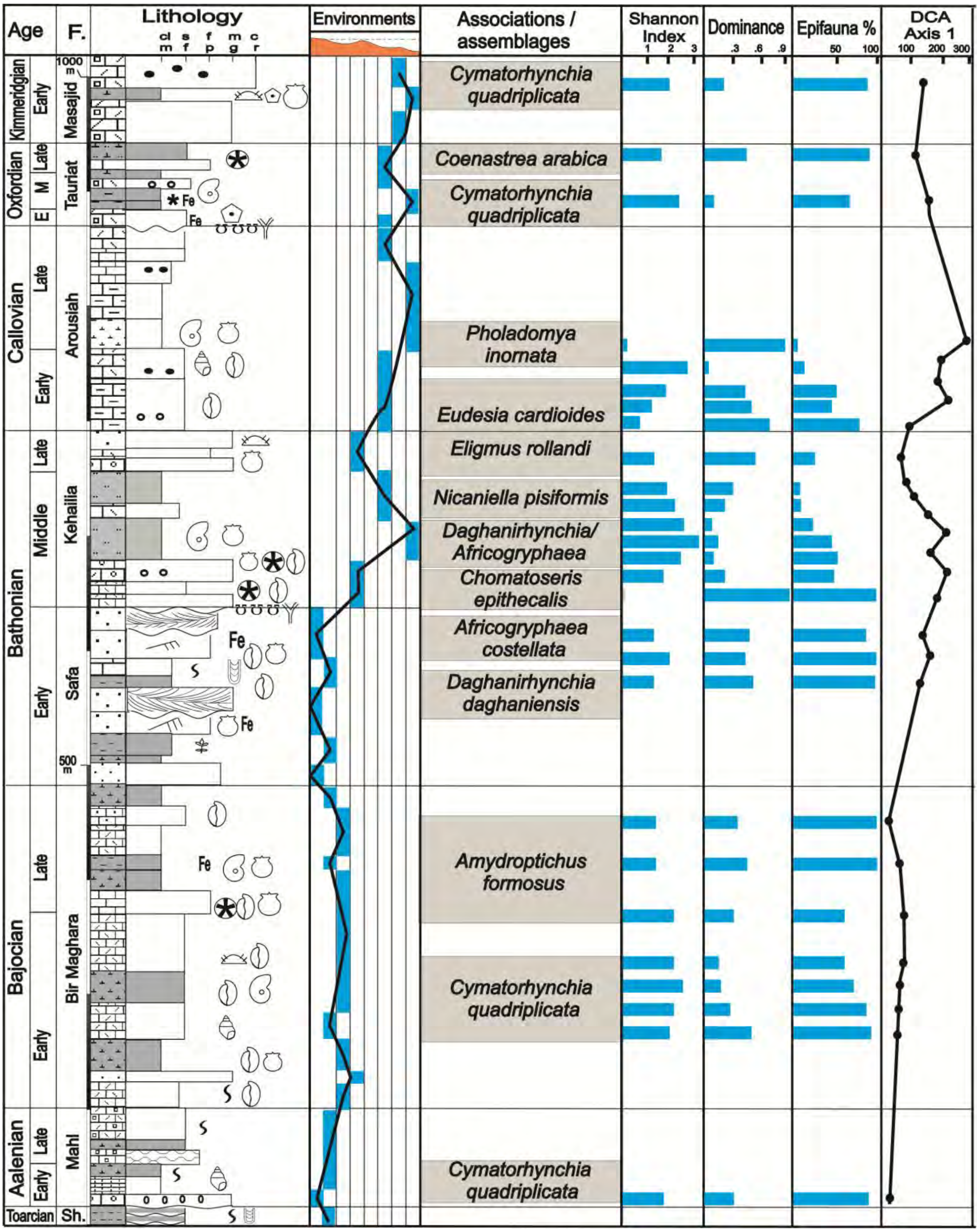

Fig. 5.10. Environments, distribution of associations/assemblages and changes in community attributes in the Jurassic succession of the G. Engabashi section. F.: Formation. For key of symbols see Fig. 2.1.

Rosenberg (1995) analysed a benthic marine fauna in a more than 100-m-deep trench in the Skagerrak, western Sweden. He found that the benthic marine fauna was structured by hydrodynamic processes and food availability. Moreover, Van Hoey et al. (2004) investigated the spatial distribution of the macrobenthos on the Belgian continental shelf, and found that decreasing diversity coincided with a gradual transition from muddy fine sand to medium and coarse sandy sediments and from subtidal to intertidal environment, and related it to both current speed and organic content of the sediment.

Lauridsen et al. (2009) studied the benthic macrofauna and community structure in Cenomanian chalk and marl from Southerham Grey Pit, SE England, and found differences in diversity between chalk and marl related to long-term climatic and oceanographic changes or to a biological response in the community structure to Milankovitch cyclicity. Similarly, Smith et al. (2006) studied the distribution of Cenomanian echinoids and found that sea-level changes created a cyclic diversity curve in mid-shelf environments of south Sussex (southern England). Similarly, the diversity (H and D) of the macrofauna of G. Maghara display a cyclic pattern coinciding with the sea-level fluctuations and also with the Axis 1 scores of the DCA, which is a well-known bathymetric indicator (Fig. 5.10; Scarponi and Kowalewski, 2004).

According to the feeding mode and mode of life, the macrobenthic taxa can be grouped in the following way: (1) Epifaunal suspension-feeders/microcarnivores fed on small plankton and suspended organic matter and therefore dominated in moderate- to high-energy environments with high productivity during TST. (2) Infaunal deposit-feeders fed on organic matter concentrated in the substrate and therefore dominated in low-energy environment with fine-grained siliciclastic sediments usually during MFZ and early HST. (3) Epifaunal grazing herbivores/omnivores, which fed on any organic-rich object, are therefore found everywhere and were not restricted to a specific environment (Fig. 5.10).

5.7 Aspects of the palaeo-ecosystem

Although palaeo-ecosystem reconstructions face many problems (e.g., incomplete preservation of organic remains, taphonomic distortion, faunal mixing, and time-averaging), due to the autochthonous nature of the macrobenthos of G. Maghara, some aspects of the palaeo-ecosystem can be reconstructed.

The benthic macrofauna of G. Maghara was affected by stress factors (e.g., low oxygen, limited food supply, and low substrate consistency). Apart from sedimentological and taphonomic criteria, low diversity values are the main argument for the assumed stress levels (Fig. 5.11). The poly- to paucispecific nature of most associations suggests moderate instead of high stress levels. We therefore assume that the mixed carbonate-siliciclastic succession of G. Maghara formed in a shallow basin with marine to marginal marine and deltaic environments, which at times was influenced by reduced salinity, lowered oxygen and nutrient conditions, and by soupy substrates. The depositional environment of each of the identified associations and assemblages has been reconstructed in Fig. 5.10. Diversity, dominance, epifaunal percentage, in addition to the scores of DCA axis 1 display a cyclic pattern concurring with the sea level changes and accompanying depositional environments (Fig. 5.10). The link between the community structure of the macrobenthos and the environmental setting makes the macrobenthos a powerful tool for interpreting the latter (Figs. 5.7-5.11).

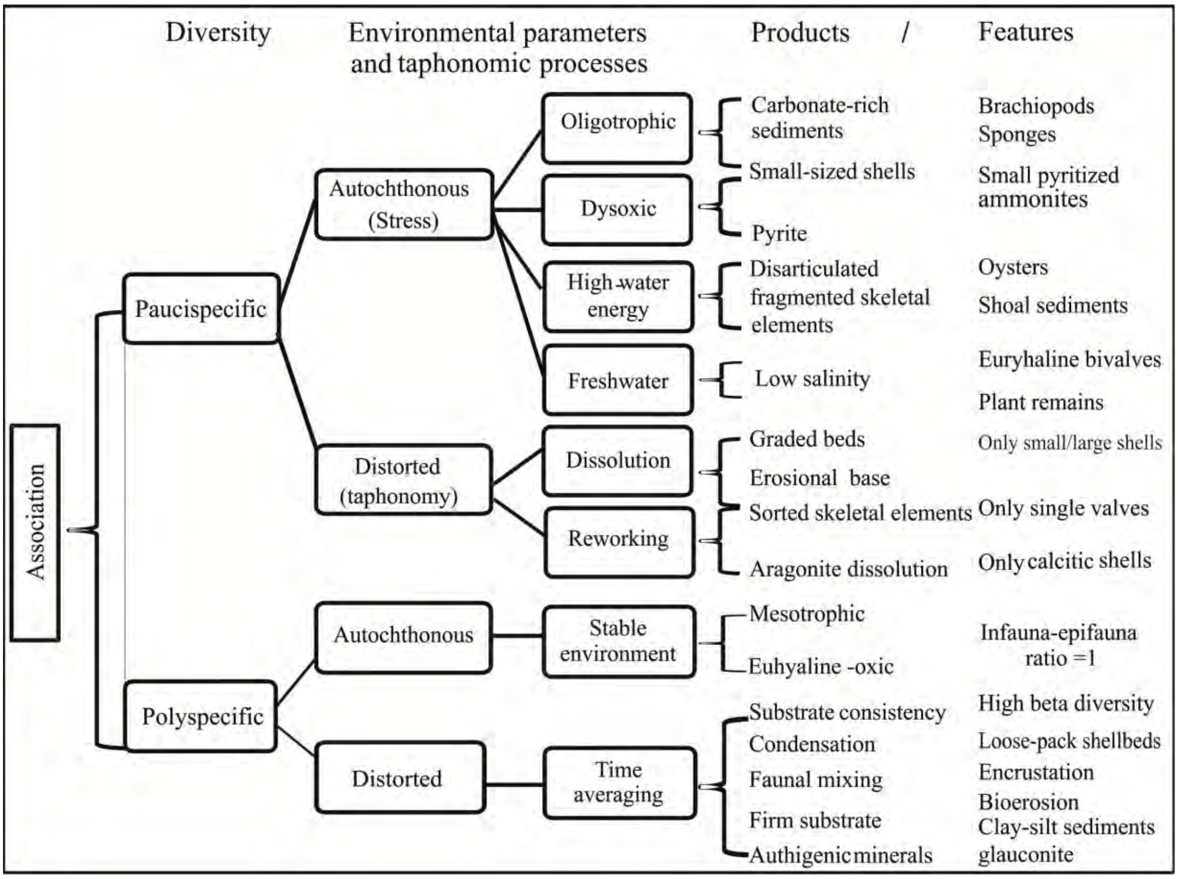

Fig. 5.11. Taphonomic and sedimentological factors influencing the species diversity of the macrobenthic associations.

The results agree with previous ecological studies on macrobenthos from Recent and fossil habitats (e.g., Rosenberg, 1976, 1995; Aberhan, 1993a, b; Van Hoey et al., 2004; Tomašových, 2006; Magni et al., 2009; Lauridsen et al., 2009), which suggest an enhanced role for nutrition and substrate type. A moderate nutrient supply (mesotrophic) and median-sized substrates provided the most suitable environment for the macrobenthic communities.

6 Palaeobiogeography

6.1 General remarks

6.1.1 Value and applications

Palaeobiogeographic studies play a significant role in studying continental drift and plate tectonics. In addition, they provide an important assessment for palaeomagnetism (Smith and Tipper, 1986). Thus, Aberhan (1998) used biogeographic data of pectinoid bivalves to reconstruct the palaeogeographic evolution of the Canadian terranes within the Early Jurassic. His results indicate that biogeographic analyses are a reliable test of palaeomagnetic data. Reconstruction of global biogeographic patterns of the Jurassic Period based on different groups of fossils and migration trends have been attempted by a number of authors in the past (e.g., Marwick 1953; Hallam, 1969, 1971, 1983; Fürsich and Sykes, 1977; Newton, 1988; Liu, 1995; Heinze, 1996; Aberhan and Fürsich 1997; Liu et al., 1998; Aberhan, 1998, 1999, 2001, 2002; Sha et al., 2002; Damborenea, 2000; Liu et al., 2007; Kiessling and Aberhan 2007; Kiessling et al., 2011; Damborenea et al., 2013).

6.1.2 Comparing macrofaunal groups

Differences between the distribution pattern of benthic and pelagic organisms are to be expected (Masse, 1992). Ammonites are nektic with a pelagic larval stage. Brachiopods, in contrast, are fixo-sessile having non-planktotrophic larvae. Although most bivalves are fixed to the substrate, many taxa have a wide biogeographic distribution, due to their planktotrophic larval stage (Kauffman, 1975). As bivalves are strongly facies-dependant (Hallam, 1969, 1971), this may strongly influence their biogeographic pattern (Damborenea et al., 2013). Kiessling et al. (2011) found, however, that facies is not a main driver of the biogeographic pattern. Corals have planktotrophic larvae, but are very sensitive of environmental changes (temperature and terrigenous input). Thus, by combining results from different groups (e.g. ammonites, brachiopods, corals, and bivalves) the dispersal potential of these groups can be assessed in detail. To what extent do these biological features (nektic versus fixosessile life habit, planktotrophic vs. non-planktotrophic larval stage, facies-dependence vs. independence) enhance/hinder the dispersal potential?

As ammonites are a powerful biostratigraphic tool in the Jurassic, they received more attention and many authors used them for palaeobiogeographic studies. However, although ammonites may be a valuable tool in global studies; other benthic groups may show more detailed regional differences than ammonites (Liu et al., 1998). According to the ammonite distribution pattern, most authors consistently recognize only two realms during the Bajocian, a high-latitude Boreal and a low-latitude Tethyan realm (Arkell, 1956; Hillebrandt et al., 1992; Cecca, 1999; Grant-Mackie et al., 2000). Aberhan (1998) arrived at similar plate tectonic reconstructions based on the pattern of Pliensbachian ammonite and bivalve distributions. Also, the comparative palaebiogeographic analysis of bivalves and ammonites (benthic and nektonic) in the Jurassic of Siberian palaeo-basins shows a good agreement (Meledina et al., 2005). However, Liu et al (1998) suggested that the boundaries of provinces based on ammonites and bivalves do not always coincide. And they explained this by the differing mode of life of the two groups.

The results of Sha et al. (2002) for the same time slice suggested that in the case of ostreid bivalves, species such as *Actinostreon gregareum* and *Nanogra nana* were cosmopolitan*,* while*, Eligmus rollandi* (which they regarded as a potential ostreoid) was endemic. Kiessling et al. (2011), in contrast, concluded that the Jurassic biogeographic patterns of corals, brachiopods and bivalves from the Ethiopian Province were identical, and suggested that physical drivers such as ocean currents or plate tectonics might have been more important than biological drivers such as environmental tolerance, life style, and larval strategies.

6.1.3 Dynamic palaeobiogeography and provinciality

A northwards shift of the Boreal/Tethyan boundary took place from Pliensbachian to Bathonian times. Hallam (1971) suggested that palaeotemperature changes were the cause, but recent studies (i.e., Clark et al., 1995; Callomon, 2003; McCann, 2008) indicated that the reason is the existence of a land barrier (Mid-North-Sea-High) that prevented cold polar waters to flow towards the South. The Bathonian is the time of the greatest spread of the Tethys realm during the Jurassic (Hallam, 1971). The boundary then moved southwards during the Callovian and reached its southernmost extension in the Oxfordian (Liu, 1995). A distinct fall in temperatures during the Middle Oxfordian (Martin-Garin et al., 2012; Alberti et al, 2012) may be connected to the break-up of Gondwana and the opening of the Transgondwana Seaway, which might have caused a stronger upwelling in the northwestern Tethys (Alberti et al., 2012) and permitted influx of polar water. Based on the distribution of Holocene molluscs in the Sea of Japan, Lutaenko (1993) concluded that an increase of 0.1- 0.2°C in surface water temperature can cause a shift of about 100 km of the boundary between warm-water molluscs and the Pacific boreal region.

The Ethiopian Province geographically comprises the eastern part of Gondwanaland with North Africa (Algeria, Tunisia, Libya, and Morocco), East Africa (Somalia, Kenya, Tanzania, and Ethiopia), and the Middle East (Saudi Arabia, the Levant, Iraq, Yemen, and Egypt) in addition to India and Madagascar. This province contains numerous endemic taxa and has been recognized from the Early Jurassic until the Late Cretaceous (Weir, 1925; Muir-Wood, 1935; Arkell et al., 1952; Arkell, 1956). Heinze (1996) mentioned that although similarities of bivalves between the European (North Tethys) and the Ethiopian (South Tethys) provinces are very high at the genus level and even at the species level, 35% of the Bathonian and Callovian genera of the Ethiopian province are endemic.

According to Liu et al. (1998) the Ethiopian Bivalve Province is less distinct than other bivalve provinces, and explained this by the transitional nature of the Middle East, which in the Middle Jurassic apparently was a spreading center for taxa originating in that area and migrating both westward towards North Africa and southward into India and Madgascar. According to these authors, the Ethiopian Bivalve Province can be well defined at the species level. For example, in the Bathonian and Callovian rocks of India about 25% of the bivalve species are endemic. Similarly, according to Kiessling et al. (2011) the distribution patterns of corals and brachiopods are indicate of a fairly sharp boundary between the Ethiopian and European provinces running north of Jordan and Tunisia. Also Damborenea et al. (2013) suggested that a new Ethiopian unit was recognizable since the Bajocian based on the high ratio of endemic genera. This unit became indeed evident in Callovian-Kimmeridgian times.

As the endemism of the Ethiopian fauna increased from the Bathonian to the Late Jurassic, Heinze (1996), suggested to split the Ethiopian Province into two-subprovinces; the 'Ethiopian-Tethyan' subprovince to the north and the 'Ethiopian-Austral' subprovince to the South. The splitting of the Ethiopian Province was also suggested by Enay and Cariou (1997), who assigned the Indian ammonite fauna to a Subaustral Province.

Mette (2004) proposed that the Bajocian faunas of Madagascar migrated from Arabia and North Africa, while the Callovian–Kimmeridgian ones are indicative of intensive migration between Madagascar and India and isolation from Africa, Arabia, and South America due to physical and/or ecological barriers (probably the Mozambique corridor) between Madagascar-India and East Africa. Although certain Oxfordian-Kimmeridgian bivalves such as *Megacuccullaea and Seebachia* occur in both India and East Africa, the quantitative analysis suggests some degree of differentiation.

The Trans-Erythraean Seaway permitted faunal exchange during the Middle Jurassic (Bathonian and Callovian), providing a direct migration route from Madagascar toward the south, before becoming fully established as the Indian Ocean in Tithonian times (Hallam, 1983; Krishna, 1994; Gardner and Campbell, 2002; Challinor and Hikuroa, 2007).

6.2 Methods assessment

6.2.1 Similarity coefficients

As the samples from different localities included in our data matrix are not equal, not having been treatedin the same way in the literature, the selection of an appropriate index of similarity is crucial. Among the numerous coefficients of similarity, Simpson, Bray-Curtis, and Jaccard are commonly used. However, many authors (e.g., Archer and Maples, 1987; Maples and Archer, 1988; Smith, 1989; Sandy, 1991) regard them critically, as different coefficients yielded different results. Endemism may be underestimated (ignoring mutual absence), and faunal similarity may be overestimated.

The Simpson coefficient was considered to be the most adequate by Shi (1993) and Hammer and Harper (2006), but it is highly affected by a number of variables (Maples and Archer, 1988). The Bray–Curtis coefficient is relatively independent of sample size and diversity (Wolda, 1981; Magurran, 2004), but it is primarily designed for abundance data not for binary ones (which are generally used in biogeography). The results are more reliably only in case of large numbers of taxa used in such analyses (Cheetham and Hazel, 1969; Sandy 1991); consequently, districts with diversities lower than five taxa were excluded from the quantitative analysis as they may be liable to cluster (Smith, 1983; Kreft and Jetz, 2010; Kiessling et al., 2011).

A test has been carried out to select one of the similarity coefficients. A binary data matrix comprising the geographic distribution of the Oxfordian bivalves of G. Maghara at the species-level was subjected to a PCoA analysis three times using Bray-Curtis (Fig. 6.1A), Simpson (Fig. 6.1B), and Jaccard (Fig. 6.1C). The best clustering of the well-known provinces and subprovinces (i.e., North Tethys Province, North-Ethiopian Subprovince, and South-Ethiopian Subprovince) was obtained from the Jaccard-based plot. The result of the test (as shown in Fig. 6.1A-C) helped to decide directly which similarity coefficient was more sensitive and more valuable for the nature of the data.

The Jaccard Coefficient has been highly recommended (Hughes, 1973). It shows the lowest number of poorly informative structures (Archer and Maples, 1987; Shi, 1993; Murguia and Villaseñor, 2003). Although Archer and Maples (1987) indicated that the Jaccard Coefficient is highly limited in comparison to the Simpson Coefficient, the latter apparently produces results of low significance, especially when the number of variables is low. Moreover, the Simpson Coefficient is not as sensitive as the Jaccard one (Sandy, 1991) as it neglects mutual absences (i.e., endemism may be underestimated), and similarities are overestimated. Based on these results, the Jaccard Coefficient was chosen.

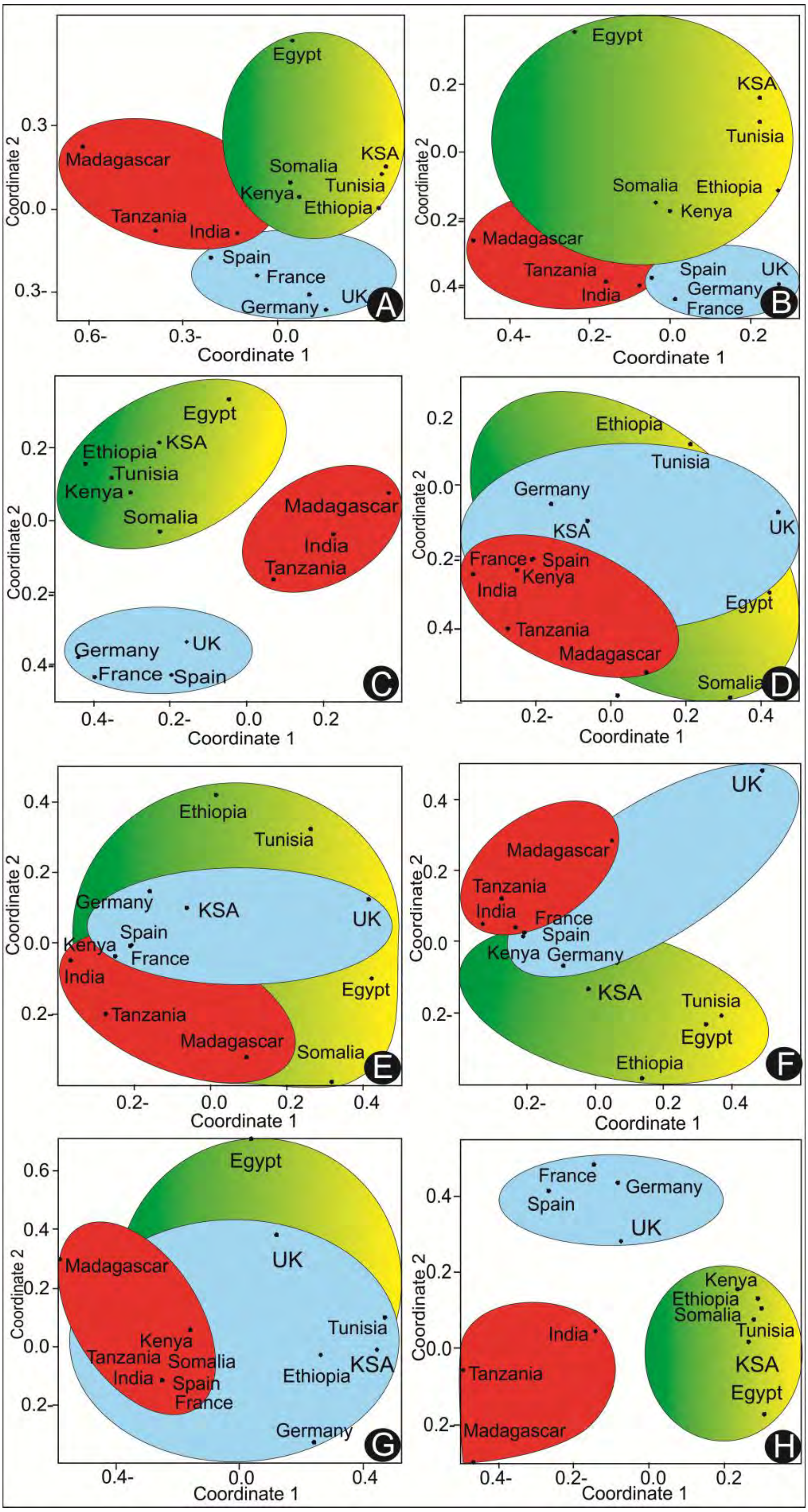

Fig. 6.1 Assessment of the implemented methods; plot of species-level PCoA of binary data based on Bray-Curtis (A), PCoA plot based on Simpson (B), PCoA plot based on Jaccard (C), NMDS plot based on Jaccard (D), PCoA plot based on Jaccard for genus-level binary data (E) and for abundance data (F), PCoA plot based on Jaccard for species-level oysters (G) and for the rest of bivalves (H).

6.2.2 Ordination techniques

Both Principal Coordinates Analysis ('PCoA', = Multidimensional scaling 'MDS') and Non-metric Multidimensional scaling (NMDS) are methods to explore and to visualize similarities or dissimilarities of data. They start with distance matrix and assign for each item a location in a low-dimensional space. As there is a genetic difference between the two methods, the same data were analysed twice, based on each method, to select the appropriate one for our data.

The results displayed by PCoA (Fig. 6.1C) do not closely coincide with those displayed by the NMDS analysis (Fig. 6.1D). Although NMDS makes fewer assumptions on the nature of the data (Minchin, 1987; Legendre and Legendre, 1998; Kreft and Jetz, 2010), PCoA always finds a globally optimum solution. NMDS seeks a best solution that may never exist. Moreover, PCoA plot preserves the distances between both samples (taxa) and variables (regions) in the same space of reduced dimensions (Legendre and Legendre 1979, Achab et al., 1992), while the axes in NMDS are meaningless.

6.2.3 Nature of the data

In their palaeobiogeographic analysis of Jurassic bivalves Liu et al. (1998) concluded two important points that should considered before doing a biogeographic analysis. First, in case of absence of abundance data, the substitution by binary (presence/absence) data may be sufficient for large-scale palaeobiogeographic studies (e.g., Digby and Kempton, 1987; Shi, 1993). Second, a palaeobiogeographic analysis carried out at the species level yields more detailed information than that carried out at the generic level, if the taxonomic basis is sound.

As the global scale lies beyond the goal of this study, and in order to assess the eligibility of the data, a small test with the PCoA method was carried out using the binary (presence/absence) data of Oxfordian bivalves; first at the species-level (Fig. 6.1C), then at the genus-level (Fig. 6.1E), and finally by converting the binary genus-level to abundance data (Fig. 6.1F). The abundance data were built by considering the number of different collections, which were included in the downloaded data or by considering the number of times a taxon was reported from the same locality by different authors.

The species level yielded a more informative plot (Fig. 6C-F). The best clustering of the well-known provinces was obtained from the binary data at the species-level (Fig. 6.1C). The latter seems to be logical as endemism was expected to increase with lower taxonomic levels. Hence differentiation among different geographic localities will increase. The results support the disadvantage of binary data (Fig. 6.1E) compared to abundance data (Fig. 6.1F) at the genus-level. However, the palaeobiogeographic analysis carried out at the species level yields more detailed information than that carried out at the generic level, even when abundance data are considered. As the taxonomy of the Jurassic bivalves is fairly advanced, and as the goal is to only analyse the biogeographic relationship of the taxa occurring in the study area, such an analysis not requiring the global picture offered by generic-level analyses, the species-level data were used.

6.2.4 Bivalve larval-strategies

Although most bivalves are not very mobile, many taxa such as oysters have a remarkably wide biogeographic distribution (Liu et al., 1998). This may be related to a long-lived, planktotrophic larval stage (Kauffman, 1975). The planktotrophic larval types have a higher dispersal potential (by currents). However, Liu et al. (2007) did not find great differences between the geographic dispersal of planktotrophic and non-planktotrophic larval types of bivalve. For this reason the distribution pattern of oysters, which have a well-known planktotrophic larval stage, was analysed separately from the rest of the bivalves.

The PCoA plot of the oysters indicates a distinctly higher dispersal pattern (Fig 6.1G) than the rest of the bivalves (Fig. 6.1H), thus the well-known geographic areas clustered with high overlap in case of only oysters, while the rest of the bivalves display a more discrete pattern. The latter supports the advantage of combining different groups in palaeobiogeographic analyses.

6.2.5 Cluster versus ordination methods

In contrast to the Cluster Method (CM), ordination methods have shown promise (Hughes, 1973; Gauch et al., 1977; Kenkel and Booth, 1987; Jackson et al., 1989). CM always produces a hierarchy (clusters) even though the objects are not hierarchial or random. In addition, clustering algorithms may produce misleading results (for details see Legendre and Legendre, 1983; McShane et al., 2002).

The dendrograms resulting from CM produced a primary picture of provincialism (Fig. 6.2). However, the results of the ordination (i.e., PCoA) are much better. The plot of PCoA indicated a better separation between areas than did the clusters of time slices (Fig. 6.2), some geographically neighbouring countries clustering in different branches of the CM dendrograms. Moreover, in the PCoA plot geographically nearby areas plotted at small distances, whereas the distance of similarity between the same areas in the dendrogram is much greater (Fig. 6.2).

6.3 Palaeobiogeographic patterns of Macroinvertebrates

6.3.1 Bivalves

Based on the Jaccard distance of similarity, the results of both CM and PCoA (Fig. 3A-D) allows recognition of a dynamic biogeographic pattern from the Bajocian to the Oxfordian. The pattern shows that during the Bajocian, the Middle East and East Africa tend to cluster separately (Fig. 6.2A), which may result from the tectonic setting of the depositional basins. The intracratonic setting of G. Maghara during the Bajocian may have limited the dispersal potential of the macrofauna and provided limited chance for faunal exchange even with nearby areas (East Africa). The same intracratonic setting prevailed in Jordan, in Saudi Arabia (Droste, 1990; Powell and Moh'd, 2011), and also in East Africa (Kreuser, 1995; Hunegnaw et al., 1998). These settings started in the Early Jurassic and continued until the Bajocian/Bathonian when the eastern Gondwanaland started to split. For this time interval India and Tanzania plotted close to the North Tethys and not close to the Middle East. However, this may be an artifact due to the small size of the analysed data (appendix D).

Although the barriers existing during the Bajocian in the G. Maghara area (for details see previous chapters) vanished at the beginning of the Middle Bathonian, the same pattern as in the Bajocian (isolation from northeastern Africa) persisted during the Bathonian. Both CM and PCoA results are identical (Fig. 6.2.B) and show a clear pattern of separated clusters. The latter seems confusing, especially as the Bathonian represents the global expansion of the Tethyan realm (Hallam, 1971). However, the results obtained from both CM and PCoA may be related to the global sea-level lowstand (Haq et al., 1987).

Starting from the Callovian (Fig. 6.2C), the Ethiopian province was strongly differentiated from the North Tethys province. In both Cluster and PCoA, India and Madagascar plotted with the Middle East and North Africa. This indicates that the Ethiopian province became more homogeneous during the Callovian. In contrast to the Bajocian and the Bathonian time slices, the fauna of the study area became very similar to that of Northeast Africa by Callovian times, coinciding with a global sea-level highstand (Haq et al., 1987). Similarly, Wierzbowski et al. (2013) argued that the occurrences of (Sub) Mediterranean ammonites and belemnites in the Middle Russian Sea during the Callovian was a result of the opening of seaways during a sea-level highstand.

During the Oxfordian time slice, the Callovian patterns dramatically changed. The Ethiopian Province split into two sub-provinces, the Northern Ethiopian (including northern Africa and Middle East) and Southern Ethiopian sub-province (India, Madgascar, and Tanzania).

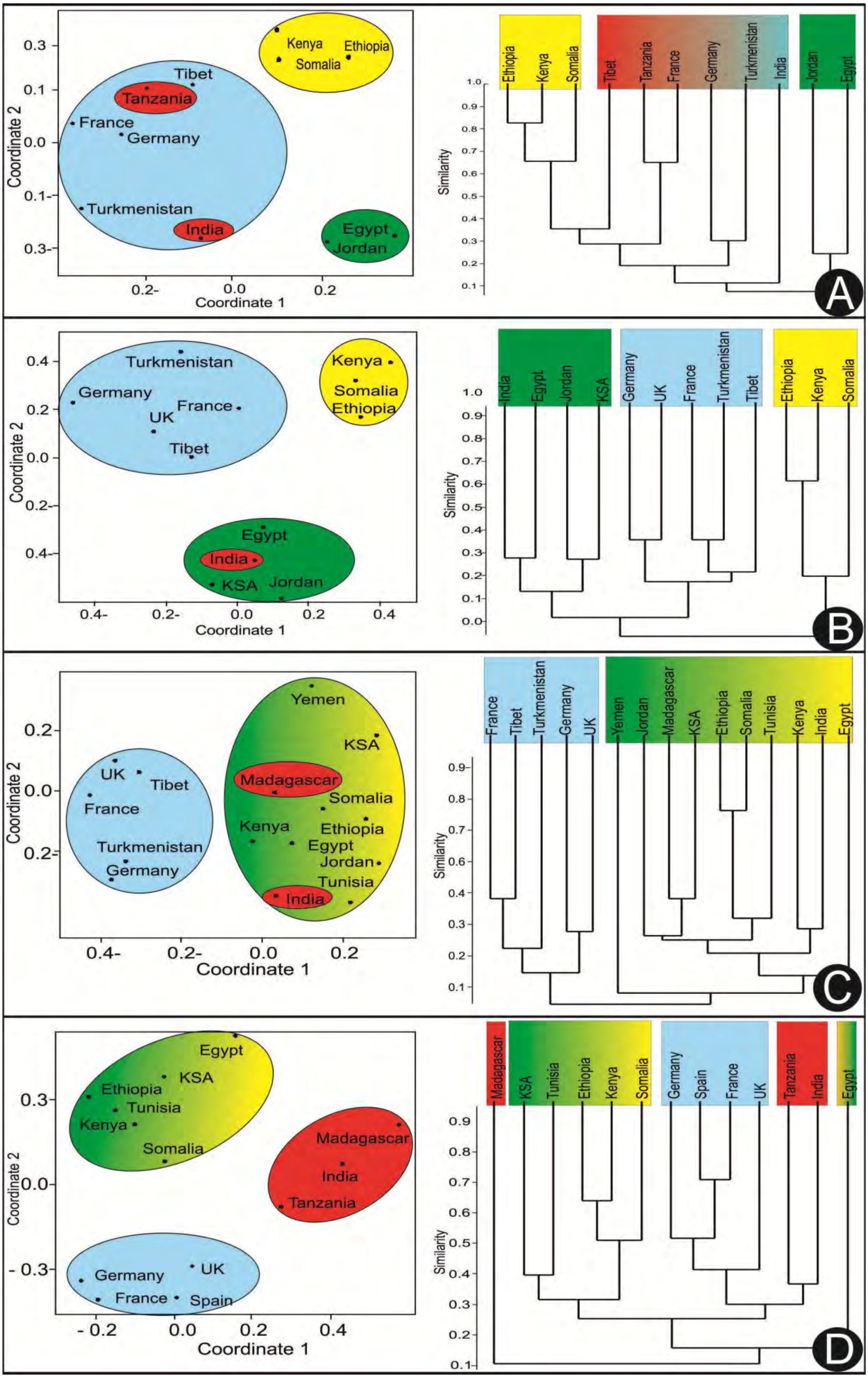

Fig. 6.2. Jaccard-based dendrograms resulting from (UPGMA) hierarchical cluster analyses (right) and PCoA plots (left) for the Bajocian (A), Bathonian (B), Callovian (C), and Oxfordian (D).

Absence of common genera argue for this splitting (see also Heinze, 1996; Kiessling et al., 2011). Moreover, the boundaries between the North Tethys Province, the Northern Ethiopian, and the Southern Ethiopian subprovinces, became more evident as seen from the plot of PCoA (Fig. 6.2D). In contrast to the CM, PCoA plot shows isolation patterns better (Fig. 6.2D).

The differentiation of the Ethiopian Province into low-order biochoremas toward the Oxfordian may be related to the opening and widening of the Mozambique Corridor (Heinze, 1996). However, as the Mozambique corridor opened between the African Plate (including Tanzania) to the west and India and Madagascar (which were connected), it did not act as a barrier hindering faunal dispersion, but instead it may have been a factor responsible for the general cooling during the Oxfordian.

The opening and broadening of the seaway may have permitted invasion of cold polar waters from the south, subsequently producing a lowering of temperatures during the Oxfordian (Martin-Garin et al., 2012; Alberti et al., 2012). This may have limited the expansion of Tethyan faunal elements to less than 28^{o} S. As a result, the fauna of Tanzania, Madgascar, and India (southeastern Ethiopian province, approximately above 28°S) slightly differentiated from the rest of the Ethiopian Province. Moreover, Gondwanaland has moved southward from the Early to the Late Jurassic (palemap reconstructions of Scotese, 2001) pushing India, Madgascar, and Tanzania to higher latitudes.

Latitudinal diversity changes in some bivalve taxa, especially Trigonioidea, Limoidea, Pholadomyoidea, Nuculanoidea, Monotoidea, Pectinoidea, and Crassatelloidea (Damborenea et al., 2013) support the role of temperature in leading to faunal differentiation within the Ethiopian Province. This coincides with the result of Kiessling et al. (2011) based on the analysis of different faunas.

6.3.2 Ammonites

As species-level data of these groups were not sufficient, genus-level data of ammonites, brachiopods, and corals were subjected to PCoA for the Bajocian and Callovian time slices. The resulting plots show a certain degree of dissimilarity between the macrofaunal groups. A positive correlation was found between the life habits of the taxa and the dispersal potential (Fig. 6.3). However, all plots from different groups point to separation of the study area and Middle East countries from the North Tethys (Fig. 6.3) during the Bajocian, similarly to the results obtained from the distribution patterns of bivalves.

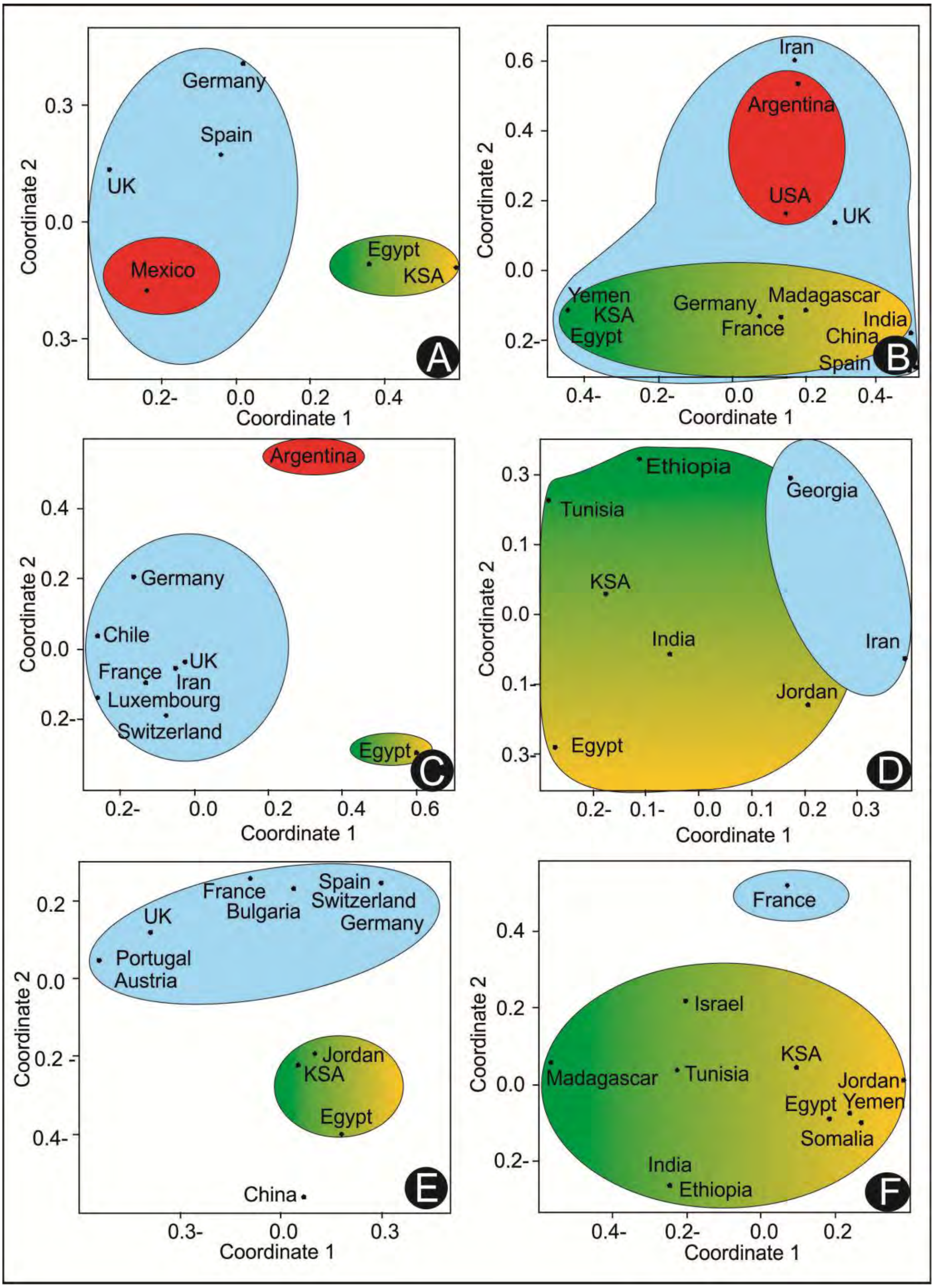

Fig. 6.3. PCoA plot of faunas corresponding to different taxa and time slices. A, Bajocian ammonites, B, Callovian ammonites, C, Bajocian corals, D, Callovian corals, E, Bajocian brachiopods, and F, Callovian brachiopods. All faunal groups of the Middle East (Egypt, Jordan, and KSA) formed a separate unit during the Bajocian (intracratonic setting). By the Callovian, the pelagic ammonites show a global expansion, while the benthic fauna shows no or only little similarity with that of the North Tethys Province.

In general, ammonites have a wider distribution pattern than all benthic groups (Fig. 6.3). In the PCoA plot of ammonites (Fig. 6.3A), Mexico plots near the North Tethys Province, which indicates successful immigration of ammonites via the newly opened

Hispanic corridor. Zatoń and Marynowski (2006) suggested migration trend of Mediterranean ammonites toward the shallow epicratonic Polish Basin during the Late Bajocian sea-level rise. By the Callovian, Madagascar, and India plot near Spain and Tibet (North Tethys Province) and away from the Northern Ethiopian Subprovince (Middle East; Fig. 6.3B), however, these provinces have no clear boundaries, probable due to a sea-level highstand during this time.

6.3.3 Corals

The distribution patterns of the few corals identified from the study area during the Bajocian (Fig. 6.3C) show a high level of endemism, but some genera are comparable to those of the North Tethys Province. The endemic nature of the corals of G. Maghara decreased toward the Callovian (Fig. 6.3D), where a distinct Ethiopian Province became discernable coinciding with a change from the intracratonic setting to an open marine setting and also with a world-wide sea-level highstand (Haq et al., 1987). The latter is also reflected by the high similarities between the Ethiopian Province and the North Tethys Province (Georgia and Iran, Fig 6.3D).

6.3.4 Brachiopods

Brachiopods generally exhibit a low dispersal potential. None of the genera occurring at G. Maghara are known from either North or South America. During the Bajocian, brachiopods show a high level of dissimilarity with the North Tethys regions (Fig. 6.3E). By the Callovian, a few taxa were recorded also from France (North Tethys Province) (Fig. 6.3F). A possible explanation of the latter was suggested by Vörös (1993, 2005) who argued that by the Middle Jurassic (Bathonian-Callovian?), the widening oceanic belt (Alboran-Ligurian-Penninic oceans) probably formed a true barrier which prevented the migration of brachiopods between the Mediterranean microcontinent (Adria and Turkish blocks) and the Ethiopian shelf, areas that were connected during Early Jurassic times.

6.4 Migration and endemism

Based on the analysis of palaeobiogeographic data (ostracods, ammonites, brachiopods, and bivalves), Arias (2008) suggested that the Panthalassic circulation was characterized by two large subtropical gyres rotating clockwise in the northern hemisphere and anti-clockwise in the southern hemisphere. The Tethyan Ocean was dominated by monsoonal westerly-directed equatorial surface currents that, reaching its western corner, were deflected to the north, along the northern side of the Tethys Ocean during summer and in the opposite direction during the winter (Arias, 2008; Fig. 6.4).

The great faunal similarities between the northeastern Tethys (to Tibet) and western Europe (to Portugal) indicate dispersal from east to west associated with a clock-wise circulation of the ocean current system in the northern hemisphere (Arias, 2008). Similarly, the macrofauna of the southern hemisphere may have migrated from the northern Ethiopian Province toward the south (East Africa, India and Madagascar; Fig. 6.4).

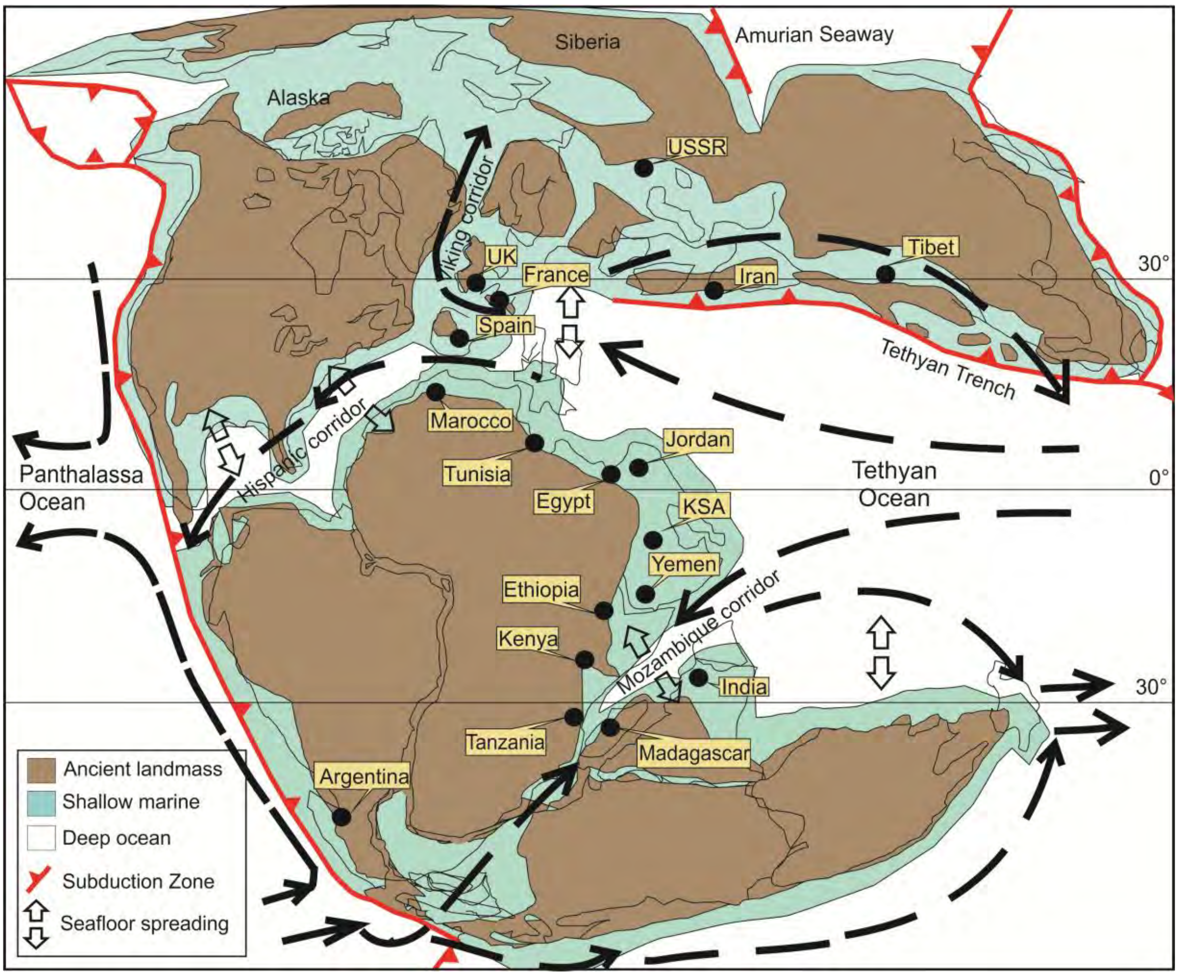

Fig. 6.4. Palaeogeographic reconstruction of the Middle-Late Jurassic world (after Scotese, 2001; Golonka, 2002) showing the position of some countries included in the biogeographic analyses. Arrows refer to marine circulation pattern (modified after Parrish, 1992, Arias, 2008).

The occurrence of some taxa, especially ammonites, of the Ethiopian Province in Argentina and Mexico may be due to a successful migration through the Hispanic Corridor (Aberhan, 2001), which opened during the Early Jurassic (see also Heinze, 1996). According to Aberhan (2001), the Hispanic Corridor developed from an effective barrier in early Jurassic into a filter (allowing the passage of a few morphotypes) during later Early Jurassic times. The apparently two-way faunal exchange through the Hispanic Corridor is related to a mega-monsoonal climate that changed directions of the oceanic currents through the corridor. Occurrence of some low-latitude taxa in northern Europe may be related to a northward migration during the Middle Jurassic as result of climatic amelioration (Liu et al., 1998).

The distribution pattern of the oyster *Actinostreon gregareum* implies migration through the Hispanic Corridor during the Bathonian towards Canada, and in an eastern direction as far as Burma, arriving in the northwestern Pacific (Japan) in the Callovian (Sha et al., 2002). Ghasemi-Nejad et al. (2012) argued that the close similarities of the Late Bajocian to Late Callovian dinoflagellates and ammonite fauna of Iran and the northwestern Tethys was the result of a direct marine connection facilitating the faunal exchange between the two areas.

The palaeobiogeographic dynamics influenced the extinction pattern of the macrofauna of the G. Maghara area. As seen from Fig. 6.5, both extinction rates and number of endemic genera changed through time. The diversity increased continuously from the Bajocian onward, but from the Middle Bathonian onward, the extinction rate of the benthic fauna also increased (Fig. 6.5A). Probably, the newly immigrating cosmopolitan taxa replaced the endemic fauna of the intracratonic setting, which flourished during the Bajocian. The endemism of the Jurassic bivalve taxa of G. Maghara decreased from a relatively high value of 25% during the Bajocian-Bathonian to 12% during the Oxfordian. This may reflect the global sea-level highstand, which enhanced the dispersal of bivalves.

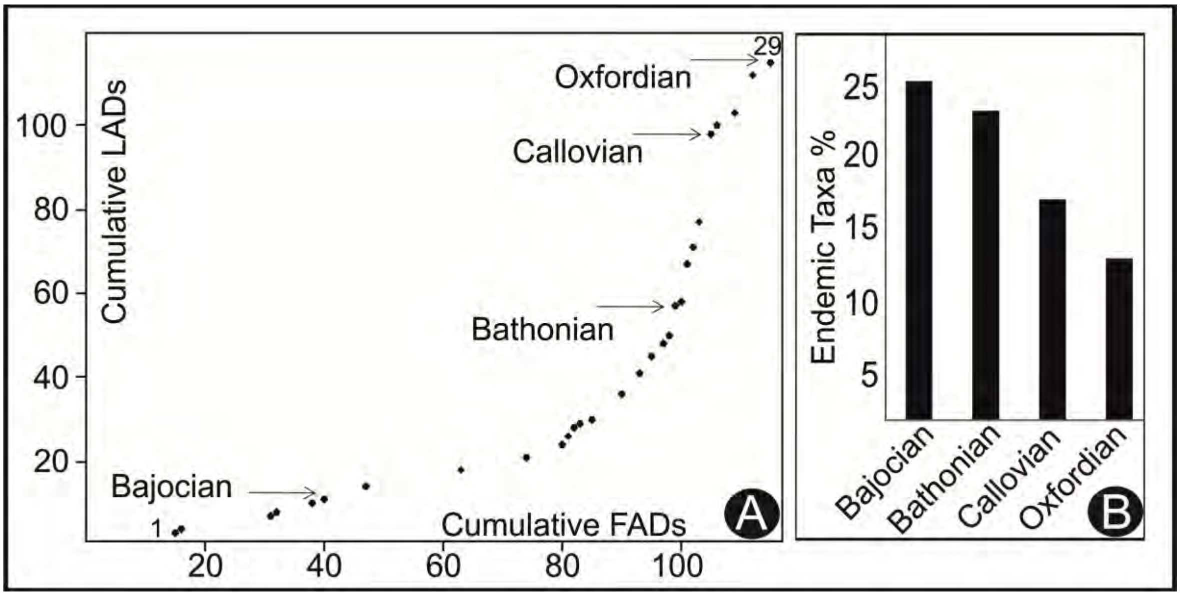

Fig. 6.5. (A) Extinction rate (FADs/LADs) of the macroinvertebrates of G. Maghara (points represent the UAs (from 1 to 39; see chapter 2.2). Note the increasing extinction rate from the Middle Bathonian onward. (B) Percentage of endemic bivalve taxa during the Bajocian-Oxfordian interval (total species number = 42).

7 Conclusions

7.1 Facies and lithostratigraphy

The Middle and Upper Jurassic mixed carbonate-siliciclastic sedimentary succession of G. Maghara has been analysed based on four sections taken along a 20 km wide continuous outcrop belt. Outcrop observations are combined with detailed microfacies studies. These sections provide the opportunity to illustrate the differences in the geometry and lateral continuity of facies, parasequences, facies successions, and facies heterogeneity, which documents environments varying from tidal flat and delta to open-marine. The Middle and Upper Jurassic succession of G. Magara was deposited on a ramp, and the architecture of this ramp varied from homoclinal to distally-steepened. Combining information from both fossils and rocks led to a modifcation of existing stratigraphic schemes and to the subdivision of the Middle-Upper Jurassic succession into seven formations, namely Mahl (Aalenian), Bir Maghara (Bajocian), Safa (Early Bathonian, Kehailia (Middle-Late Bathonian), Arousiah (Callovian), Tauriat (Oxfordian), and Masajid (Kimmeridgian). All of these formations are laterally continuous in the four measured sections except the Tauriat Formation, which is absent at G. Mowerib. The age of these formations was estimated based on the quantitative biostratigraphic method.

7.2 Quantitative biostratigraphy

Quantitative biostratigraphy was applied to obtain maximal stratigraphic resolution with a minimum of superpositional contradictions. A data matrix comprising 231 macrobenthic taxa in 93 samples from the four sections has been processed with the unitary association method. This led to construction of a sequence of 29 UAs (maximal sets of actually or virtually coexisting taxa), which have been grouped into 14 laterally reproducible association zones. The UA method allowed an in-depth analysis of the stratigraphically conflicting taxa, enabled the biostratigraphic subdivision of the studied interval, and also provided stratigraphic correlation among the measured sections and with the Tethyan ammonite zones.

7.3 Depositional sequences and basin evolution

The Jurassic strata of G. Maghara formed within an intracratonic extensional rift basin. Sea-level changes and subsidence rates were the decisive factors influencing sedimentation on the ramp. The different lithological elements were controlled by tectonic activity which continuously changed the ramp topography and hence storm intensities. The development of the Jurassic succession of G. Maghara can be summarized as follows:

(1) An intracratonic half-graben basin developed in the Early Jurassic (probably Toarcian), when a thick package of alluvial to deltaic sandstones were deposited (Shusha Formation, Depositional Sequence (DS) 1).

(2) A carbonate ramp developed at the margin of the basin, and a large lagoon, episodically protected by ooid shoals, developed during the Bajocian. The facies association of this cycle indicates an inner ramp setting with high terrigenous supply (Mahl and Bir Maghara formations, DS 2 and DS 3).

(3) A major unconformity occurred at the Bajocian–Bathonian boundary indicating peak regression. For the first time since the late Early Jurassic the area was subaerially exposed.

(4) During the Early Bathonian, the global sea-level fall was accompanied in G. Maghara by faulting and development of a distally steepened ramp resulted in the development of a deltaic system, where a thick sandstone package (Safa Formation, LST of DS 4) accumulated between the carbonate ramp sediments.

(5) During the Middle Bathonian, a second major change occurred when environments deepened concomitant with a slow sea-level rise and slow subsidence resulting in the spread of middle to outer ramp sediments of a homoclinal ramp, comprising the Kehailia (TST and HST of DS 4) and Arousiah (DS 5) formations, over the previous inner to middle ramp sediments.

(6) During the Callovian, sedimentation switched from marl-dominated to carbonate-dominated.

(7) By the Oxfordian, deepening of the sea resulted in deposition of the glauconitic shale of the Tauriat Formation (DS 6).

(8) Further subsidence at the beginning of the Kimmeridgian led to development of a distally steepened ramp, on the slope of which a crinoid-grainstone facies became established (Masajid Fm., DS 7).

(9) From the Kimmeridgian onwards, the G. Maghara Basin started to close by uplifting. Finally, by the late Senonian, the collision of the African–Arabian plate with the Eurasian plate resulted in closure of the basin and the development of the Syrian Arc fold system. At that time the area underwent folding and faulting, and G. Maghara gained its current structural shape.

7.4 Macrobenthic palaeo-communities

Based upon multivariate analysis of 198 taxa in 138 samples, the macrobenthic associations and assemblages were reconstructed and their palaeoenvironmental and palaeoecological significance was evaluated. Non-Metric Multidimensional Scaling

(NMDS) delineated the same degree of habitat partitioning as hierarchical clusters with very little overlap. From Detrended Correspondence Analysis (DCA) the primary environmental gradients controlling the distribution of the faunal were the water depth, while Axis 2 has ordered the taxa according to differences in life habits. Nine associations and three assemblages were distinguished and were interpreted to be representative of their original environment. Their guild structure, facies, diversities, and taphonomic characteristics were analysed.

Within-habitat diversity (alpha diversity) increased in low stress associations, while habitat partitioning (beta diversity) started only when a considerable environmental stability with respect to salinity, nutrient availability and oxygen levels was reached. Hence, high beta diversity is a potential criterion for ecosystem stability. Sea-level alone played only a negligible role. Based on diversity indices, the associations and assemblages were divided into two major groups and discussed within the sequence stratigraphic framework;

1. Low-stress, polyspecific associations representing two habitats:
   (a) a high energy, firm substrate habitat, in which epifauna dominated during middle to late stages of TST (*Daghanrihynchia angulocostata, Eudesia cardioides Africogryphaea/Daghanirhynchia, Chomatoseris epithecalis*, and *Cymatorhynchia quadriplicata* associations);
   (b) a low energy, soft substrate habitat dominated by infauna during MFZ and early HST (*Nicaniella pisiformis* association).
2. High-stress, paucispecific associations which occur in:
   (a) dysoxic distal prodeltaic environments with soupy substrates and dysoxia below the sediment-water interface (*Daghanirhynchia daghaniensis* and *Africogryphaea costellata* associations);
   (b) oligotrophic environments with reduced terrigenous input in a restricted inner ramp early HST (*Amydroptichus formosus* association);
   (c) environments with a relatively high rate of sedimentation during late HST (*Coenastrea arabica* assemblage);
   (d) dysoxic deep outer ramp environments during MFZ to early HST (*Pholadomya inornata* assemblage); and
   (e) high-energy shoal environments during FSST (*Eligmus rollandi* assemblage).

The results agree with those of previous ecological studies on the macrobenthos of Recent and fossil habitats, which suggest an enhanced role of nutrition and substrate type. A moderate nutrient supply (mesotrophic conditions) and medium-grained sediment provided the most suitable environment for the benthic palaeo-communities. These conditions were realized mainly in middle ramp settings during middle TST to MFZ times.

7.5 Brachiopods versus bivalves

The distribution pattern of brachiopods and bivalves suggests that the replacement between both is related to their different feeding strategies and nutritional requirement. The brachiopod-dominated associations occur preferentially in nutrient-poor carbonate environments with low food supply, low grazing activities, and low rates of sedimentation. In contrast, bivalves dominated in nutrient-rich siliciclastics. The most suitable substrate for the macrobenthos was found to be marl, which includes samples with the highest species diversities. Dominance of the reclining oyster *Africogryphaea*, the small oyster *Nanogyra nana*, in addition to the large comparatively compressed rhynchonellid *Daghanirhynchia daghaniensis*, which is characterized by a very small foramen and deep sulcus, in soft substrates are examples of epifaunal adaptations to soft-bottoms in quiet-water environments.

7.6 Fauna-substrate relationships

Hydrodynamic conditions were most likely the main indirect factor controlling the palaeo-communities. Hydrodynamic conditions influenced the substrate type, redistributed nutrients, and were responsible for the stratified water masses and hypoxia. According to the feeding mode and mode of life, three groups of macrobenthic taxa were distinguished (1) epifaunal suspension-feeders/microcarnivores, which dominated in moderate- to high energy environments with high productivity during TST, (2) infaunal deposit-feeders, which dominated in low-energy environments with fine-grained siliciclastic sediments usually during MFZ and early HST, and (3) epifaunal grazers (herbivores and omnivores) were found everywhere and not restricted to any specific environment.

7.7 Relationship of macrobenthic associations to sequence stratigraphy

In general, the macrobenthic communities can be grouped into two main categories. ‘Immature’ communities (paucispecific) occurred when a given environment lost its stability. Such conditions may have developed during the LST or the FSST. In contrast, ‘mature’ communities (polyspecific) developed during the middle to late stage of TST, MFZ, and during the early HST. However, in deep settings, unfavourable conditions may also develop during the early HST such as dysoxia generated by the establishment of stratified water masses. In addition, shells of these intervals may remain for a prolonged time interval in the diagenetic active zone and hence may have a high dominance and low diversity (assemblage D).

7.8 Palaeobiogeography

The intracratonic setting, which prevailed at G. Maghara and in the Levant margin during the Bajocian, led to a joint geographic pattern of this area. The similarity within both areas indicates those both were connected and, at the same time, were isolated from the ocean by lislands and shallows. These barriers may have limited the dispersal potential of the macrofauna and prevented faunal exchange even with nearby areas in northern Africa. Certain similarities exist in the geographic pattern of the different faunal groups during the Bajocian. A positive correlation was found between the life habits of the taxa and their dispersal potential, the dispersal potential being ammonites > bivalves ≥ corals > brachiopods.

Although the barriers formed during the Bajocian disappeared from the Middle Bathonian onward, the same pattern as in the Bajocian prevailed during the Bathonian (i.e., isolation from northeastern Africa), which may be related to the global sea-level lowstand. By the Callovian, in contrast, the fauna of the study area became very similar to that of northeastern Africa, coinciding with a global sea-level highstand. Moreover, diversity and extinction rate increase from the Bajocian to the Oxfordian. The latter may have been partly caused by the invasion of cosmopolitan taxa due to the open marine setting from the Middle Bathonian onwards and the global sea-level highstand of the Callovian.

The differentiation of the Ethiopian Province into low-order biochoremas toward the Oxfordian may be linked primarily to the widening of the marine seaways, which permitted invasion of cold polar waters and subsequently a lowering of temperature, which had reached a maximum during the Bathonian, in the Oxfordian,. The latter may have limited the expansion of Tethyan faunal elements to a latitude of less than 27°S. For this reason the fauna of Tanzania, Madgascar, and India (southeast Ethiopian Province, situated approximately at a latitude above 27°S) slightly differed from the rest of the Ethiopian Province.

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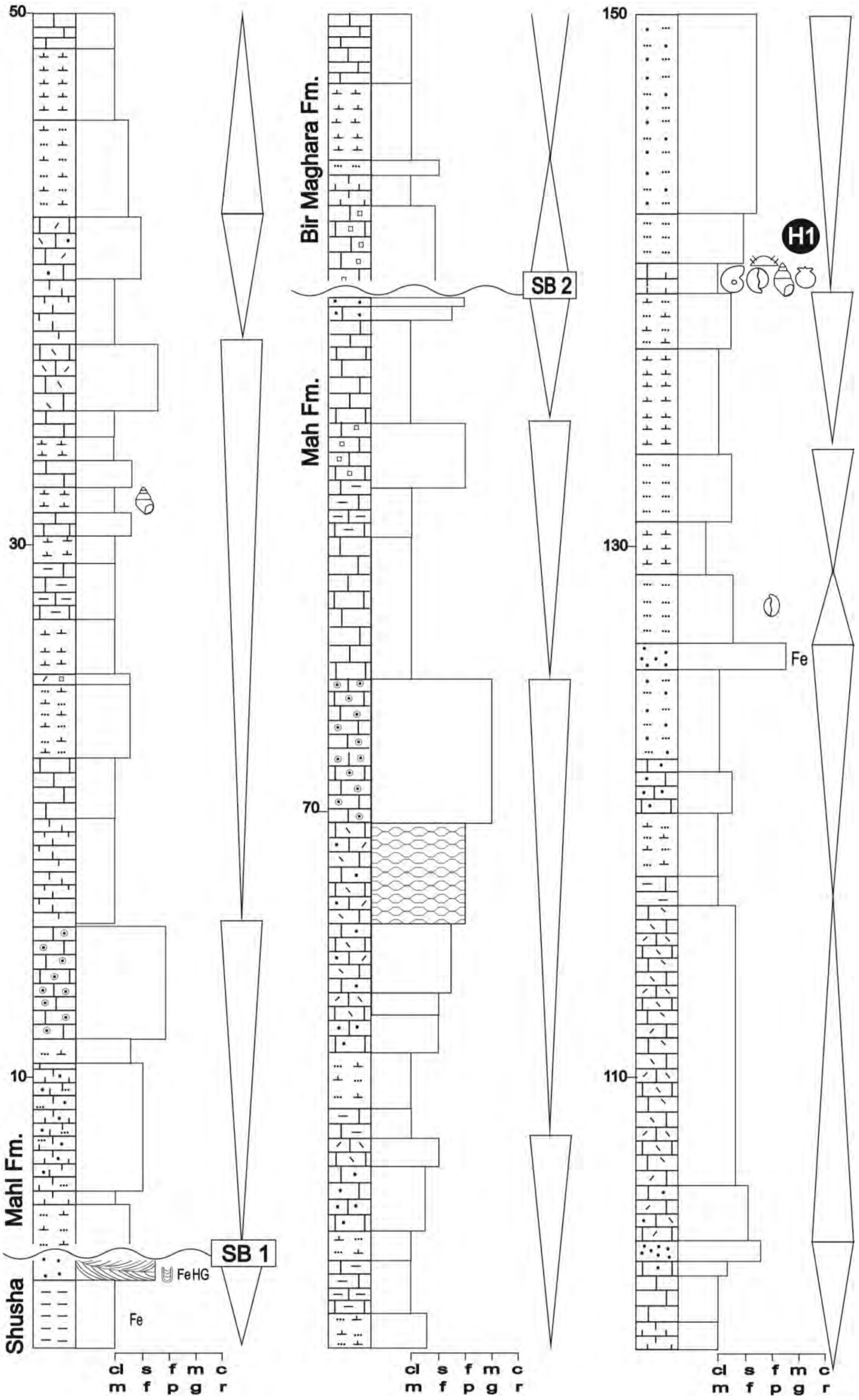
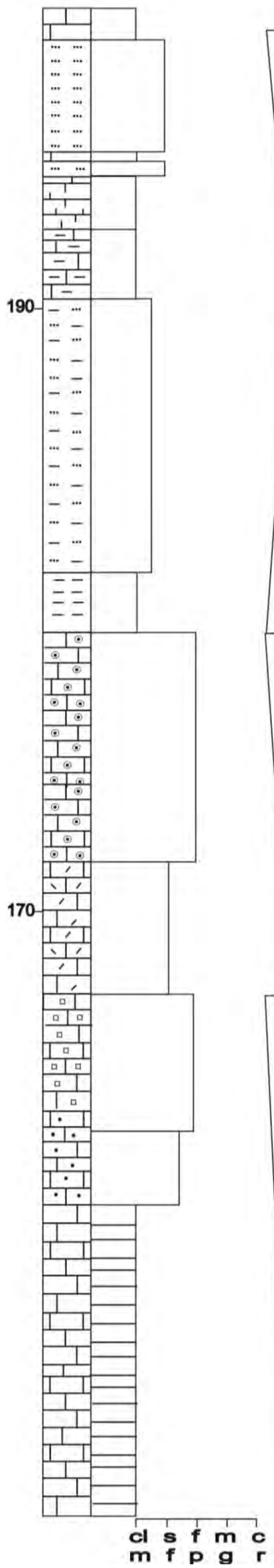
Appendix A: Detailed sections

1. Section of G. Homayir (key at the end of G. Arousiah section)

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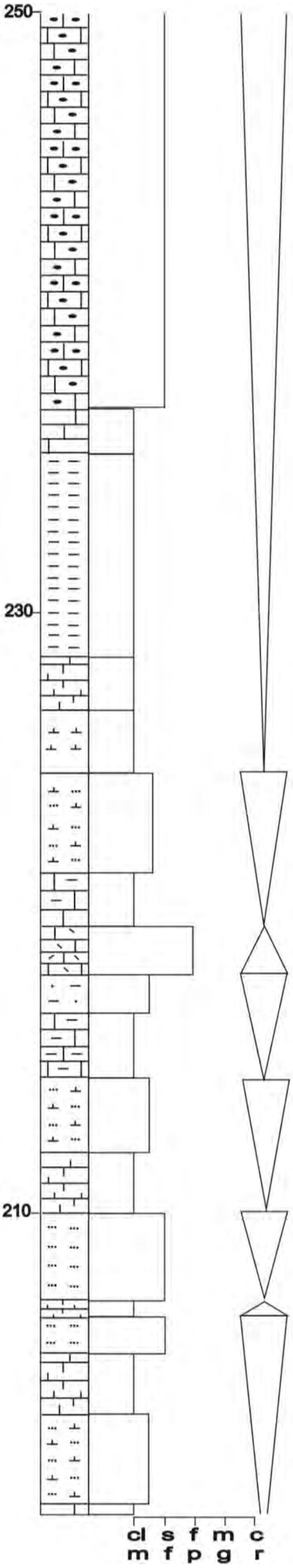
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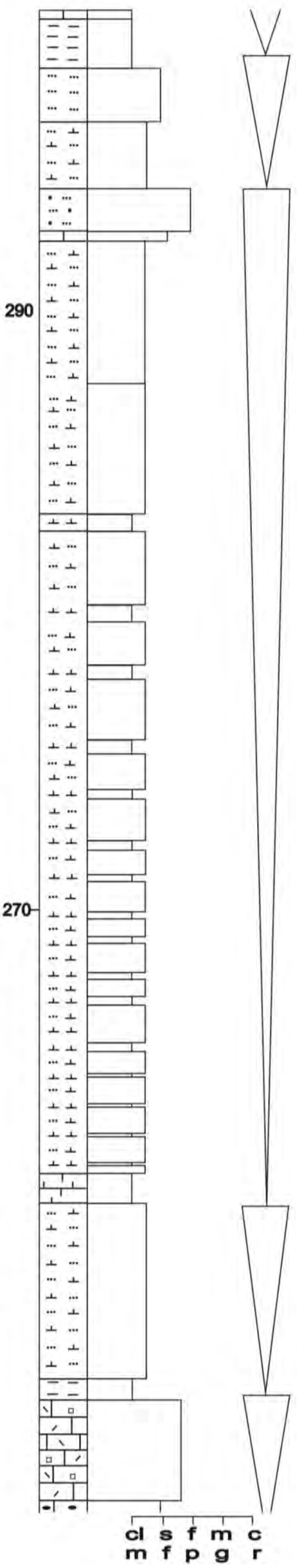
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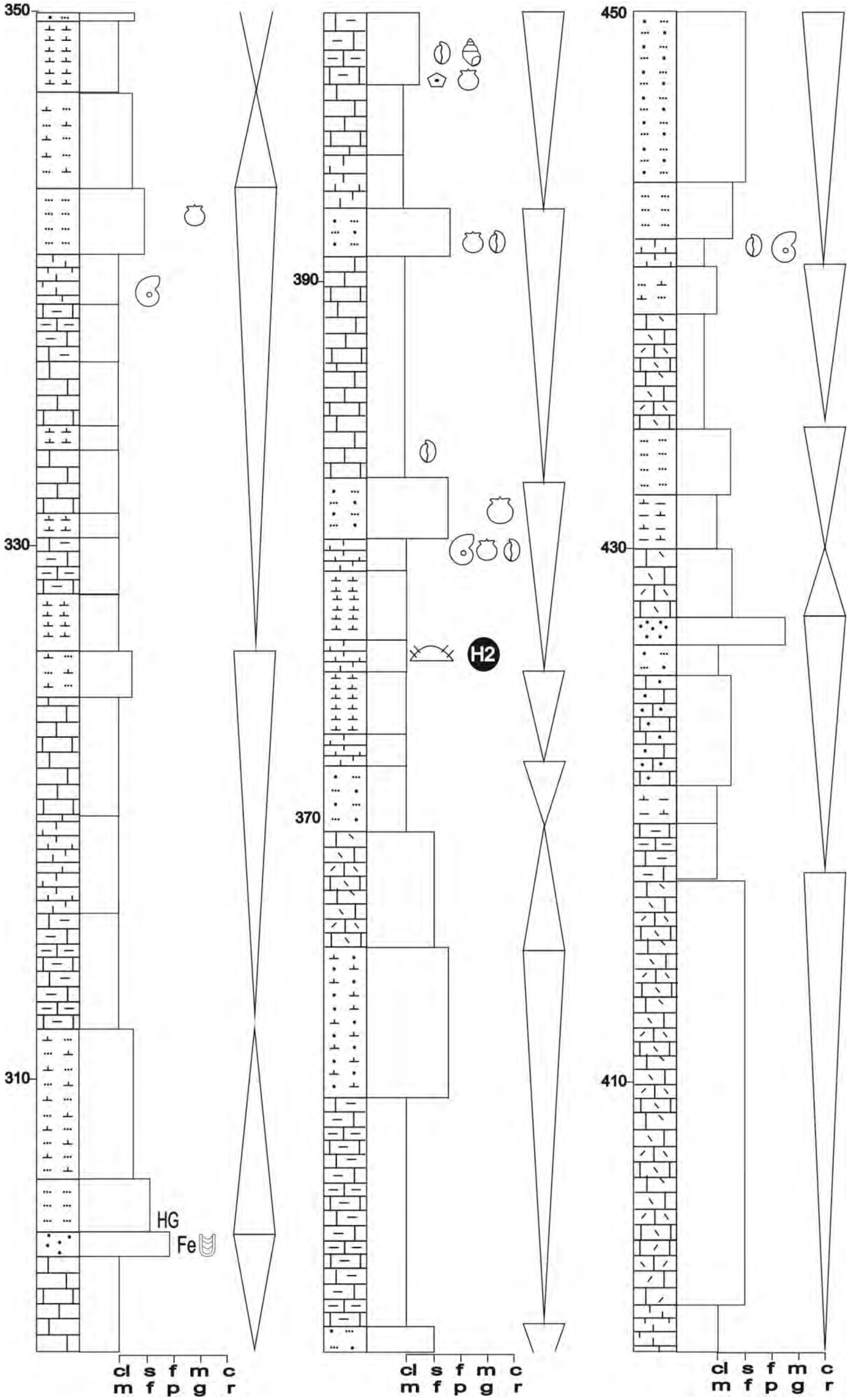
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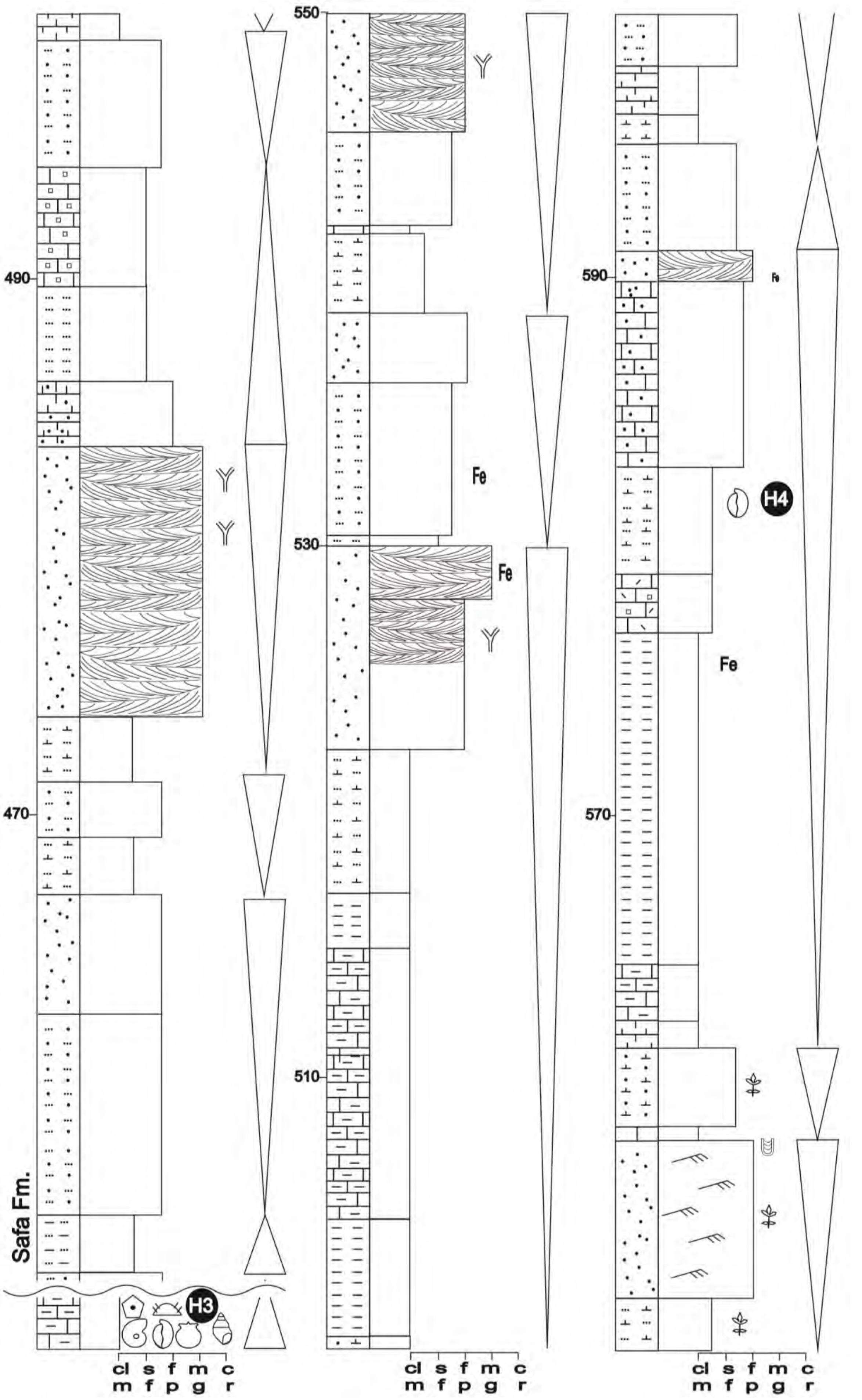
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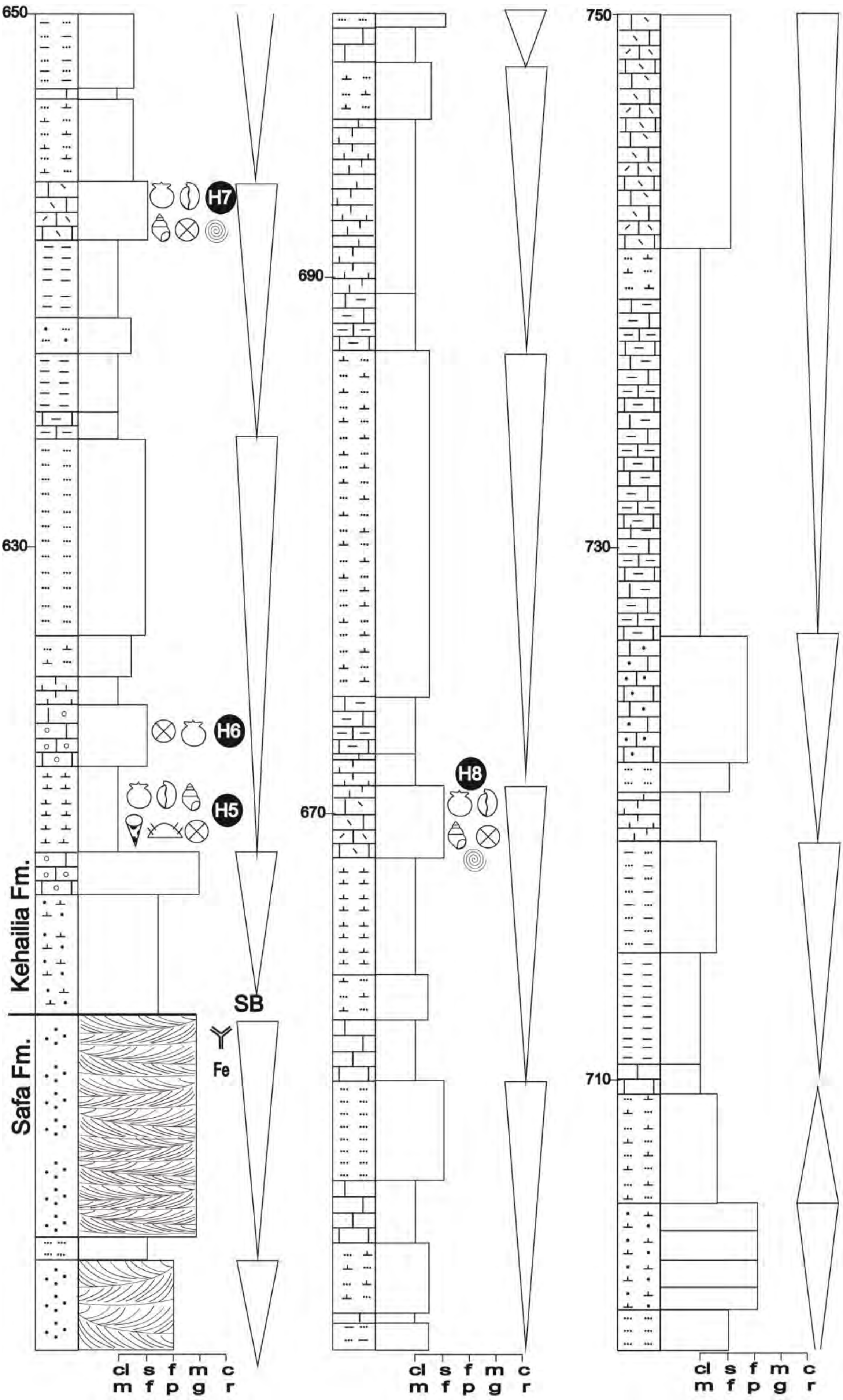
m f p g r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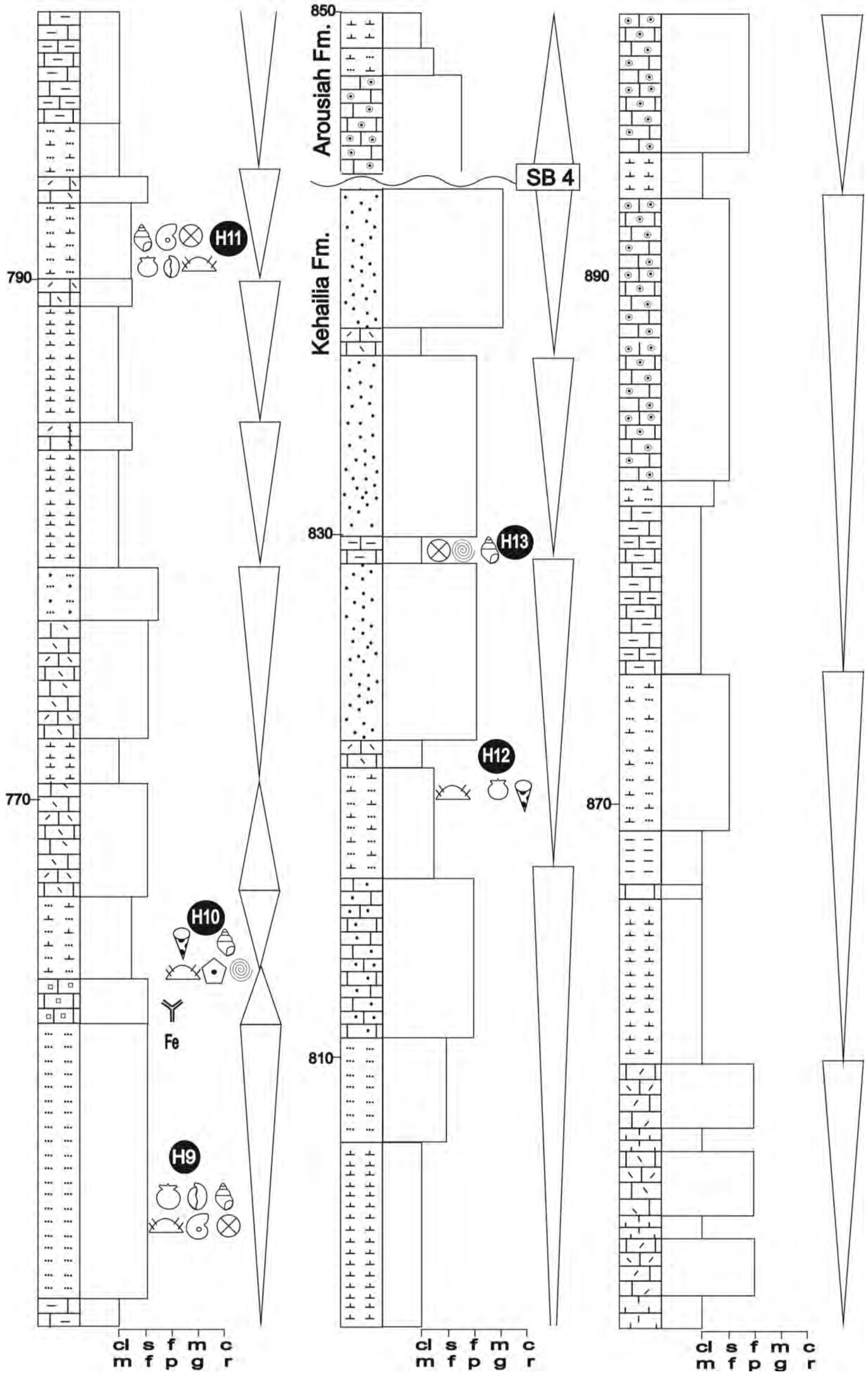
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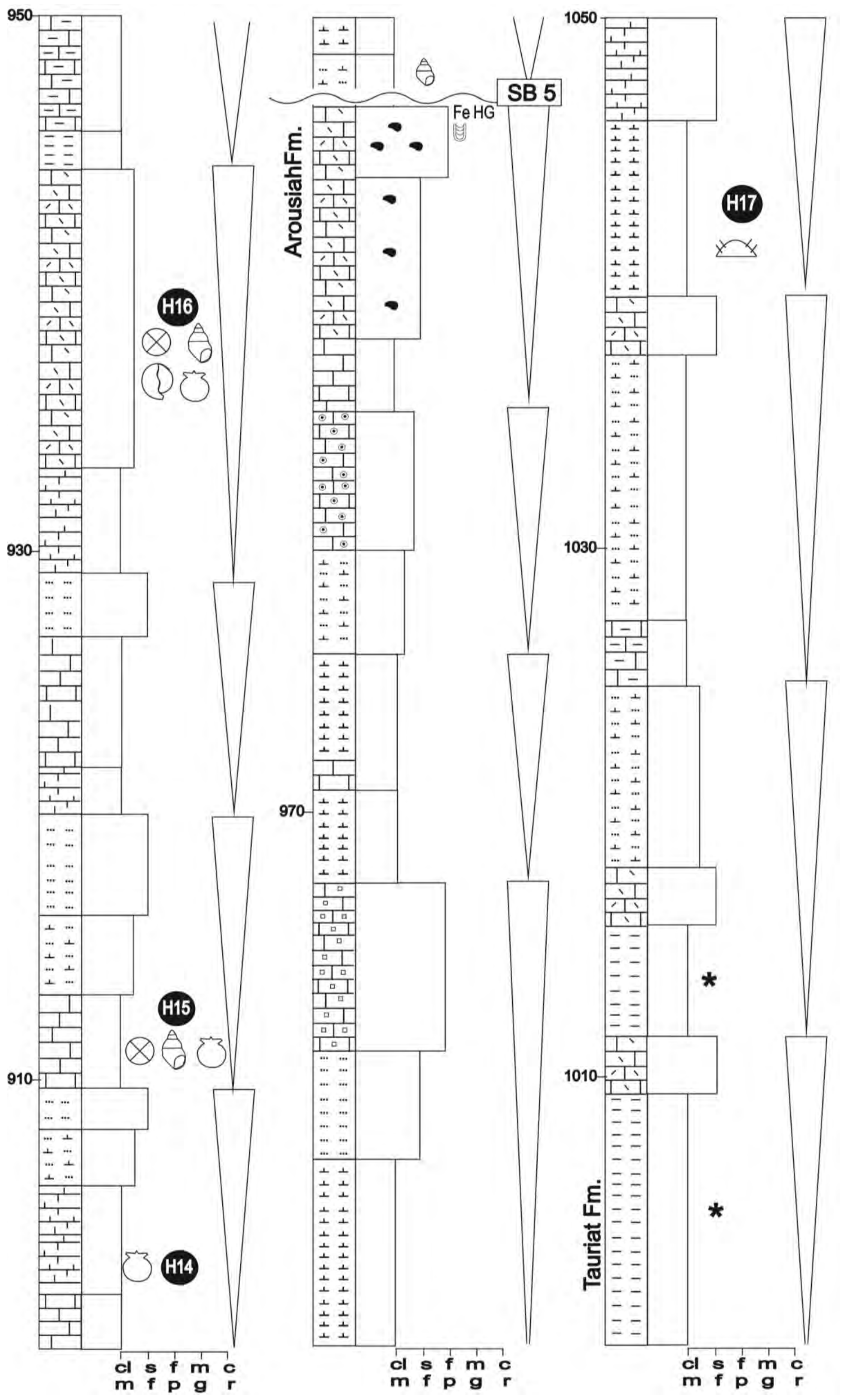
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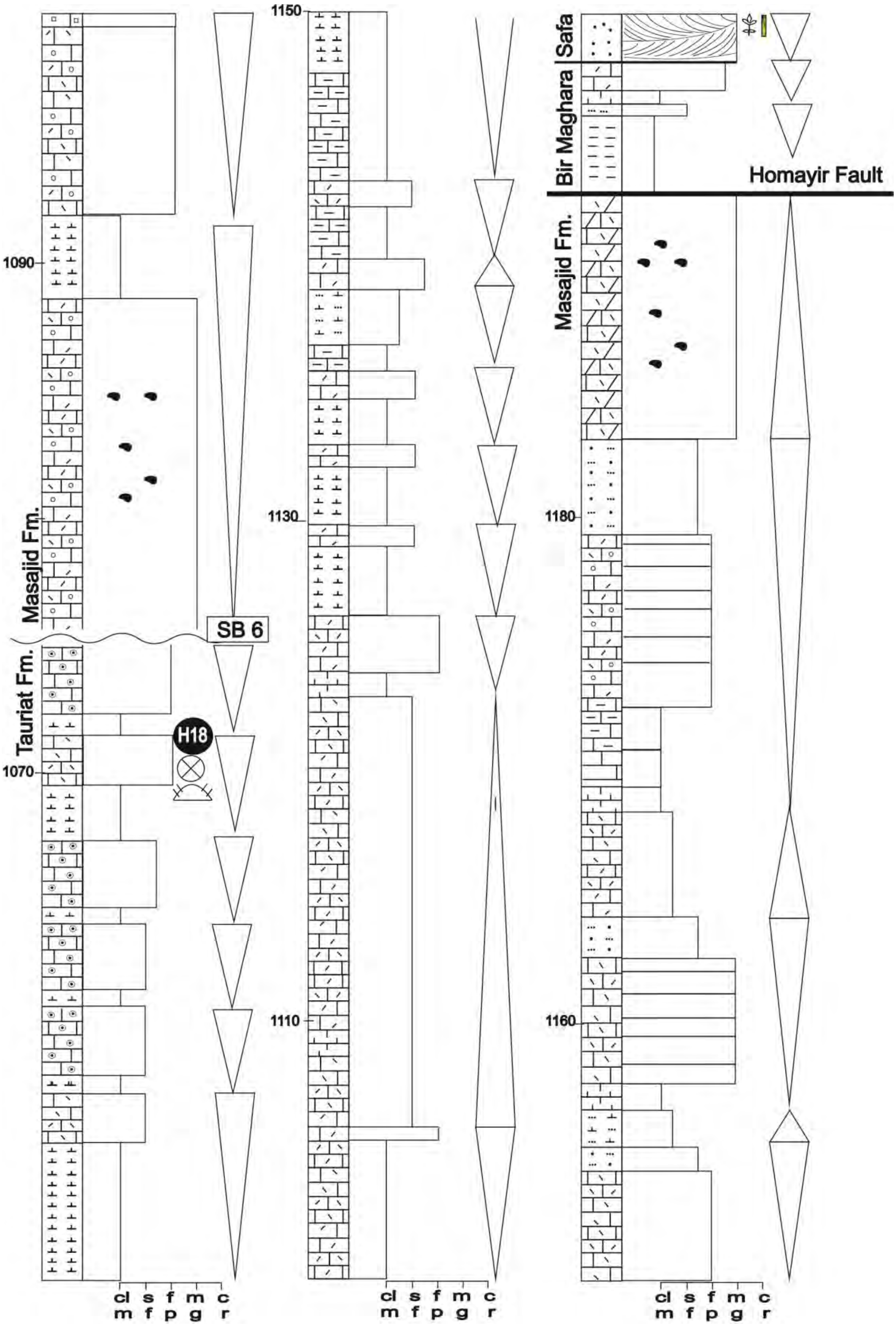
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Masajid Fm.
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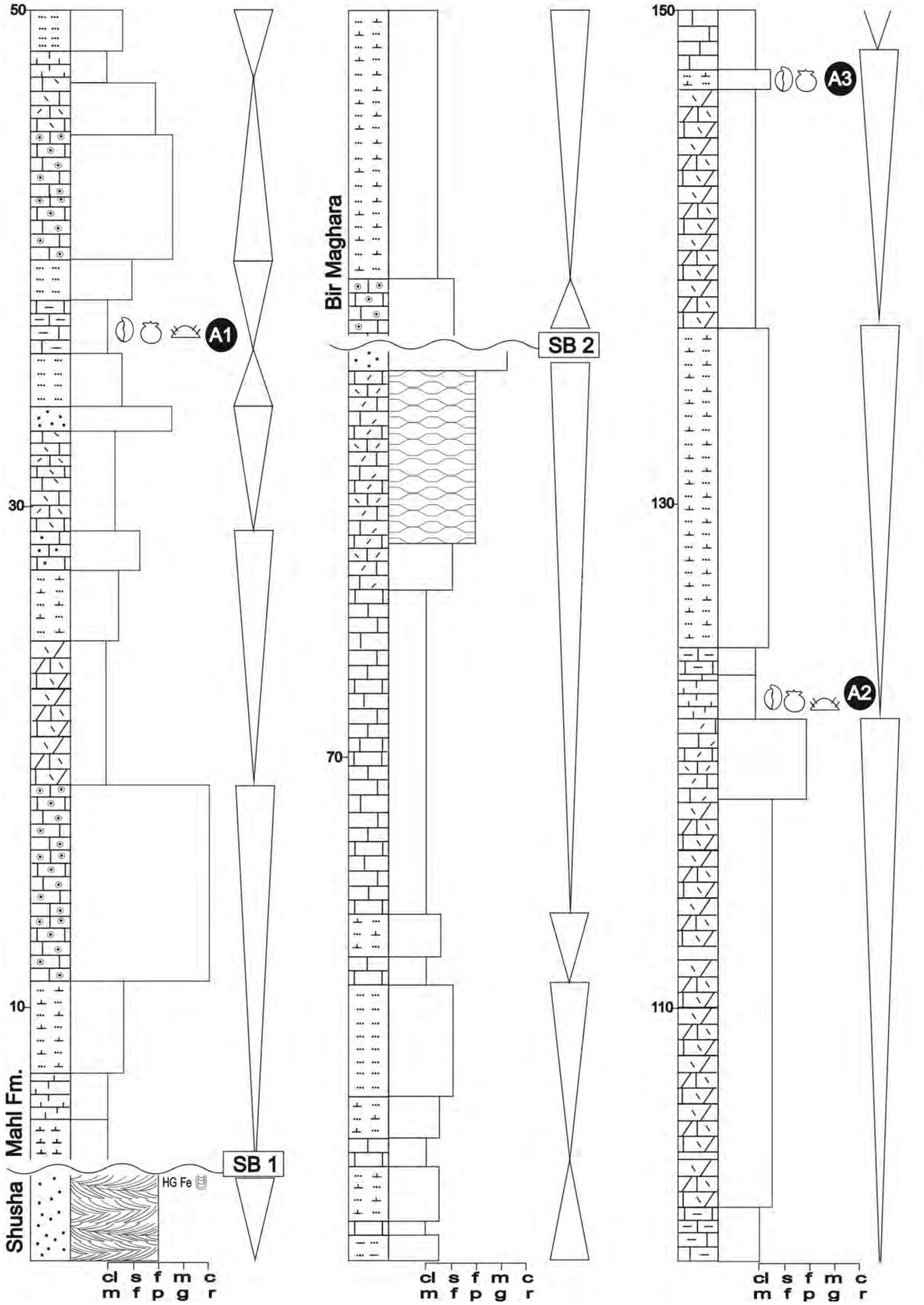
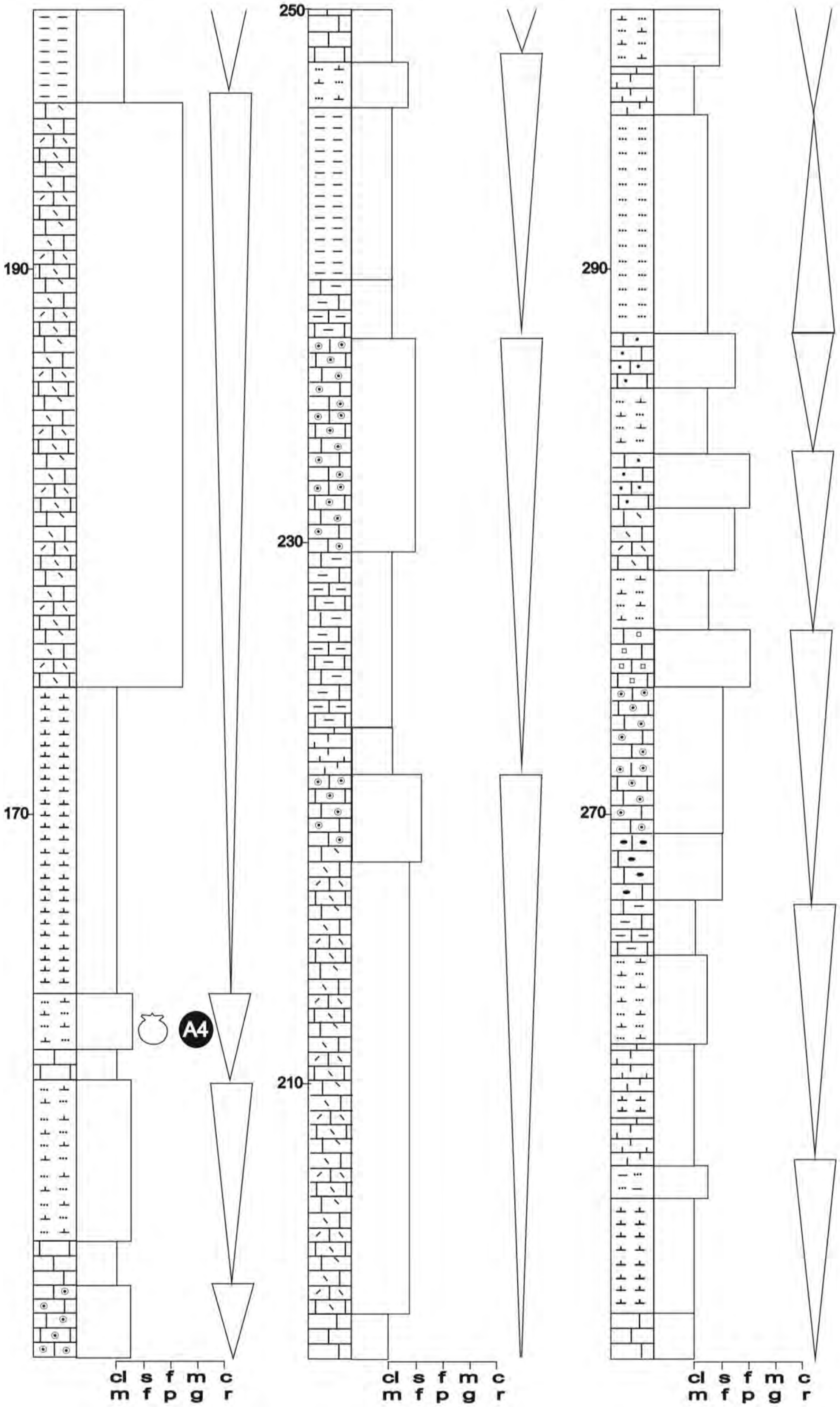
2. Section of G. Arousiah

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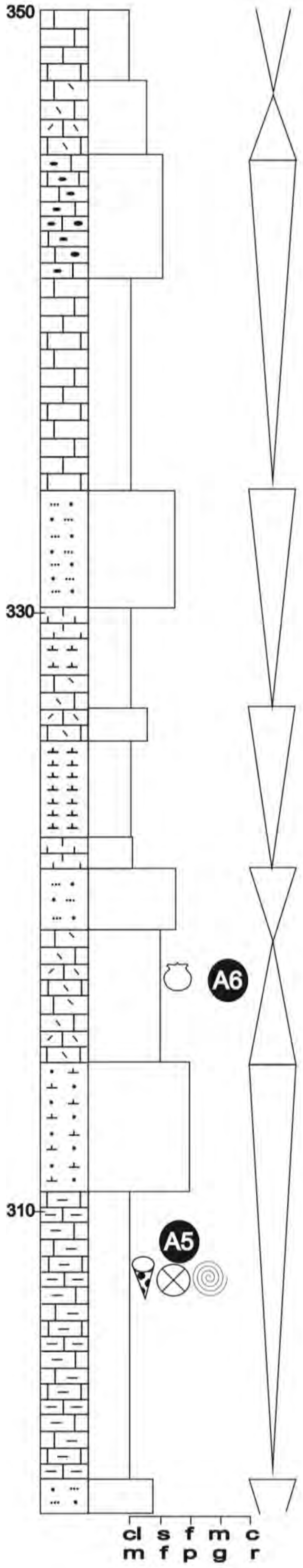
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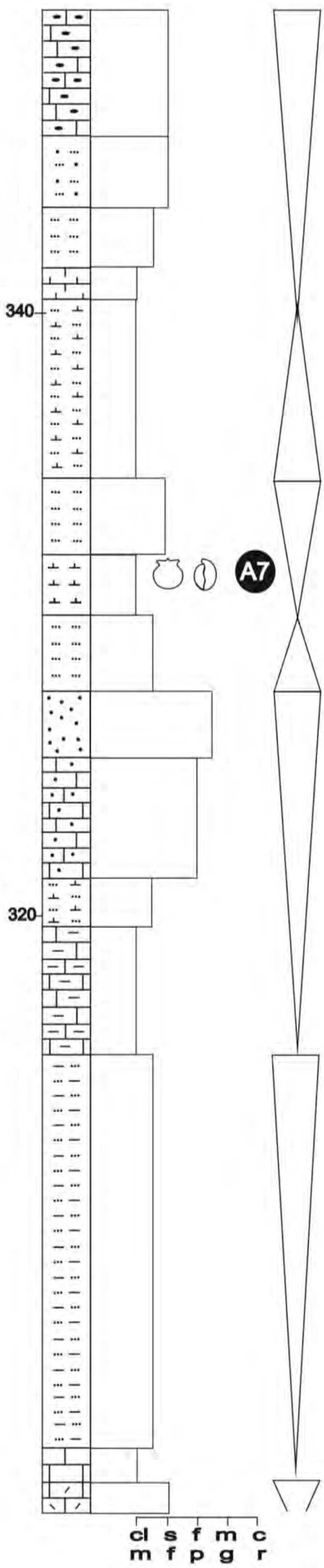
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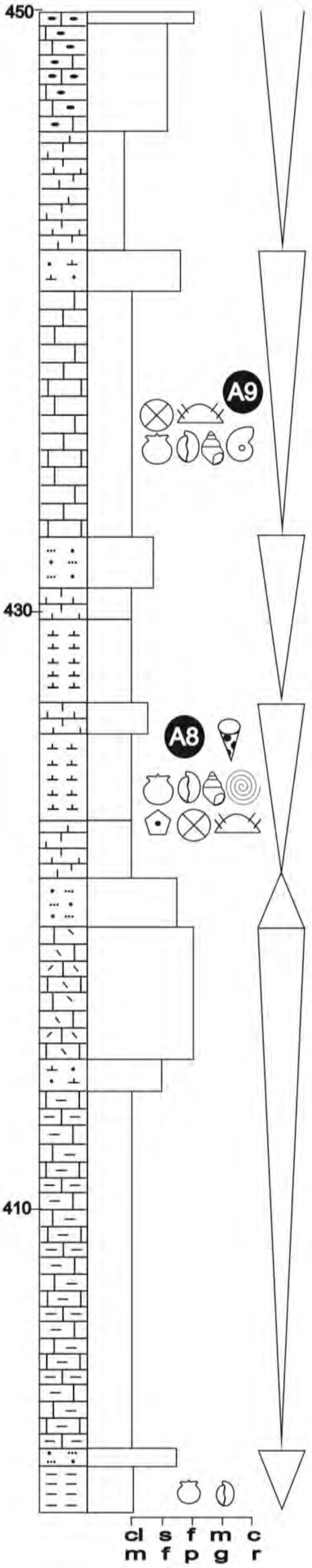
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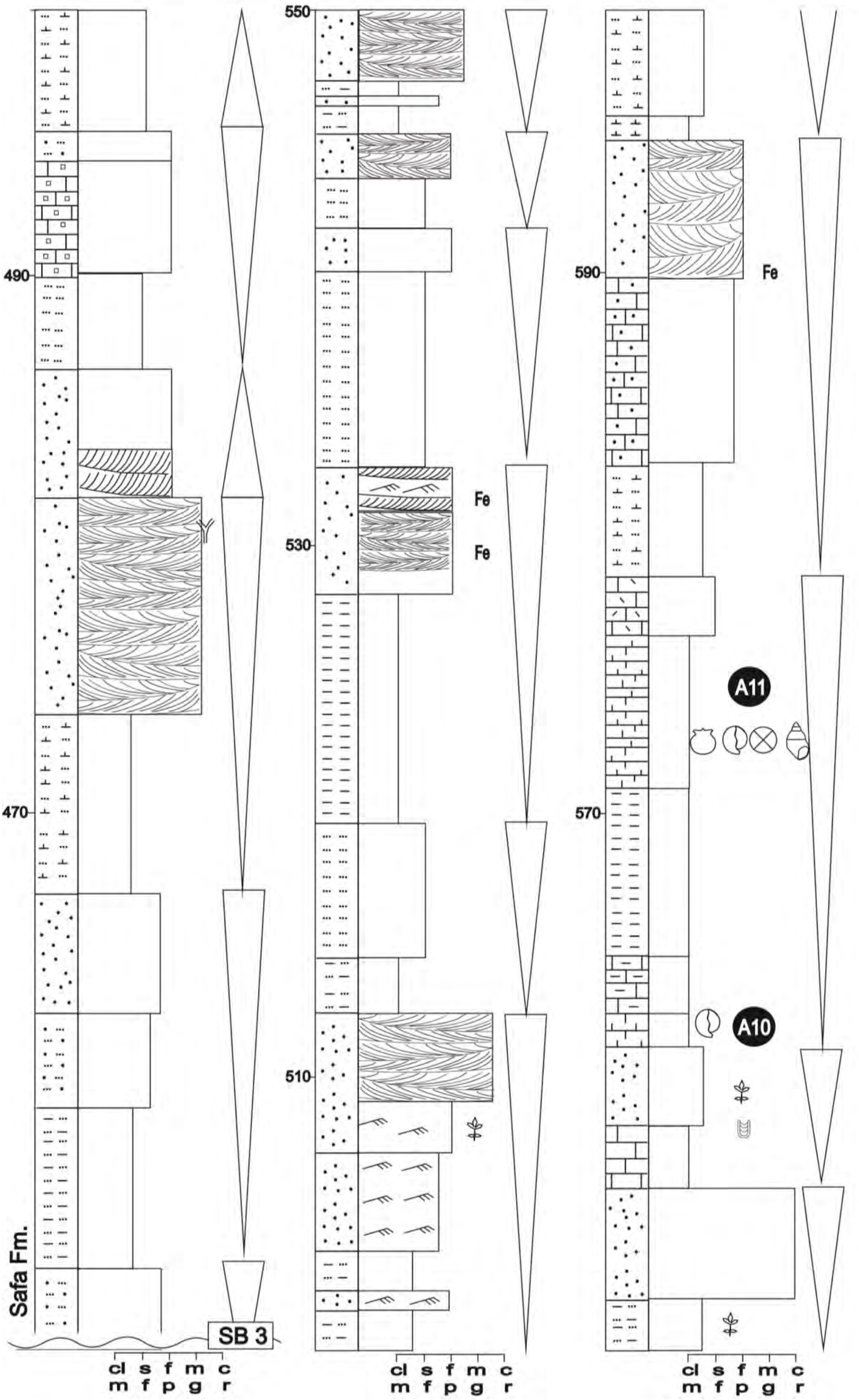
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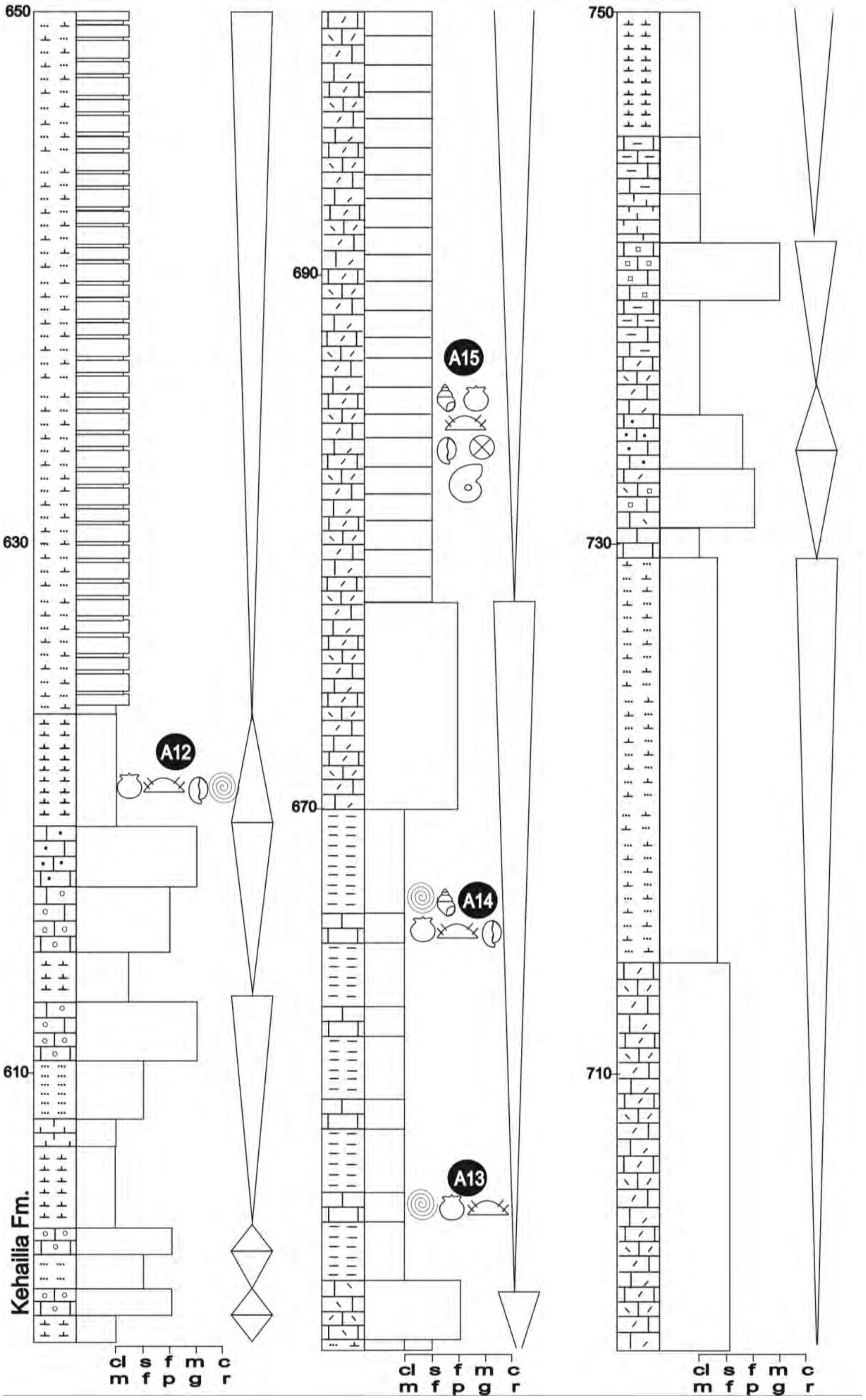
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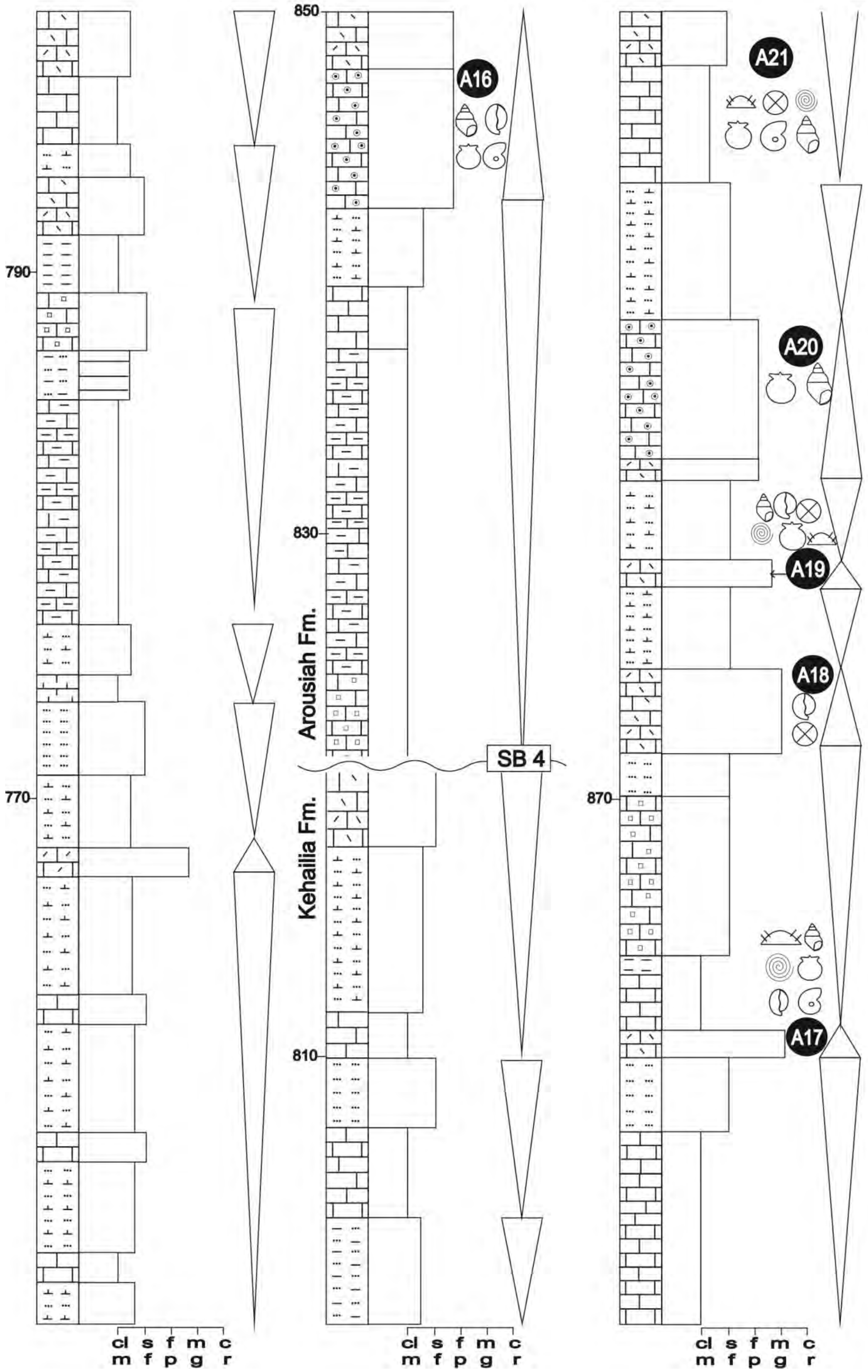
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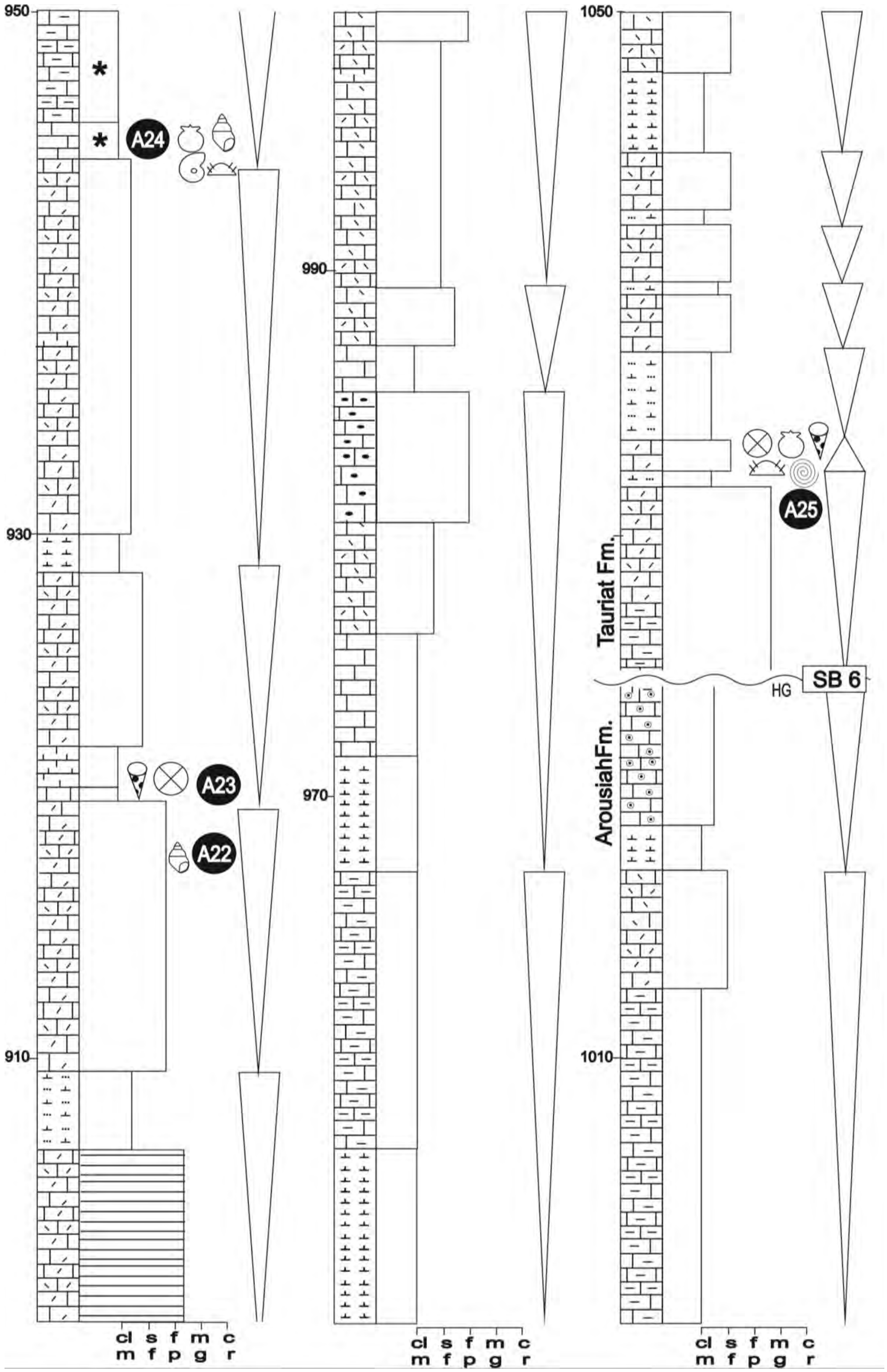
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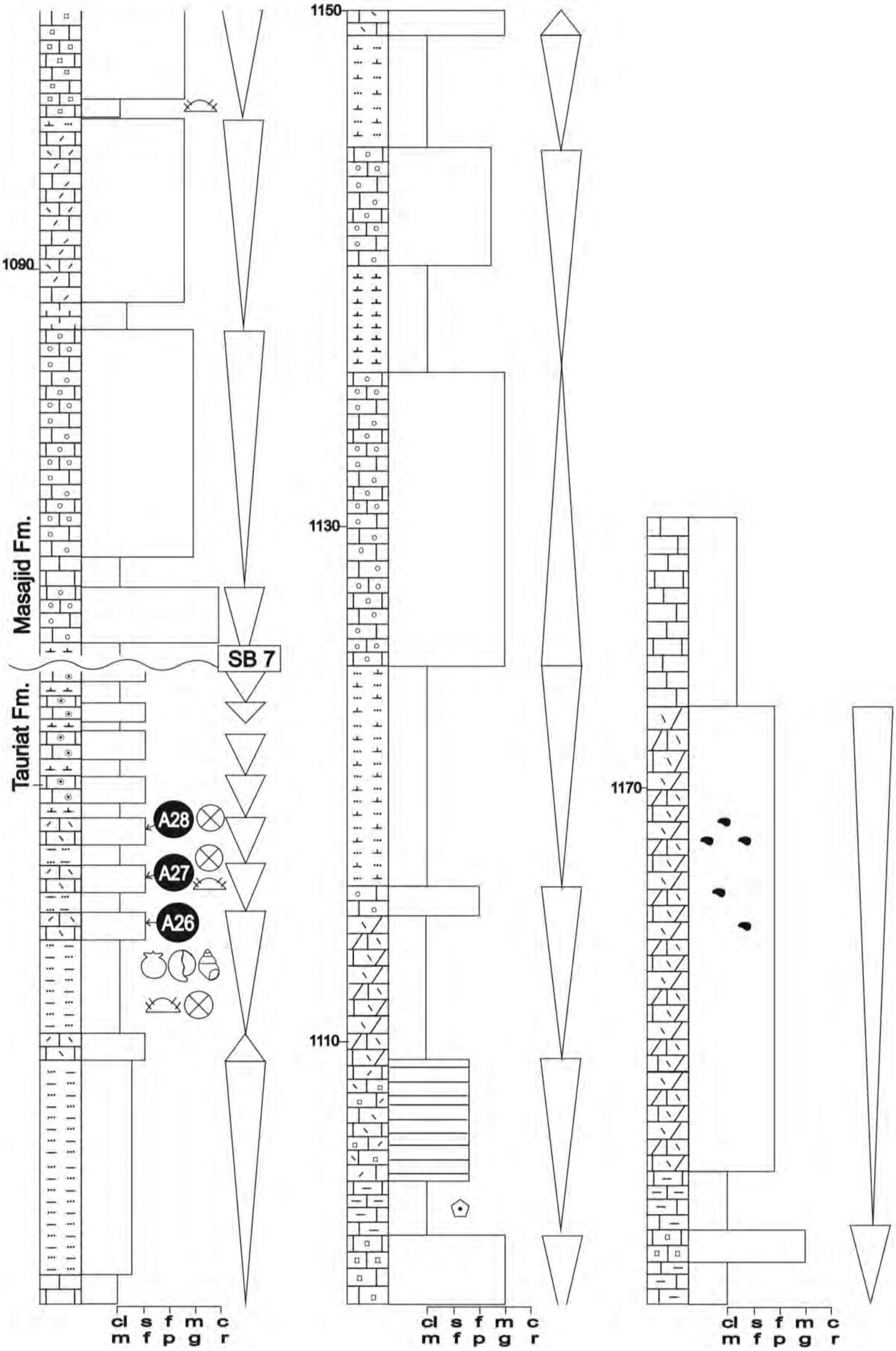
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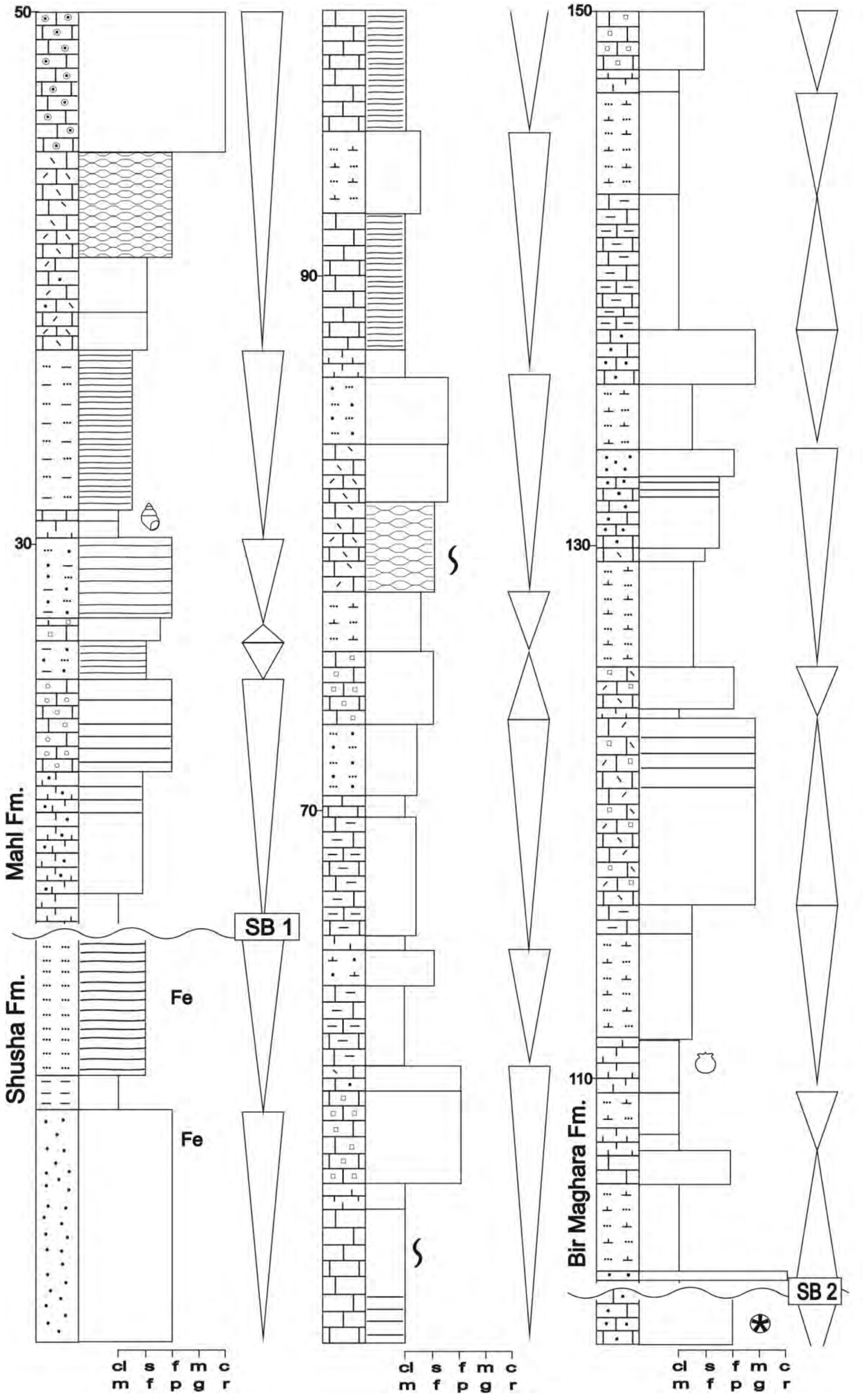
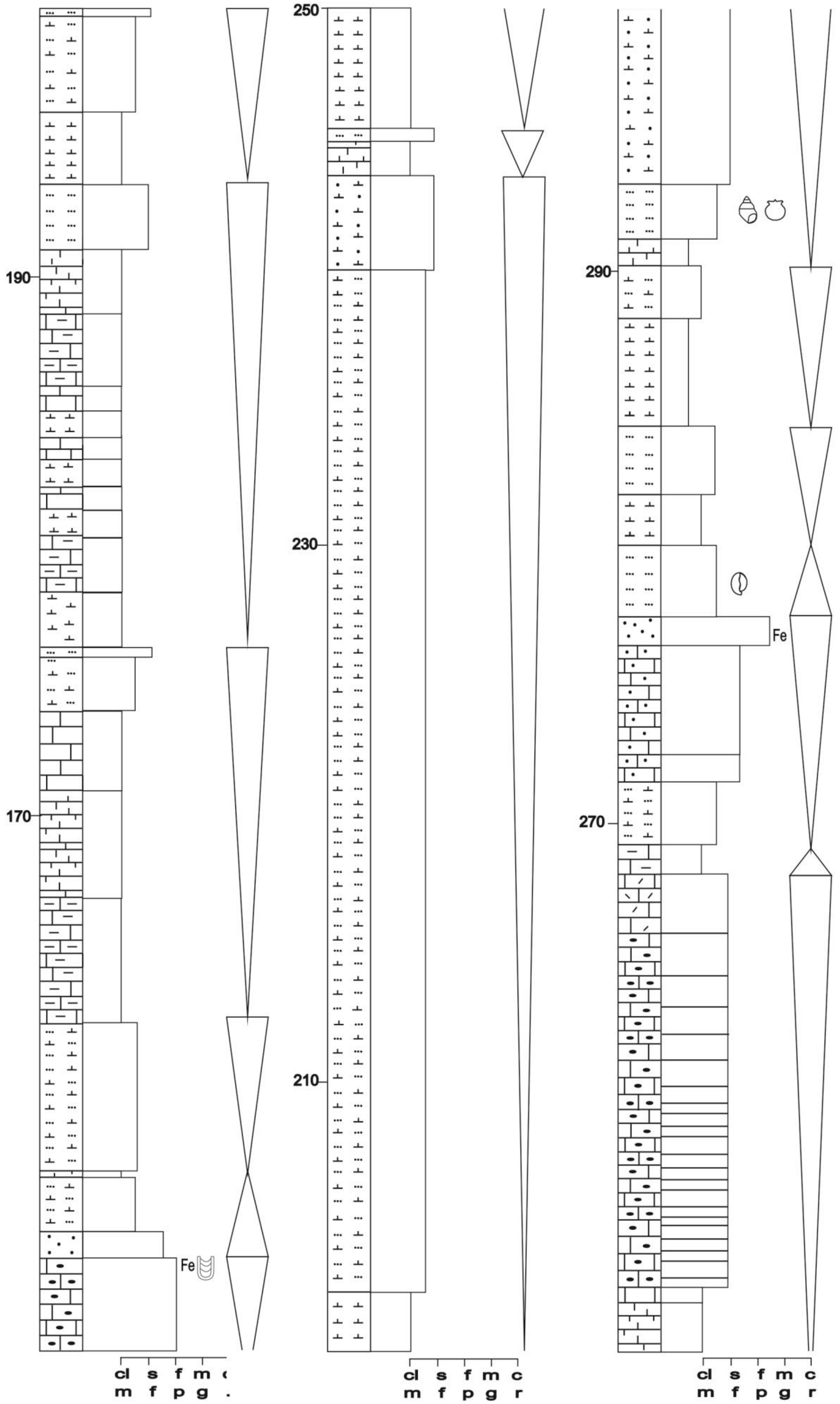
3. Section of G. Engabashi

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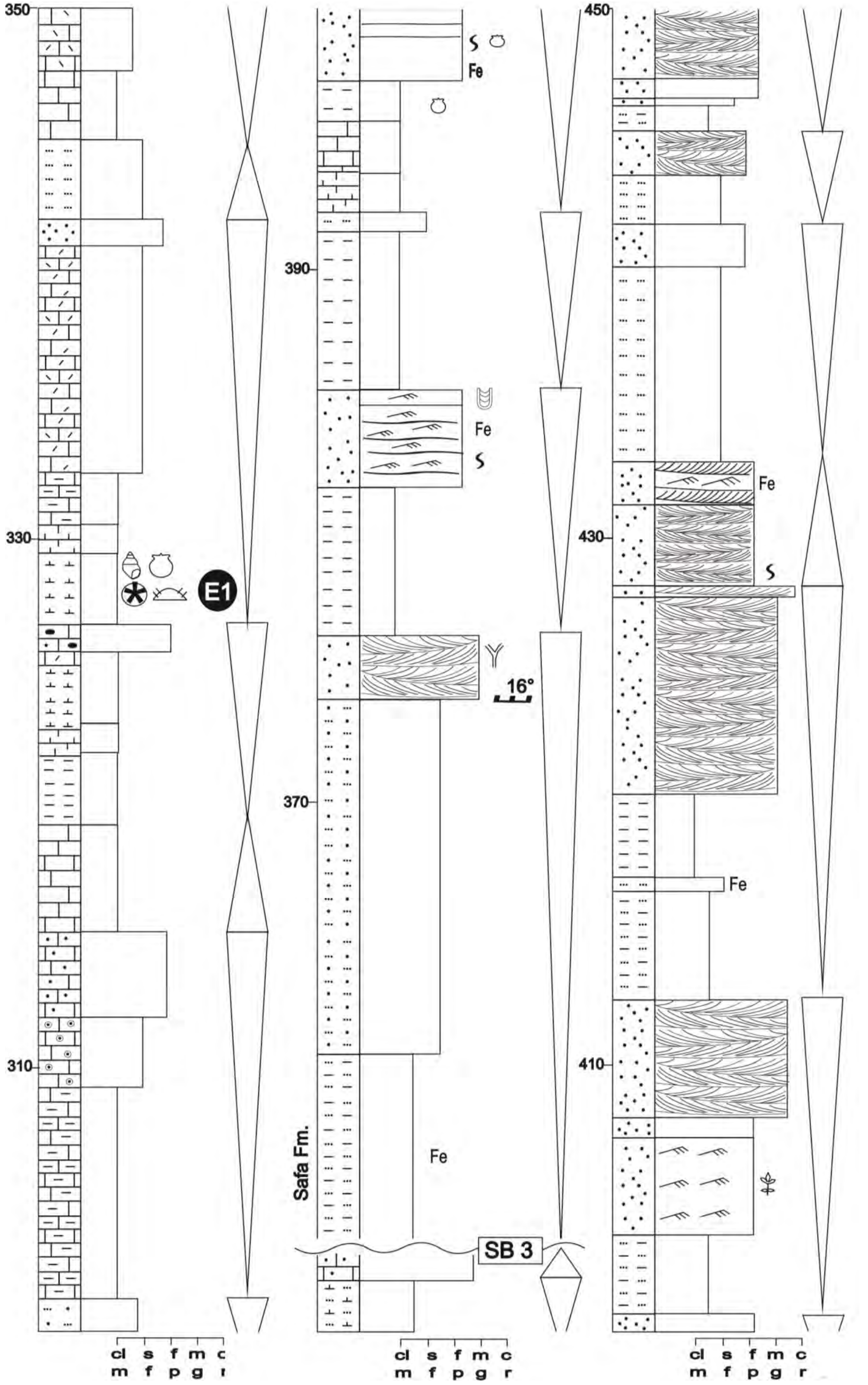
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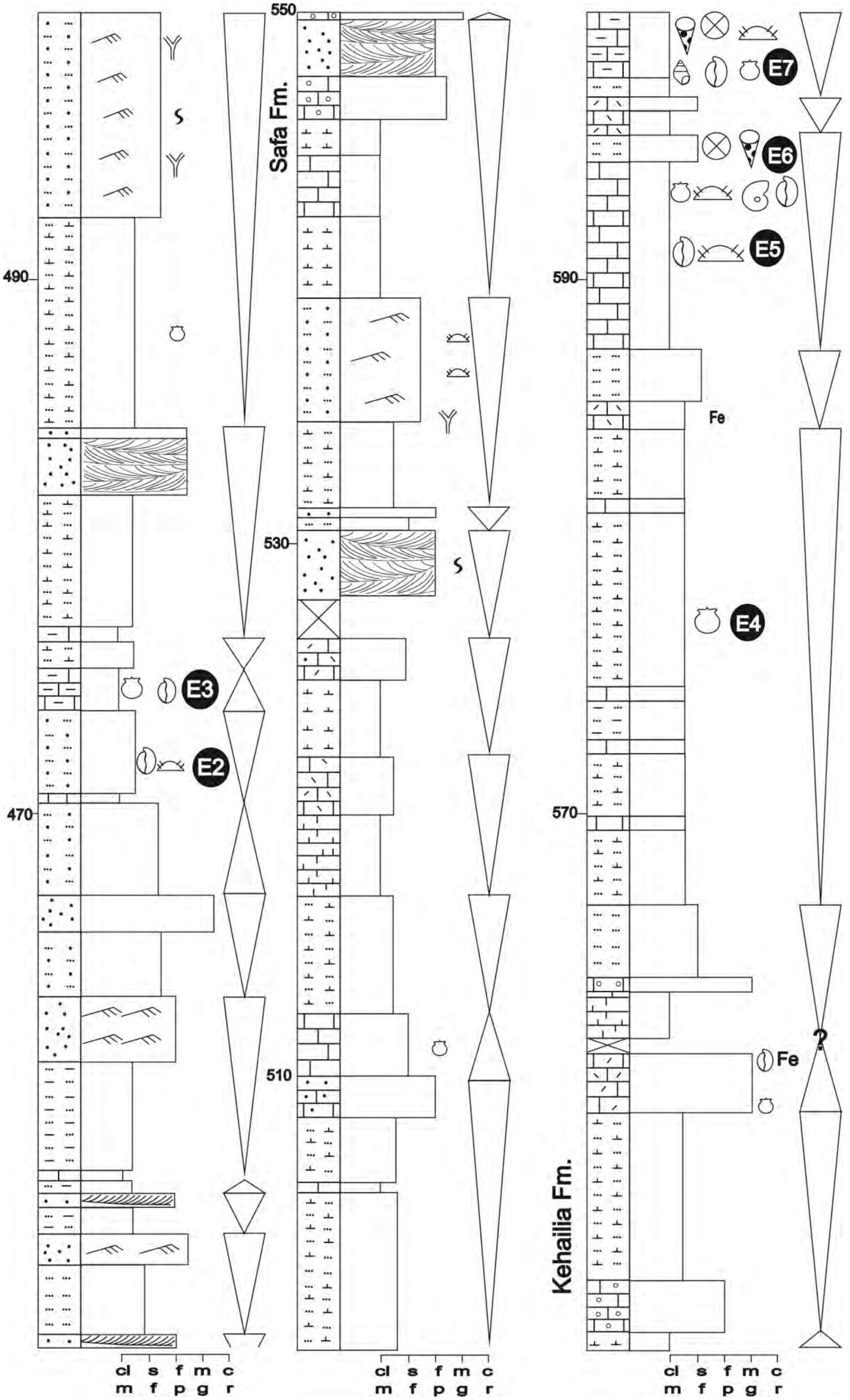
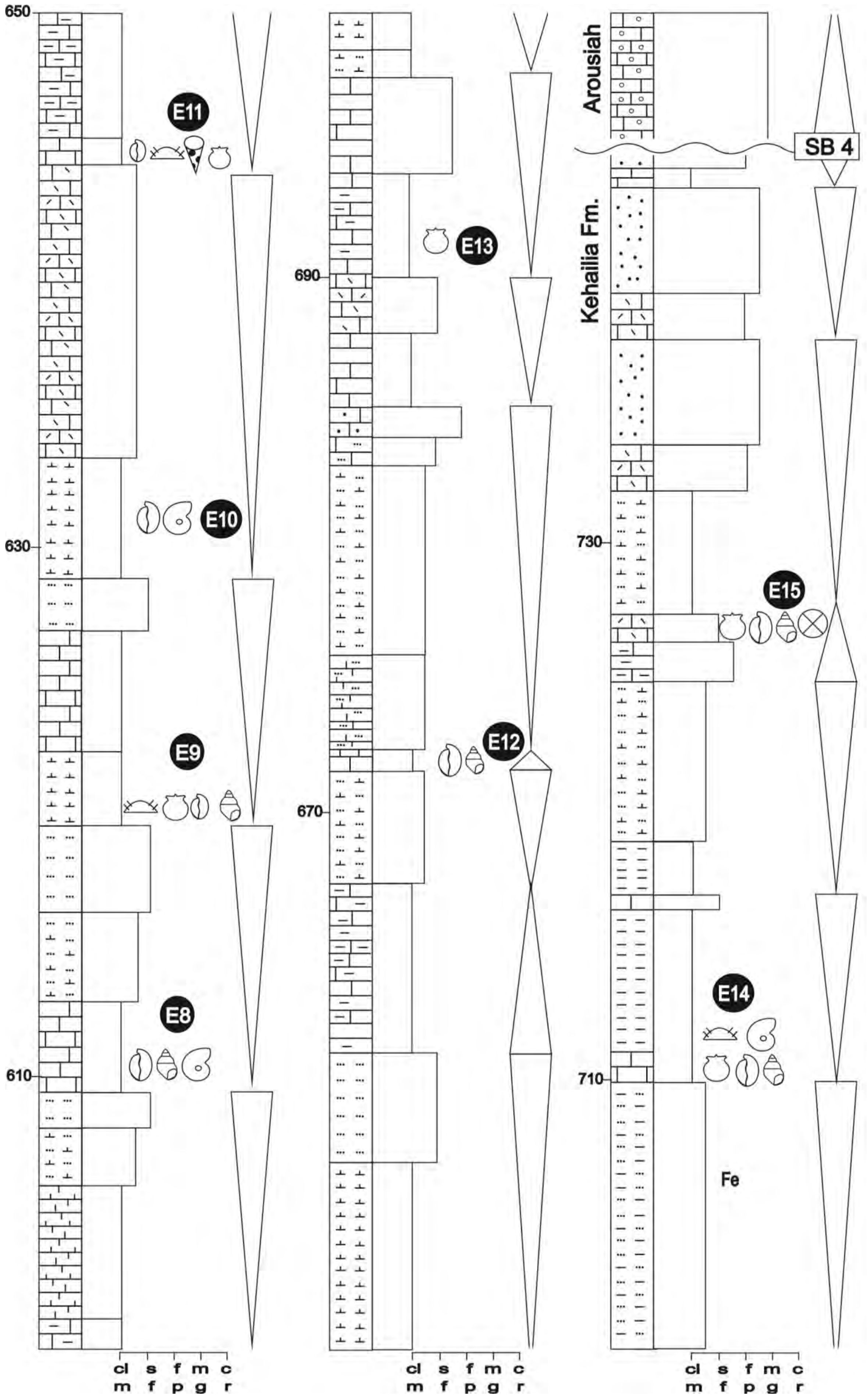

490
470
550
Safa Fm.
530
510
590
570
Kehailia Fm.
E2
E3
E4
E5
E6
E7
Fe
Fe
?
cl s f m c
m f p g r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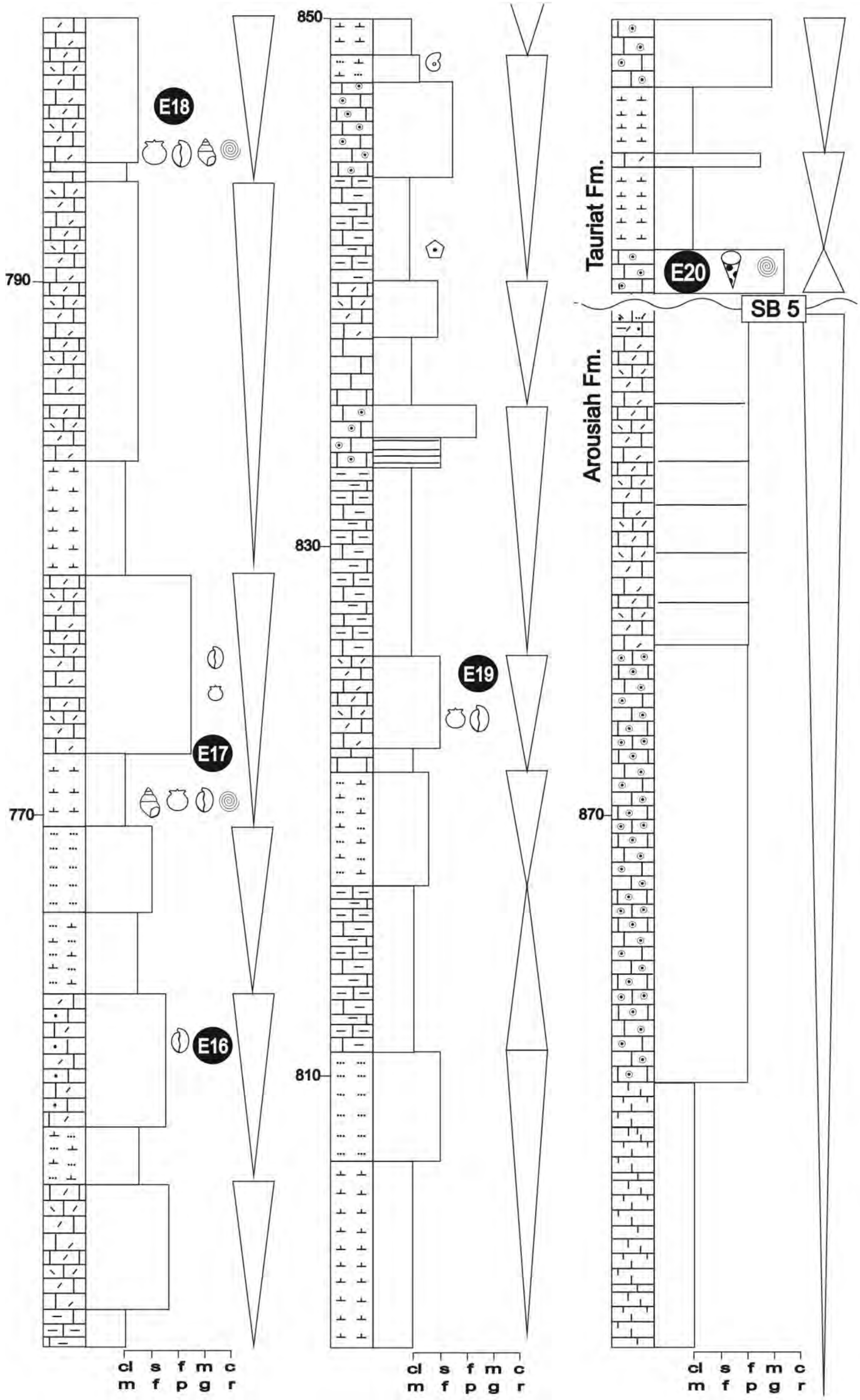
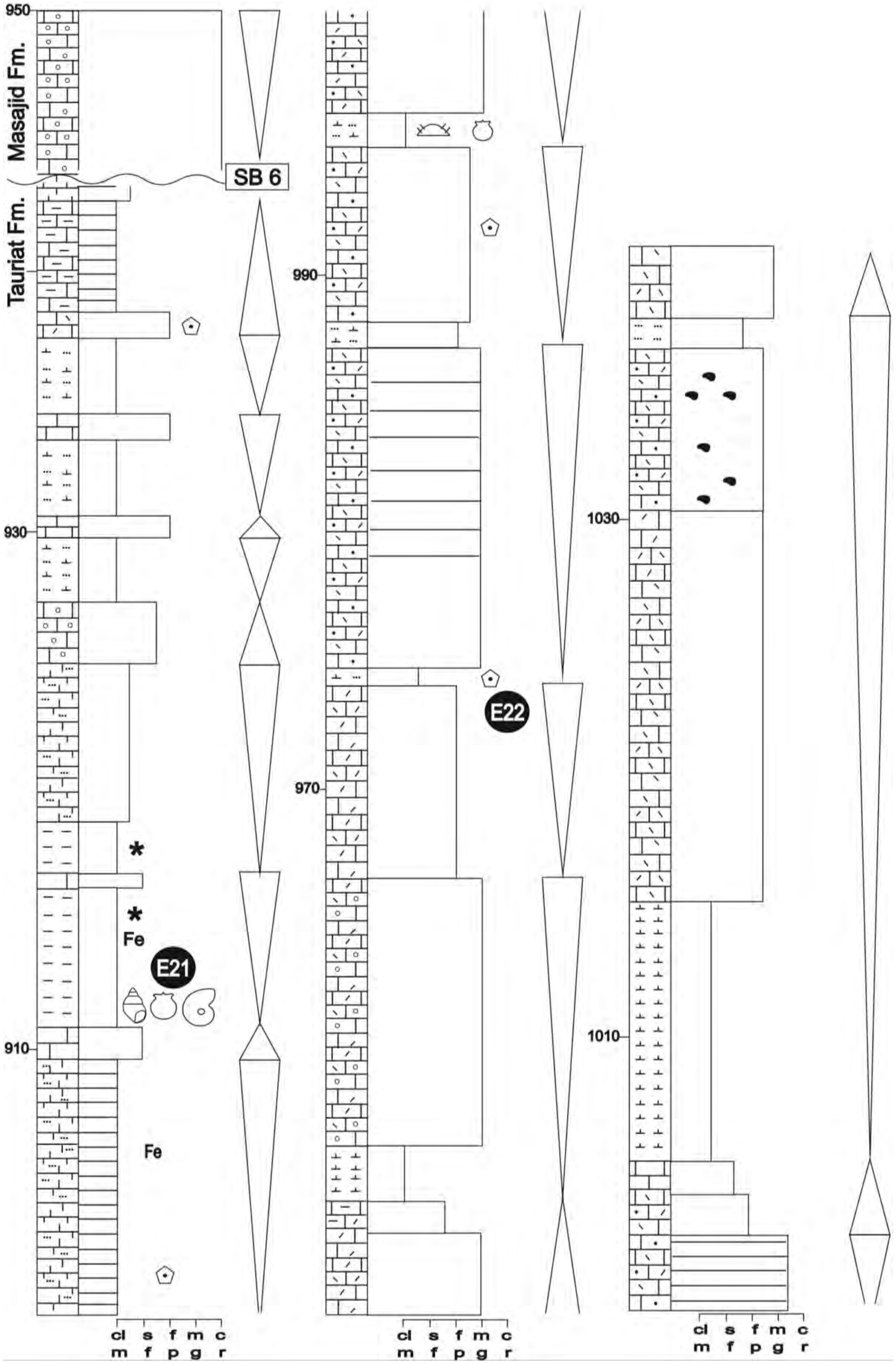
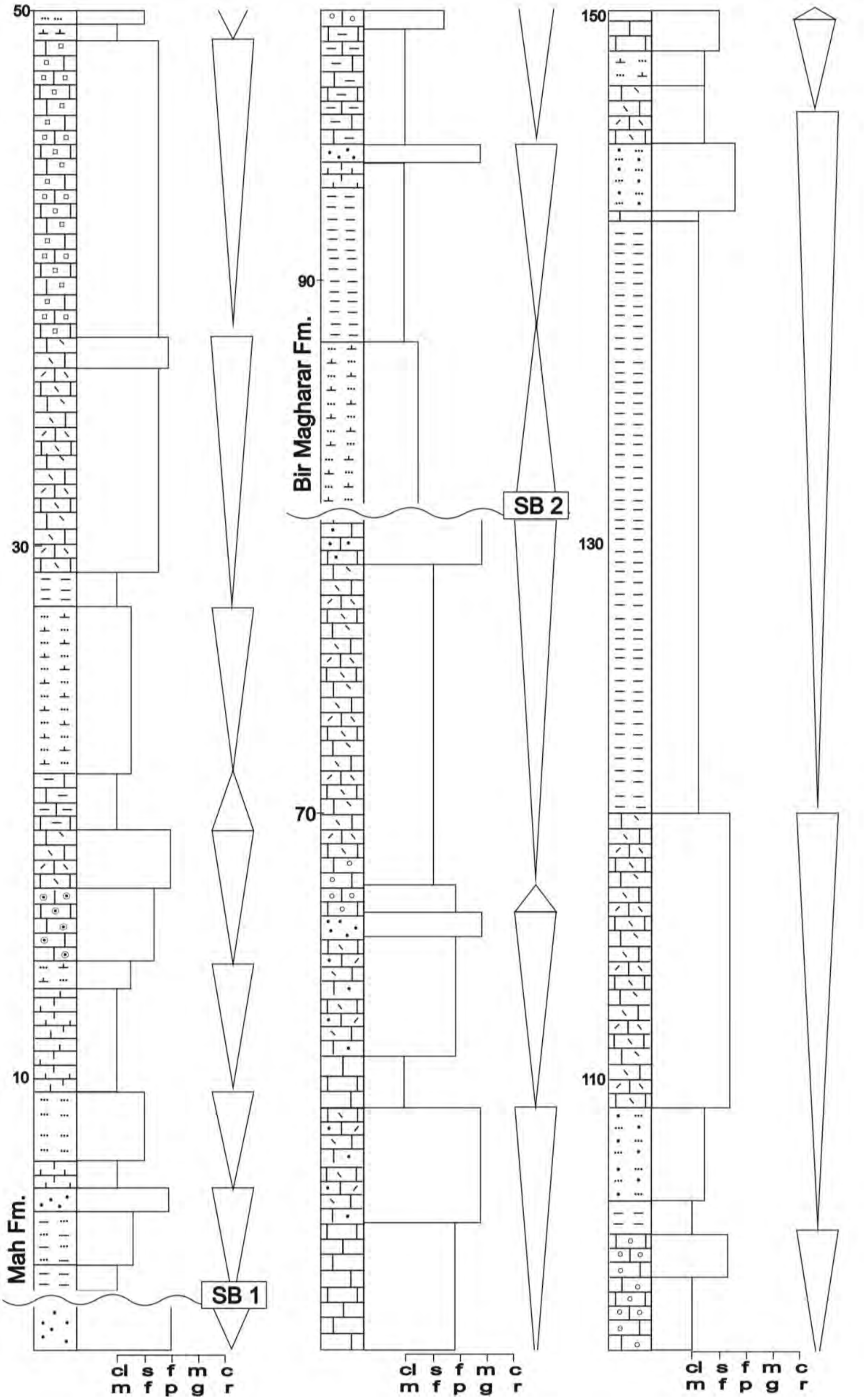
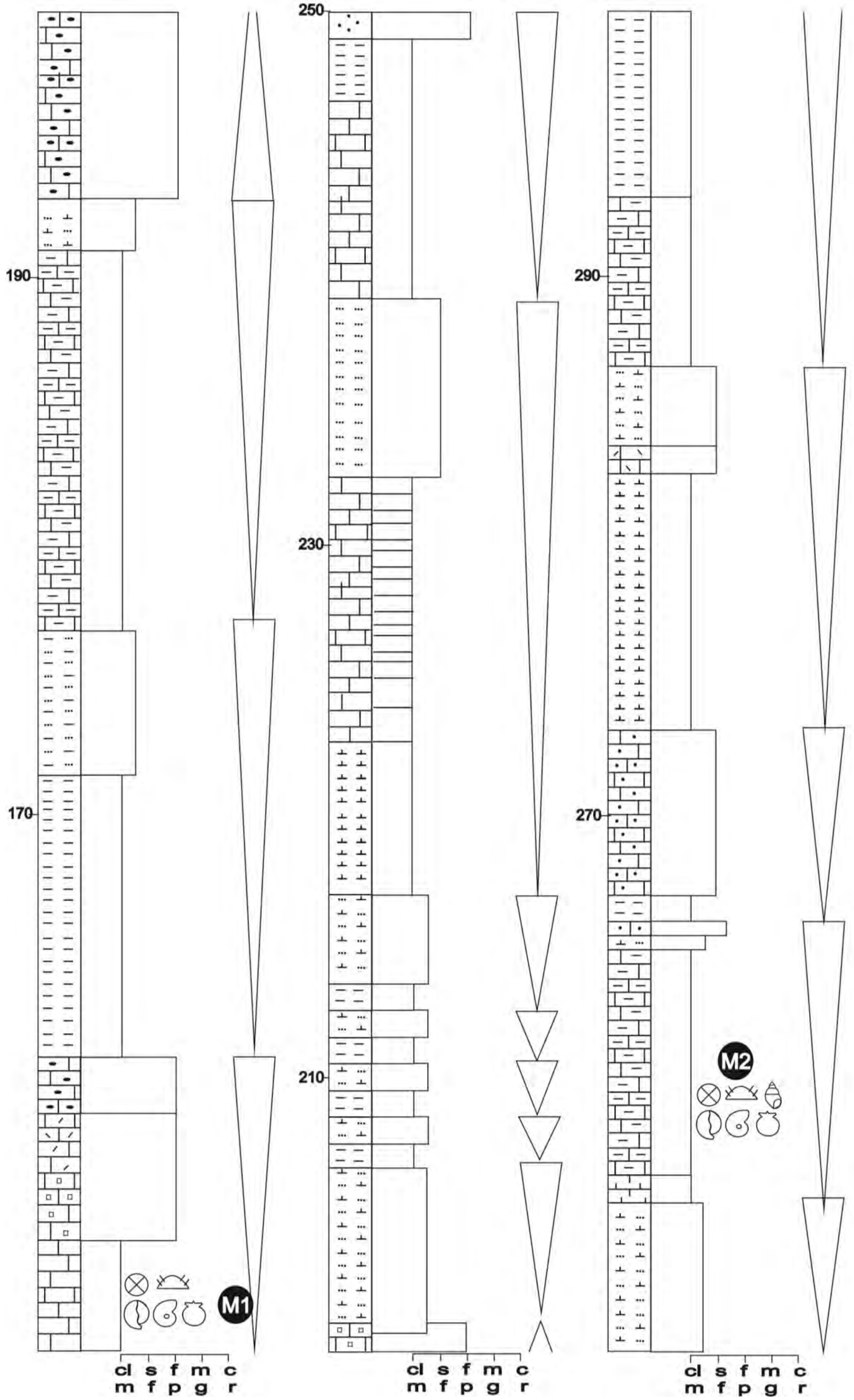
E11
630
E10
E9
E8
610
cl s f m c
m f p g r
E13
690
E12
670
cl s f m c
m f p g r
Arousiah
SB 4
Kehailia Fm.
730
E15
E14
710
Fe
cl s f m c
m f p g r

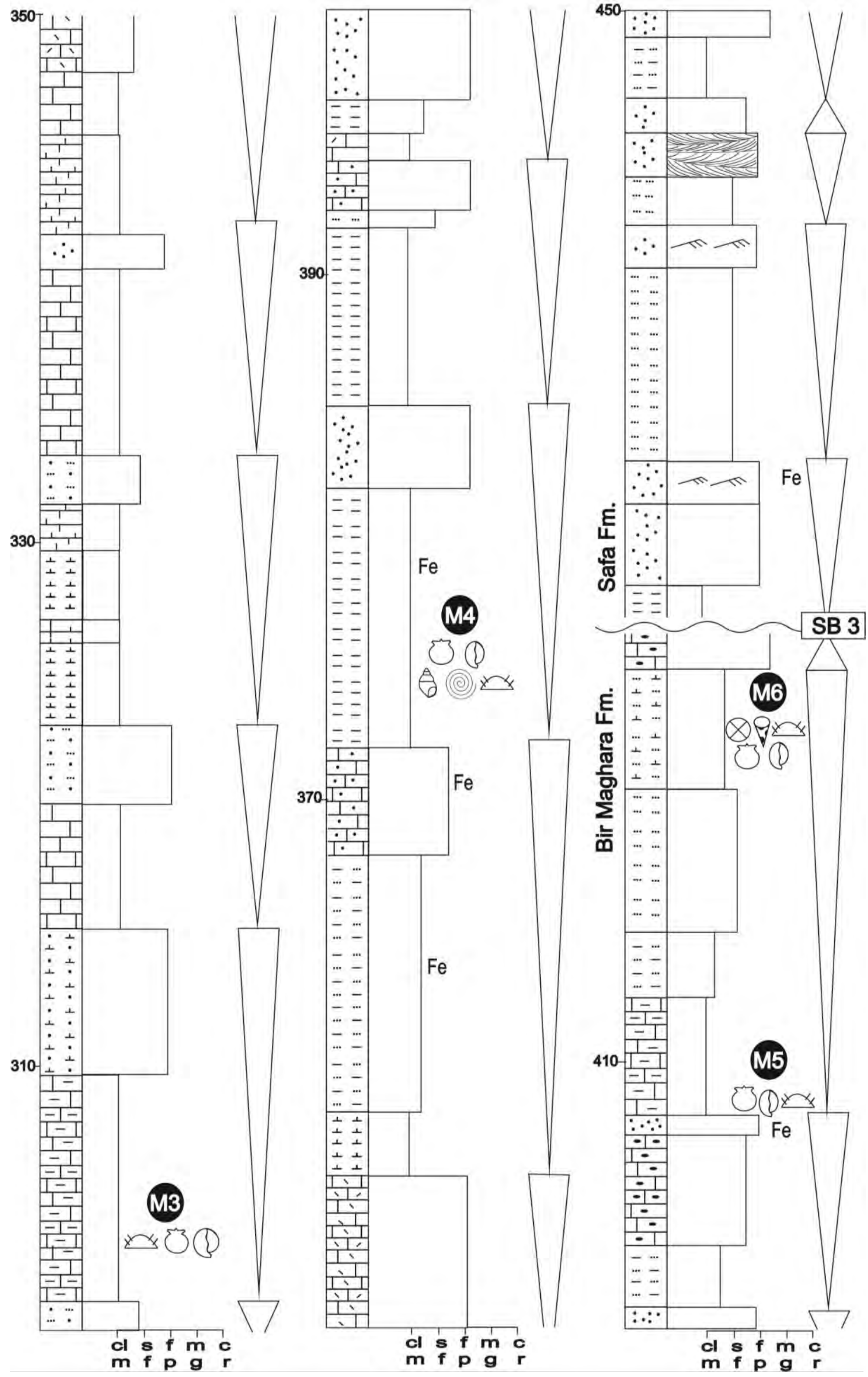

E18
790
E17
770
E16
850
830
E19
810
Tauriat Fm.
E20
SB 5
Arousiah Fm.
870
cl s f m c
m f p g r
cl s f m c
m f p g r
cl s f m c
m f p g r

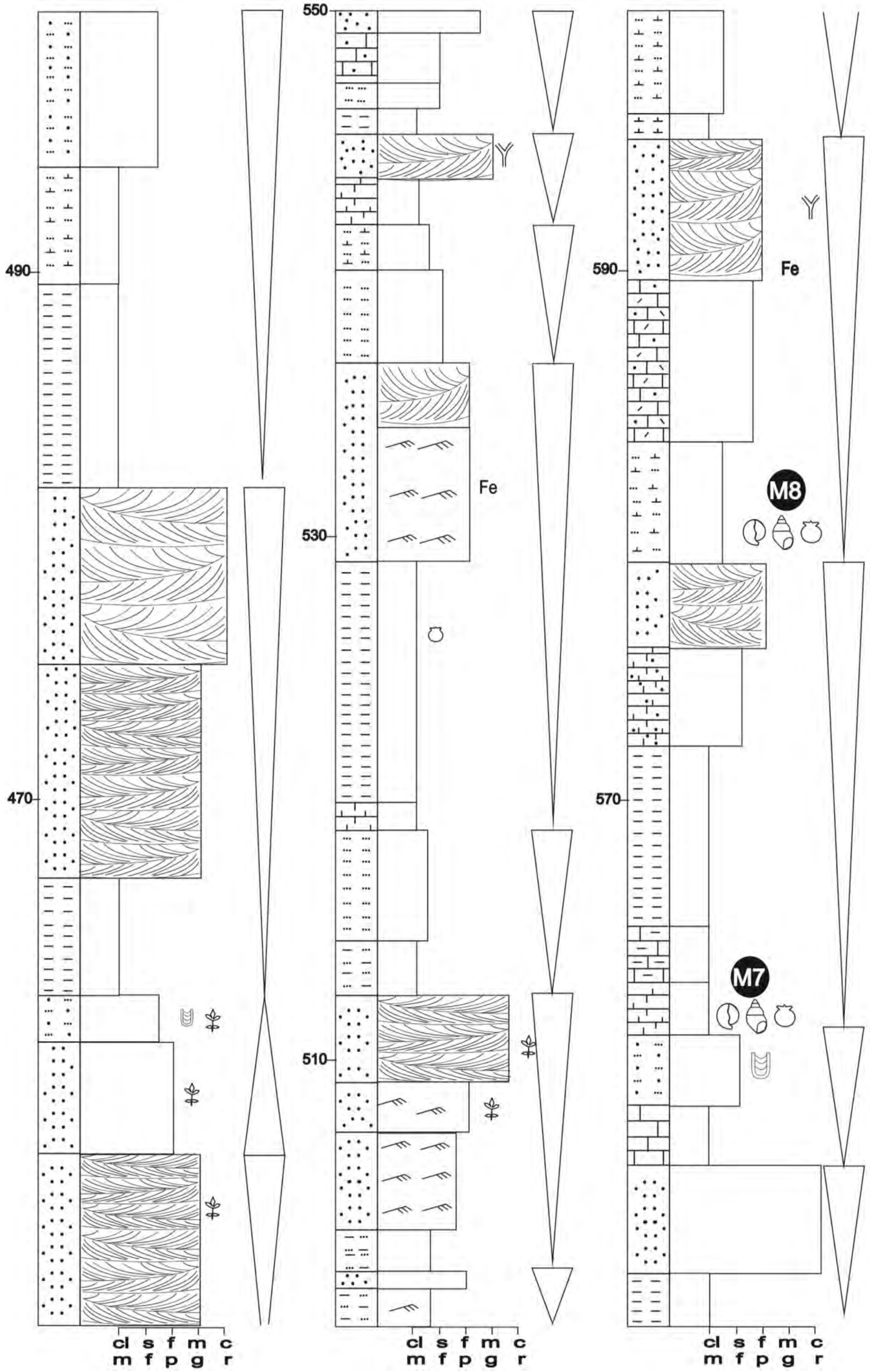

950
Masajid Fm.
SB 6
Tauriat Fm.
930
*
*
Fe
E21
910
Fe
cl s f m c
m f p g r
990
E22
970
cl s f m c
m f p g r
1030
1010
cl s f m c
m f p g r

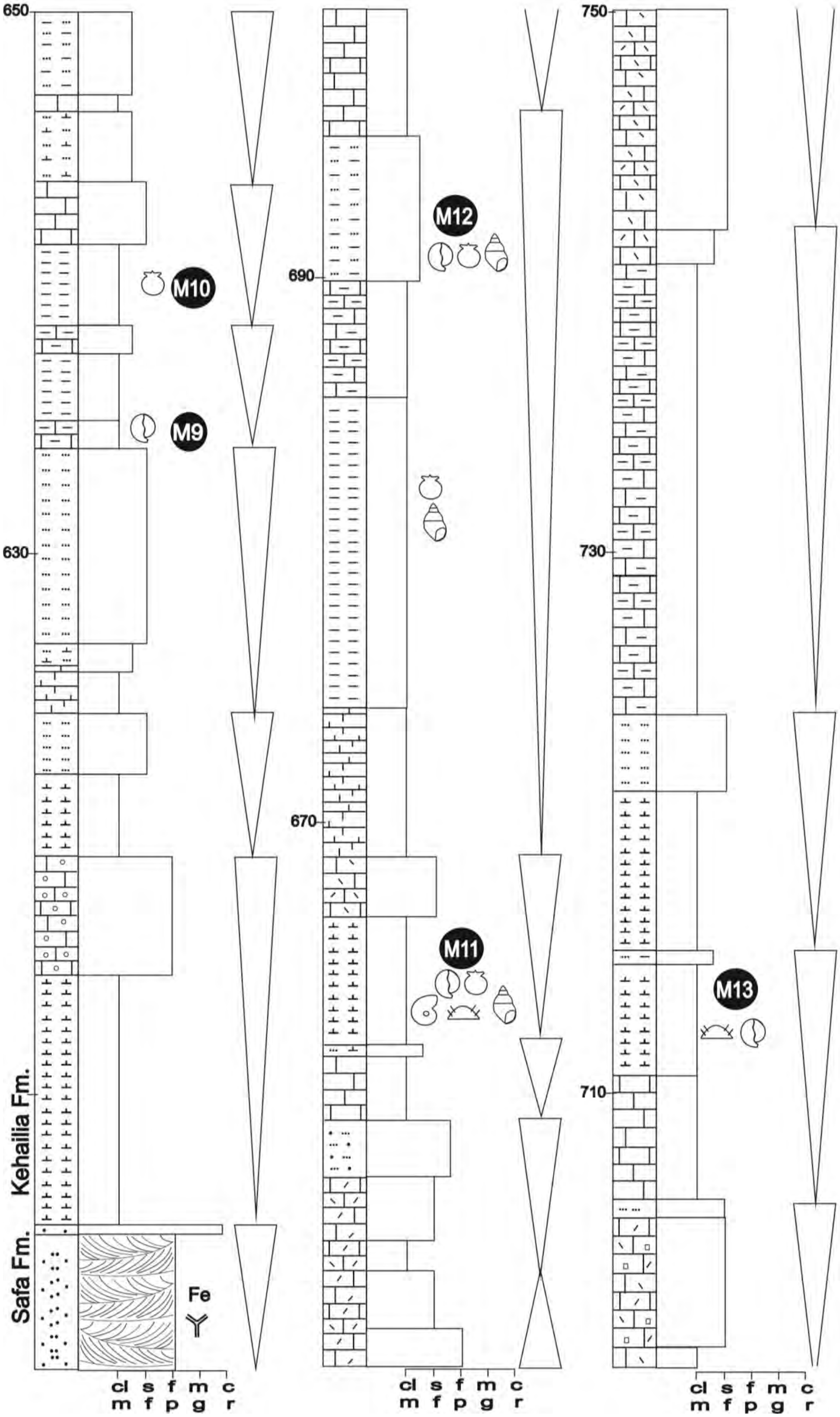
4. Section of G. Mowerib

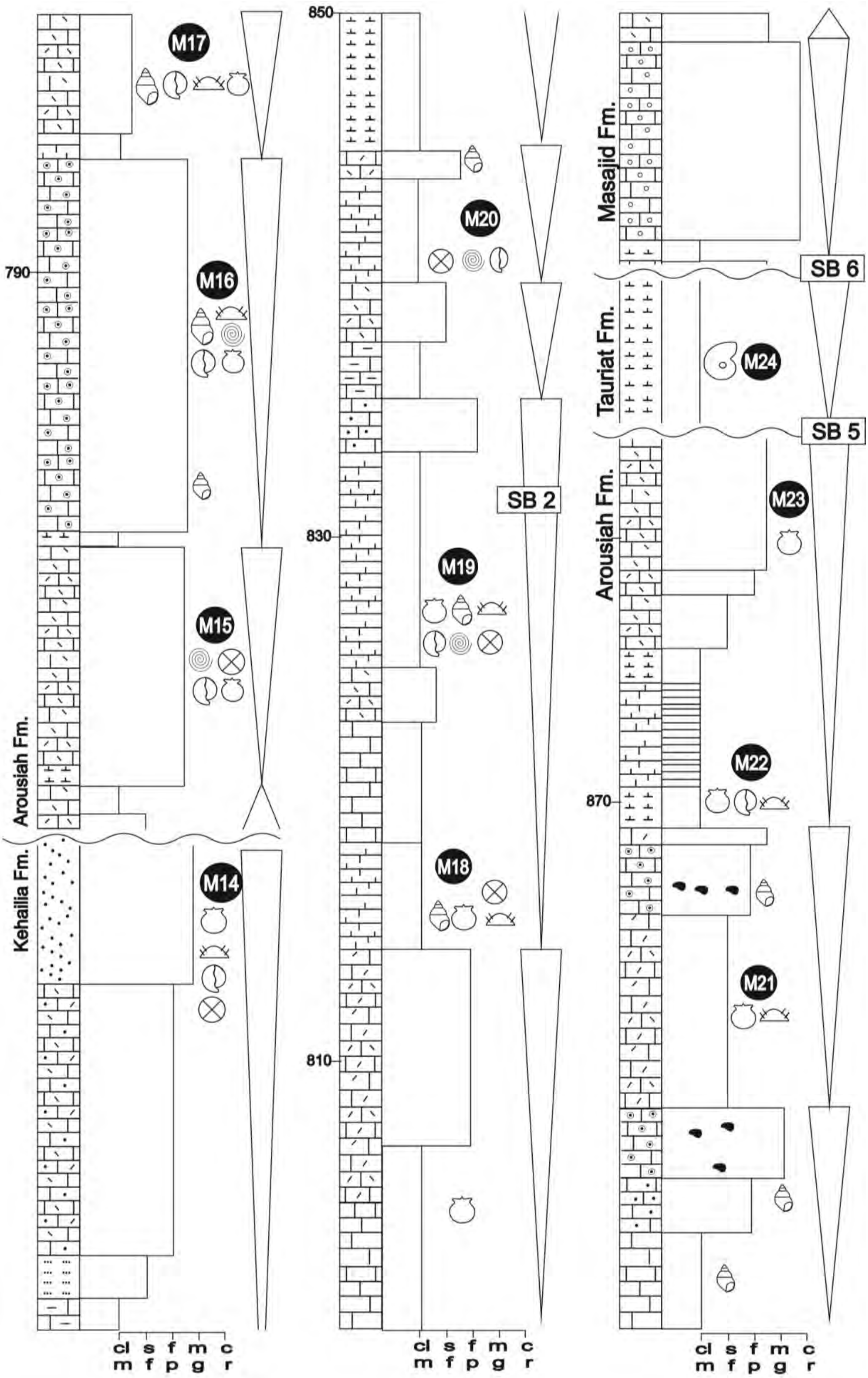


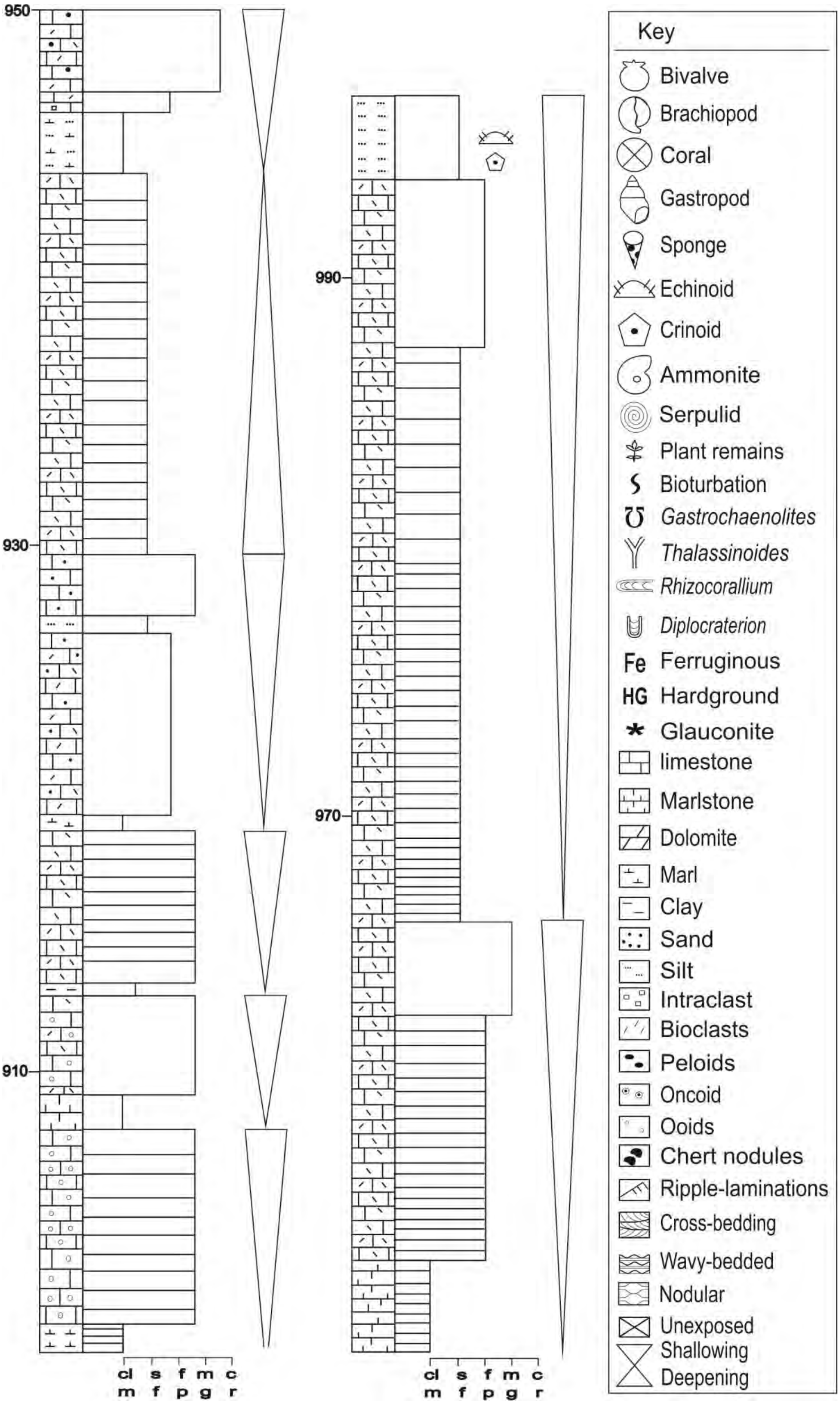

250
190
170
M1
cl s f m c
m f p g r
230
210
cl s f m c
m f p g r
290
270
M2
cl s f m c
m f p g r


350
330
310
cl s f m c
m f p g r
M3
390
370
Fe
M4
Fe
Fe
cl s f m c
m f p g r
450
410
Safa Fm.
Bir Maghara Fm.
SB 3
Fe
M6
M5
Fe
cl s f m c
m f p g r


490
470
550
530
510
Fe
590
570
Fe
M8
M7
cl s f m c
m f p g r
cl s f m c
m f p g r
cl s f m c
m f p g r


650
630
M10
M9
Kehailia Fm.
Safa Fm.
Fe
cl s f m c
m f p g r
690
670
M12
M11
cl s f m c
m f p g r
750
730
710
M13
cl s f m c
m f p g r


M17
M16
790
M15
Arousiah Fm.
Kehailia Fm.
M14
cl s f m c
m f p g r
850
M20
SB 2
830
M19
M18
810
cl s f m c
m f p g r
Masajid Fm.
SB 6
Tauriat Fm.
M24
SB 5
Arousiah Fm.
M23
M22
870
M21
cl s f m c
m f p g r


950
930
910
990
970
cl s f m c
m f p g r
cl s f m c
m f p g r
Key
Bivalve
Brachiopod
Coral
Gastropod
Sponge
Echinoid
Crinoid
Ammonite
Serpulid
Plant remains
Bioturbation
Gastrochaenolites
Thalassinoides
Rhizocorallium
Diplocraterion
Fe Ferruginous
HG Hardground
* Glauconite
limestone
Marlstone
Dolomite
Marl
Clay
Sand
Silt
Intraclast
Bioclasts
Peloids
Oncoid
Ooids
Chert nodules
Ripple-laminations
Cross-bedding
Wavy-bedded
Nodular
Unexposed
Shallowing
Deepening

Appendix B: Faunal list (for abbreviations see Table 5.2, serial number of taxa will be used for the next appendices).

Sr.	Taxon	Class	Mode of life	Feeding mode	Shell composition	Mobility
1	*Acesta subantiquata* Adams 1858	B	EB	S	A	S
2	*Actinostreon erucum* (Deferance, 1821)	B	EC	S	C	S
3	*Actinostreon gregareum* (J. Sowerby, 1815)	B	EC	S	C	S
4	*Africogryphaea costellata* (Douvillé, 1916)	B	ER	S	C	S
5	*Anisocardia* sp.	B	IS	S	A	S
6	*Anisocardia (Antiquicyprina)* sp.	B	IS	S	A	S
7	*Arcomytilus laitmairensis* (de Loriol, 1883)	B	EB	S	A	S
8	*Awadia lepidomorpha* Abdallah & Fahmy, 1969	B	SI	S	A	S
9	*Bositra buchi* (Roemer, 1836)	B	ER	S	C	S
10	*Ceratomya wilderriensis* Cox, 1965	B	ID	S	A	S
11	*Ceratomyopsis arabica* (Cox,1935)	B	IS	S	A	S
12	*Ceratomyopsis rostrata* (Douvillé, 1916)	B	IS	S	A	S
13	*Ceratomyopsis somaliensis* (Weir, 1929)	B	IS	S	A	S
14	*Coelastarte praelonga* (Rollier, 1912)	B	EB	S	A	S
15	*Coelopis deshayesi* (Morris & Lycett, 1854)	B	IS	S	A	S
16	*Coelopis langruensis* Bigot, 1894	B	IS	S	A	S
17	*Corbulomima involuta* (Goldfuss, 1841)	B	IS	S	A	S
18	*Eligmus rollandi* (Douvillé, 1907)	B	EB	S	C	S
19	*Eopecten* sp.	B	EB	S	C	S
20	*Fimbria* sp.	B	IS	S	A	S
21	*Gervillella orientalis* (Douvillé, 1916)	B	SIB	S	A	S
22	*Grammatodon (Cosmetodon)* sp.	B	EB	S	A	S
23	*Grammatodon (G.) concinnus* (Phillips, 1829)	B	EB	S	A	S
24	*Grammatodon (Indogrammatodon*) *virgatus* (Sowerby, 1840)	B	EB	S	A	S
25	*Gryphaeligmus jabbokensis* (Cox, 1925)	B	ER	S	C	S
26	*Integricardium* sp.	B	IS	S	A	S
27	*Isocardia* sp.	B	I	S	A	S
28	*Limopsis* sp.	B	EB	S	A	S
29	*Liostrea ornati* Schäfle, 1929	B	EC	S	C	S
30	*Mactromya aequalis* Agassiz, 1843	B	IS	S	A	S
31	*Mesosaccella* sp.	B	I	D	A	M
32	*Modiolus (Modiolus) imbricatus* (J. Sowerby, 1818)	B	SIB	S	A	S
33	*Musculus (Musculus) somaliensis* (Cox, 1935)	B	EB	S	A	S
34	*Myophorella* sp. A	B	IS	S	A	S
35	*Nanogyra nana* (J. Sowerby, 1822)	B	EC	S	C	S

36	*Nicaniella (N.) pisiformis* J. de C. Sowerby, 1840	B	IS	S	A	S
37	Nuculoidea . n.sp.	B	IS	D	A	M
38	*Nuculoma variabilis* (J. de C. Sowerby, 1825)	B	IS	D	A	M
39	*Palaeonucula lateralis* (Terquem & Jourdy, 1869)	B	IS	D	A	M
40	*Paleaonucula tenuistriata* (J. de C. Sowerby, 1837)	B	IS	D	A	M
41	*Pholadomya (B.) lirata* (J. de C. Sowerby, 1818)	B	ID	S	A	S
42	*Pholadomya (P.) inornata* (J. de C. Sowerby, 1837)	B	ID	S	A	S
43	*Pinna* sp.	B	SIB	S	A/C	S
44	*Pleuromya varians* Agassiz, 1845	B	ID	S	A	S
45	*Praesaccella* sp.	B	IS	D	A	M
46	*Pronoella (Pronella) loweana* (Morris & Lycott, 1853)	B	IS	S	A	S
47	*Prorokia* sp.	B	EB	S	A	S
48	*Protocardia (P.) africana* (Cox, 1965)	B	EB	S	A	S
49	*Pseudolimea duplicata* (J. de C. Sowerby, 1827)	B	EB	S	A	S
50	*Quenstedtia* sp.	B	EB	S	A	S
51	*Rollierella* sp	B	IS	S	A	S
52	*Rollieria* sp.	B	IS	D	A	M
53	*Ryderia decorata* (Douvillé, 1916)	B	IS	D	A	M
54	*Sphaera madagascariensis* Newton, 1889	B	IS	S	A	S
55	*Sphaeriola madridi* (d'Archiac, 1843)	B	IS	S	A	S
56	*Spondylopecten (Plesiopecten) palinurus* (d'Orbigny, 1850)	B	EB	S	C	S
57	*Spondylopecten (Spondylopecten) globosus* (Quenstedt, 1843)	B	EB	S	C	S
58	*Thracia viceliacensis* d'Orbigny, 1850	B	ID	S	A	S
59	*Trigonia costata* Parkinson, 1811	B	IS	S	A	S
60	*Amydroptichus formosus* Cooper, 1989	B	EB	S	C	S
61	*Apaticosia* cf. *inornata* Cooper, 1989	BR	EB	S	C	S
62	*Avonothyris* sp.	BR	EB	S	C	S
64	*Burmirhynchia (Hopkinsirhynchia) cavagnarii* (Diaz-Romero, 1931)	BR	EB	S	C	S
65	*Cererithyris* sp.	BR	EB	S	C	S
66	*Conarosia rotundata* Cooper, 1989	BR	EB	S	C	S
67	*Cooperithyris circularis* Feldman et al., 2012	BR	EB	S	C	S
68	*Cymatorhynchia quadriplicata* (Zeiten, 1830)	BR	EB	S	C	S
69	*Daghanirhynchia daghaniensis* Muir-Wood, 1935	BR	EB	S	C	S
70	*Daghanirhynchia angulocostata* Cooper, 1989	BR	EB	S	C	S
71	*Ectyphoria sinaiensis* Feldman et al., 2012	BR	EB	S	C	S
72	*Eudesia multicostata* Tintant, 1963	BR	EB	S	C	S
73	*Eurysites rotundus* Cooper, 1989	BR	EB	S	C	S
74	*Juralina* sp.	BR	EB	S	C	S
75	*Kutchithyris landeri* Feldman et al., 2001	BR	EB	S	C	S
76	*Kutchithyris parnesi* Feldman et al., 1991	BR	EB	S	C	S
77	*Plectoidothyris* sp.	BR	EB	S	C	S
78	*Pycnoria magna* Cooper, 1989	BR	EB	S	C	S
79	*Schizoria elongata* Cooper, 1989	BR	EB	S	C	S
80	*Schizoria intermedia* Cooper, 1989	BR	EB	S	C	S

81	*Septirhynchia* sp.	BR	EB	S	C	S
82	*Somalirhynchia africana* Muir-Wood, 1935	BR	EB	S	C	S
83	*Somalirhynchia bihenensis* Muir-Wood, 1935	BR	EB	S	C	S
84	*Sphaeroidothyris sphaeroidalis* Cooper, 1989	BR	EB	S	C	S
85	*Eudesia (Sphriganaria) cardioides* (Douvillé, 1916)	BR	EB	S	C	S
86	*Eudesia (Sphriganaria) lirata* Cooper, 1989	BR	EB	S	C	S
87	*Staphrothyris* sp.	BR	EB	S	C	S
88	Terebratulid indet.	BR	EB	S	C	S
89	*Trigonithyris* sp.	BR	EB	S	C	S
90	*Acteonina (Strioacteonina)* sp.	G	IS	O	A	M
91	*Amphitrochus duplicatus* (J. Sowerby, 1817)	G	E	O	A	M
92	*Amphitrochus magharensis* Douvillé, 1916	G	E	O	A	M
93	*Amphitrochus zenobius* (d'Orbigny, 1853)	G	E	O	A	M
94	*Ampullospira* sp.	G	IS	O	A	M
95	*Ampullospira zelema* (d'Orbigny, 1852)	G	IS	O	A	M
96	*Aptyxiella* sp.	G	SI	O	A	M
97	*Ataphrus (Ataphrus) asiaticus* Douvillé, 1916	G	E	O	A	M
98	*Ataphrus (Ataphrus) belus* (d'Orbigny, 1853)	G	E	O	A	M
99	*Bathrotomaria eudora* d'Orbigny, 1850	G	E	H	A	M
100	*Bourguetia*?	G	E	O	A	M
101	*Brachytrema* sp.	G	E	O	A	M
102	*Colpomphalus costatus* (Douvillé, 1916)	G	E	O	A	M
103	*Delphinula* sp.	G	E	O	A	M
104	*Diatinostoma* sp.	G	E	O	A	M
105	*Dicroloma armata* (Morris & Lycett, 1851)	G	IS	O	A	M
106	*Dicroloma quadrifunis* Cossmann, 1925	G	SI	C	A	M
107	*Dicroloma tumida* (Laube, 1868)	G	IS	O	A	M
108	*Discohelix elegantula* Douvillé, 1916	G	E	H	A	M
109	*Eunerinea (Cossmannea) juliae* (Hirsch, 1980)	G	SI	O	A	M
110	*Exelissa solitudimus* Douvillé, 1916	G	E	O	A	M
111	Gastropod indet.	G	E	O	A	M
112	*Globularia coxi* (Stefanini, 1939)	G	E	O	A	M
113	*Goniocylindrites deserti* (Douvillé, 1916)	G	E	O	A	M
114	*Harpagodes* cf. *thirriae* (Contejean, 1860)	G	IS	O	A	M
115	*Lepidotrochus* sp.	G	E	O	A	M
116	*"Nerinea" praespeciosa* Cossmann, 1885	G	SI	O	A	M
117	*Nerinella acicula* d'Archiac, 1843	G	SI	O	A	M
118	*Nerinella*? sp.	G	SI	O	A	M
119	Nerineidae sp.	G	SI	O	A	M
120	*Neritodomus punctatus* (Piette, 1855)	G	E	O	A	M
121	*Neritopsis* sp.	G	E	O	A	M
122	*Obornella* sp.	G	E	H	A	M
123	*Ovacteonina custodiorum* Cox, 1969	G	E	O	A	M
124	*Phyllocheilus pictaviensis* (d'Orbigny, 1850)	G	E	O	A	M

125	*Pleurotomaria armata* (Munster, 1848)	G	E	H	A	M
126	*Pleurotomaria* sp.	G	E	H	A	M
127	Pleurotomariid sp.	G	E	H	A	M
128	*Procerithium (Cosmocerithium) evanescens* Cossmann, 1925	G	E	O	A	M
129	*Procerithium (Cosmocerithium) tenerum* Parnes, 1981	G	E	O	A	M
130	*Procerithium (Procerithium) deserti* (Douvillé, 1916)	G	E	O	A	M
131	*Proconulus (Proconulus) bhujensis* Jaitly, Szabó & Fürsich, 2000	*G*	*E*	*O*	*A*	*M*
132	*Proconulus (Proconulus*) sp.	G	E	O	A	M
133	*Pseudomelania (Oonia) saharica* Cox, 1969	G	E	O	A	M
134	*Pseudomelania scarburgensis* (Morris & Lycett, 1851)	G	IS	O	A	M
135	*Purpuroidea deserti* Cossmann,1925	G	E	O	A	M
136	*Purpuroidea perstriata* (Cossmann, 1925)	G	E	O	A	M
137	*Purpuroidea* sp.	G	E	O	A	M
138	*Terebrella laevis* Douvillé, 1916	G	IS	D	A	M
139	*Trochalia*? Sp.	G	E	O	A	M
140	*Trochotomaria* sp.	G	E	O	A	M
141	*Zygopleura tunisiensis* Cox, 1969	G	E	S	A	M
142	*Aligaticeras* sp.	A	N	C	A	M
143	*Belemnopsis hastatus* (d'Orbigny, 1842)?	A	N	C	A	M
144	*Cadomitus (C.) psilacanthus* (Wermbter, 1891)	A	N	C	A	M
145	*Ermoceras (E.) coronatoides* (Douvillé, 1916)	A	N	C	A	M
146	*Ermoceras (E.) mogharense* (Douvillé, 1916)	A	N	C	A	M
147	*Ermoceras (Kosmermoceras) magnificum* Arkell et al., 1952	A	N	C	A	M
148	*Ermoceras (Kosmermoceras) runcinatum* Arkell et al., 1952	A	N	C	A	M
149	*Ermoceras (Kosmermoceras) strigatum* Arkell et al., 1952	A	N	C	A	M
150	*Ermoceras* sp.	A	N	C	A	M
151	*Erymnoceras philbyi* Arkell et al., 1952	A	N	C	A	M
152	*Euaspidoceras babeaui* (d'Orbigny, 1847)	A	N	C	A	M
153	*Garantiana* (*Garantiana*) sp.	A	N	C	A	M
154	*Leptosphinctes (Prososphinctes)* sp.	A	N	C	A	M
155	*Asphinctes tenuiplicatus* (Brauns, 1865)	A	N	C	A	M
156	*Lissoceras ooliticum* (d'Orbigny, 1845	A	N	C	A	M
157	*Lissoceratoides* sp.	A	N	C	A	M
158	*Lytoceras strambergensis* Oppel, 1865	A	N	C	A	M
159	*Magharina magharensis* Arkell et al., 1952	A	N	C	A	M
160	*Clydomphalites clydocromphalus* (Arkell et al., 1952)	A	N	C	A	M
161	*Micromphalites pustuliferus* (Douvillé, 1916)	A	N	C	A	M
162	*Nautilus giganteus* d'Orbigny, 1842	A	N	C	A	M
163	*Nautilus* sp.	A	N	C	A	M
164	*Normannites egyptiacus* Arkell et al., 1952	A	N	C	A	M
165	*Normannites flexus* Westermann, 1954	A	N	C	A	M
166	*Pachyceras lalandeanum* (d’Orbigny, 1847)	A	N	C	A	M
167	*Perisphinctes varicostatus* (Buckland, 1836)	A	N	C	A	M
168	*Phylloceras kudernatschi* (Hauer, 1905)	A	N	C	A	M

169	*Phylloceras plicatum* Neumayr, 1887	A	N	C	A	M
170	*Phyllopachyceras? ebrayi* (de Ferry, 1861)	A	N	C	A	M
171	*Sowerbyceras tietzei* (Till, 1915)	A	N	C	A	M
172	*Spiroceras bifurcatum* (Quenstedt, 1858)	A	E	O	A	M
173	*Strigoceras (S.) strigifer* (Buckman, 1924)	A	N	C	A	M
174	*Strungia arabica* Arkell et al., 1952	A	N	C	A	M
175	*Thamboceras mirium* Douvillé, 1916	A	N	C	A	M
176	*Acrosalenia arabica* Kier, 1972	E	E	O	HMC	M
177	*Balanocidaris* sp.	E	E	O	HMC	M
178	*Bothryopneustes lamberti* Fourtau, 1924	E	I	O	HMC	M
179	*Bothryopneustes* sp.	E	I	O	HMC	M
180	*Eosalinea* sp.	E	E	O	HMC	M
181	*Heterosalenia* sp.	E	E	O	HMC	M
182	*Holectypus* sp.	E	IS	D	HMC	M
183	*Nucleolites*? sp.	E	IS	D	HMC	M
184	*Plegiocidaris* sp.	E	E	O	HMC	M
185	*Polycidaris* sp.	E	E	O	HMC	M
186	*Rhabdocidaris copoides* Agassiz, 1856	E	E	O	HMC	M
187	Crinoid sp. 1	Cri	E	O	HMC	M
188	Crinoid sp. 2	Cri	E	O	HMC	M
189	*Isocrinus* sp.	Cri	EC	O	HMC	S
190	*Millericrinus echinatus* Schlotheim, 1820	Cri	EC	O	HMC	S
191	*Millericrinus goubili* d'Orbigny, 1839	Cri	EC	S	HMC	S
192	*Axosmilia aegyptiaca?* Alloiteau & Farag, 1964	Cor	E	MC	A	S
193	*Actinastrea* sp.	Cor	EC	MC	A	S
194	*Chomatoseris epithecalis* Alloiteau & Farag, 1964	Cor	E	MC	A	S
195	*Chomoseris parameandrinoides* Alloiteau & Farag, 1964	Cor	E	MC	A	S
196	*Cladophylliopsis alternicosta* (Koby, 1906)	Cor	E	MC	A	S
197	*Codonosmilia elegans* Koby, 1888	Cor	E	MC	A	S
198	*Coenastrea arabica* El-Sa'ad, 1991	Cor	E	MC	A	S
199	*Collignonastrea jumarensis* (Gregory, 1900)	Cor	E	MC	A	S
200	*Dendraria?* sp.	Cor	E	MC	A	S
201	*Dermosmilia*? sp.	Cor	E	MC	A	S
202	*Epistreptophyllum* sp.	Cor	E	MC	A	S
203	*Gyrodendron* sp.	Cor	E	MC	A	S
204	*Isastrea parva* Gregory, 1900	Cor	E	MC	A	S
205	*Kobyastrea lomontiana* (Étallon, 1864)	Cor	E	MC	A	S
206	*Microphylliopsis* sp.	Cor	E	MC	A	S
207	*Microsolena areshensis* Alloiteau & Farag, 1964	Cor	E	MC	A	S
208	*Montlivaltia engebashi* Alloiteau & Farag, 1964	Cor	E	MC	A	S
209	*Montlivaltia magharica* Alloiteau & Farag, 1964	Cor	E	MC	A	S
210	*Montlivaltia shoushaensis* Alloiteau & Farag, 1964	Cor	E	MC	A	S
211	*Montlivaltia tenuicylindrata* Alloiteau & Farag, 1964	Cor	E	MC	A	S
212	*Myriophyllia* sp.	Cor	E	MC	A	S

213	*Stylina knetchi* Alloiteau & Farag, 1964	Cor	E	MC	A	S
214	*Stylina paramicromata* Alloiteau & Farag, 1964	Cor	E	MC	A	S
215	*Thamnasteria aneizahensis* Alloiteau & Farag, 1964	Cor	E	MC	A	S
216	*Thamnasteria delemontana* (Koby, 1887)	Cor	E	MC	A	S
217	*Thamnasteria libra* Alloiteau & Farag, 1964	Cor	E	MC	A	S
218	*Trigerastrea serialis* (Milne-Edwards & Haime, 1851)	Cor	E	MC	A	S
219	*Trochoplegma tenuilamellosa* Gregory, 1900	Cor	E	MC	A	S
220	*Cycloserpula* sp. A	S	EC	S	C	S
221	*Cycloserpula* sp. B	S	EC	S	C	S
222	*Dorsoserpula* sp.	S	EC	S	C	S
223	*Pentaserpula* sp.	S	EC	S	C	S
224	*Tetraserpula* sp.	S	EC	S	C	S
225	Chaetetid sponge	Spo	EC	S	C	S
226	*Coronella* sp.	Spo	EC	S	C	S
227	*Neuropora* sp.	Spo	EC	S	C	S
228	*Peronidella* sp.	Spo	EC	S	C	S
229	Sponge indet.	Spo	EC	S	C	S
230	Stromatoporid	Spo	EC	S	C	S
231	*Trochobolus*?	Spo	EC	S	C	S
232	Cirripeds	Cru	EC	S	C	S

Appendix C: Faunal distribution

1. Abundances of species in samples of G. Homayir section. (Species key in appendicx B)

Sp.	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	H15	H16	H17	H18
2	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0	0	0
4	0	0	32	0	47	22	0	0	9	1	14	0	0	0	0	0	0	0
9	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	1	7	2	1	0	0	0	0	0	0	0
21	0	0	0	0	0	1	0	7	10	6	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
24	2	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0
27	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	19	0	0	0	0	0	0	0	0	0
35	0	0	0	0	25	0	0	5	0	2	0	0	0	0	0	3	0	0
36	3	0	0	0	3	5	0	12	43	25	0	0	0	0	0	0	0	0
38	0	0	0	0	5	0	0	48	0	23	0	0	0	0	0	0	0	0
39	0	0	0	0	7	0	0	26	0	2	0	1	0	0	0	0	0	0
40	1	0	0	0	3	0	0	0	0	0	0	0	0	0	0	2	0	0
41	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	1	0	0
42	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
46	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
47	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
48	0	0	0	0	1	4	0	0	0	10	1	0	0	0	0	0	0	0
50	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
53	0	0	0	0	5	0	0	30	7	15	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	3	0	0	1	0	0	0	0	1	0	0
55	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
59	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0
64	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
65	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	1	0	0
66	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
68	33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
69	0	0	18	55	56	42	9	75	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	30	0	0	0	0	0	0	301	0	0
71	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
81	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
82	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
90	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
91	0	0	0	0	1	0	0	6	0	0	0	0	0	0	0	0	0	0
92	19	0	0	0	0	0	0	34	1	3	0	0	0	0	0	0	0	0
94	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0

Sp.	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	H15	H16	H17	H18
95	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
97	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0
99	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
105	2	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0
108	0	0	0	0	0	0	0	3	4	0	0	0	0	0	0	0	0	0
111	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
113	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
114	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
116	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	59	0	0
122	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
124	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
125	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
129	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0
132	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
134	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
138	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
149	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
150	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
160	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
162	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
165	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
168	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
170	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
172	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
173	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
175	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
176	0	0	0	0	0	0	0	9	5	0	0	0	0	0	0	0	2	0
177	0	0	0	0	4	3	0	0	0	0	0	0	0	0	0	1	0	0
178	0	0	0	0	0	2	0	0	0	0	2	0	0	0	0	0	1	0
184	4	4	0	0	0	0	2	0	0	0	0	0	0	1	2	4	0	0
185	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	1
186	0	0	0	0	2	0	0	2	0	0	0	0	0	0	0	0	0	0
190	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
191	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0
194	0	0	0	0	0	0	4	0	1	0	0	0	0	0	0	5	0	0
196	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
198	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	3
199	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0
203	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
205	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
207	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
208	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0
209	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
213	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0

Sp.	H1	H2	H3	H4	H5	H6	H7	H8	H9	H10	H11	H12	H13	H14	H15	H16	H17	H18
214	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
215	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1
216	0	0	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	1
218	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
220	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0
221	0	0	0	0	1	0	0	0	1	0	0	0	1	0	1	0	0	0
222	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0
223	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0	0	0	0
224	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
225	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	0
227	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0
228	0	0	0	0	0	0	0	0	0	0	0	0	0	3	8	0	0	0
Sum	81	4	50	55	182	97	37	293	150	105	21	1	12	13	21	402	3	6

2. Faunal distribution in the G. Engabashi section.

Sp.	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16	E17	E18	E19	E20	E21	E22
2	2	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
3	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
4	0	48	24	0	0	51	4	0	1	0	0	0	3	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0
24	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0
25	0	0	0	0	0	200	0	0	0	0	2	0	18	0	0	0	0	0	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
29	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
30	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
35	0	0	0	0	0	54	0	0	0	0	1	0	7	0	0	0	0	1	0	0	0	0
36	0	0	0	0	0	3	0	30	0	0	0	0	0	0	0	0	0	0	0	0	0	0
37	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	1	0	2	0	0	5	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
40	0	0	0	0	0	5	0	0	0	0	0	0	4	0	0	0	0	0	0	0	1	0
41	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
42	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
44	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	1	7	0	0	0	0	1	0	0	0	0	0	0	0	0	0
48	1	0	0	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
58	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
63	0	5	0	0	0	0	37	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
64	0	3	0	0	0	0	0	0	1	0	19	0	55	30	0	0	0	9	0	0	0	0

Sp.	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16	E17	E18	E19	E20	E21	E22
65	0	2	1	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0
66	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67	0	0	0	0	0	0	0	0	0	1	0	0	9	6	0	0	0	0	0	0	0	0
69	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	8	0	0	0	0	0	0
71	1	0	0	0	0	2	0	3	0	10	0	0	0	0	0	0	0	16	0	0	0	0
74	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
85	9	0	0	0	0	10	3	0	0	0	89	185	325	161	0	0	9	35	0	0	0	0
88	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
91	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
94	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	3	0	0
95	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
97	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
100	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
101	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
102	0	0	0	0	0	3	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0
108	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
112	0	0	0	0	0	0	1	1	0	0	0	0	1	1	0	0	0	0	0	0	0	0
113	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
115	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
116	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0
124	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
126	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
129	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
134	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0
142	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
143	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
151	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
152	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
156	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0
157	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
158	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
160	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	1	0	0	0
162	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
163	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
166	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
167	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0
168	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	1	0
169	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
171	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	27	0
174	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
176	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
177	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
178	0	0	0	0	0	0	0	50	0	0	0	0	0	0	0	0	0	6	1	0	0	0
181	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0

Sp.	E1	E2	E3	E4	E5	E6	E7	E8	E9	E10	E11	E12	E13	E14	E15	E16	E17	E18	E19	E20	E21	E22
184	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
185	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
190	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
191	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0
192	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
193	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
194	0	0	0	7	0	168	6	0	0	0	0	0	26	0	0	0	0	0	0	0	0	0
198	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
199	0	0	0	0	0	6	1	62	0	0	2	0	2	0	0	0	0	0	0	0	0	0
203	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
207	0	0	0	0	0	2	2	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0
208	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
215	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
216	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
220	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
221	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
222	0	1	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
223	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
224	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
228	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	2	0	0
231	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
Sum	29	64	42	8	1	530	61	177	3	11	114	185	462	202	10	14	10	75	2	31	66	5

3. Faunal distribution in the G. Mowerib section.

Sp.	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23	M24
4	0	0	0	0	0	0	23	4	0	2	51	0	0	0	2	0	0	1	2	0	0	0	0	0
7	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	2	0	0	14	0	0	0	24	0	0	0	0	0	0	0	0	0	0
19	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
21	3	0	0	0	0	0	0	0	0	37	0	5	0	0	0	6	0	0	0	0	0	0	0	0
22	0	0	0	1	0	0	0	0	0	0	0	1	2	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	0	0	0	0	4	0	0	0	2	5	1	3	0	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	1	0	0	0	0
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
30	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0
35	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0
36	0	0	0	0	0	0	0	0	0	5	0	3	14	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	1	0	0	0	15	29	0	0	0	0	0	0	0	0	0	0	0

Sp.	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23	M24
39	0	0	0	0	0	0	0	2	0	3	0	0	9	0	0	0	0	0	0	1	0	0	0	0
40	0	0	0	0	0	0	0	0	0	2	0	0	4	0	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
43	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0
44	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
45	0	0	0	0	0	0	0	0	0	0	0	1	12	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0	0	0	0	0	1	0	2	0	1	0	0	0	0	0	0	0
53	0	0	0	0	0	0	0	0	0	2	0	3	18	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
57	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
63	0	0	0	0	0	0	4	0	0	2	20	0	0	0	0	0	0	0	0	2	0	0	0	0
64	0	0	0	0	0	0	0	0	0	0	2	0	0	0	27	0	0	0	0	0	0	0	0	0
65	0	24	25	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	1	0	0	0	0	0
66	0	32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
68	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
69	0	0	0	0	0	0	0	14	0	20	24	0	0	0	0	6	0	0	0	0	0	20	0	0
70	0	0	0	0	0	0	0	15	0	0	0	5	17	0	0	0	0	0	0	0	0	0	0	0
71	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	11	0	0	0	0
77	2	12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
82	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
84	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0	0	5	0	0	0	85	14	62	11	0	52	0	0	0	0
92	0	0	0	0	0	0	0	0	0	0	0	0	14	0	0	0	0	0	0	0	0	0	0	0
94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
95	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
105	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0	0	0	0	0	0	0	0	0
112	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
116	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
117	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
121	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
124	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0
134	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
137	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
151	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	0
160	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
162	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
176	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0
178	0	0	0	0	0	0	0	0	0	3	1	1	7	1	0	0	0	0	8	0	0	0	0	0
179	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0
182	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
184	10	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
185	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
186	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
192	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0

Sp.	M1	M2	M3	M4	M5	M6	M7	M8	M9	M10	M11	M12	M13	M14	M15	M16	M17	M18	M19	M20	M21	M22	M23	M24
194	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	2	0	0	0
198	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0
199	0	0	0	0	0	0	2	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0
206	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
207	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3	0	0	0	0
208	0	0	0	0	0	0	0	0	0	17	0	0	0	0	0	0	0	0	0	2	0	0	0	0
211	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
213	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0
216	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0
217	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
220	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	1	0	0	0	0
221	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
222	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
230	0	0	0	0	1	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0
sum	22	72	27	7	3	1	34	170	6	120	114	38	277	34	133	172	65	123	14	79	10	20	1	1

4. Faunal distribution in the G. Arousiah section.

Sp.	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A166	A17	A18	A19	A20	A21	A22	A23	A24	A25	A26	A27	A28
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0
4	0	0	0	0	0	0	0	0	0	20	0	0	0	8	15	0	1	3	0	0	2	2	0	5	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	6	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
20	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	1	0	0	0	0	0
26	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
29	1	0	0	0	0	1	0	0	1	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
31	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	0	0	0	12	0	1	0	0	1	0	5	0	0	0	2	1	0	0	0	0	0	0
36	0	0	0	0	6	0	0	0	0	0	0	0	11	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	12	1	0	1	0	0	3	0	0	0	8	0	1	0	0	0	11	0	0	0	0	0	0	0
40	0	0	0	0	17	0	0	0	0	0	0	0	0	0	3	0	0	6	0	0	0	0	0	0	0	0	0	0
41	0	0	0	0	0	0	0	1	8	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0
42	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	14	0	0	0	0	0	0	201	0	0	0	0
43	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
44	0	0	0	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
45	0	0	19	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0	1	0	0
48	0	0	0	0	0	0	0	0	0	0	0	0	0	0	11	0	2	0	0	0	0	0	0	1	0	0	0	0

Sp.	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A166	A17	A18	A19	A20	A21	A22	A23	A24	A25	A26	A27	A28
51	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
53	0	0	0	0	0	0	0	0	0	0	0	0	5	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
59	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
60	0	0	0	0	0	0	20	24	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
62	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0
63	0	0	0	0	0	0	0	0	0	3	0	0	1	3	0	0	0	0	0	0	0	0	18	0	0	0	0	0
64	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0
65	0	0	0	0	0	0	0	0	0	0	1	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
66	0	0	2	0	0	0	7	0	17	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
67	0	4	0	0	0	0	0	9	3	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
68	0	0	0	0	0	18	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
69	0	0	0	0	0	0	0	0	0	0	20	0	11	3	14	0	14	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	188	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	53	0	2	0	0	0	0	0
71	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	2	0	0	0	0	0	0	0	0	0	0	0
81	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
82	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
85	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	89	129	0	0	0	0	0	153	0	0	0	0	0
87	0	0	0	0	0	1	21	11	7	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
89	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
90	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
92	1	0	0	0	73	0	0	0	0	0	0	0	4	0	1	0	0	8	0	0	0	0	0	0	0	0	0	0
97	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
99	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
105	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
106	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
111	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
112	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
113	0	0	0	0	1	1	0	0	0	0	0	0	0	0	2	0	1	0	0	0	1	0	0	0	0	0	0	0

Sp.	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A166	A17	A18	A19	A20	A21	A22	A23	A24	A25	A26	A27	A28
114	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
116	0	0	0	0	0	0	0	0	0	0	0	0	0	1	3	0	0	0	0	0	68	4	0	0	0	0	0	0
124	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
126	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
129	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
133	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0
134	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	2	0	0	0	0	0
136	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
141	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0
146	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
147	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
149	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
153	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
156	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
159	0	0	0	0	7	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
161	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
162	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0
167	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0
168	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
171	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0
172	0	0	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
174	0	0	0	0	18	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
176	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	2	0
178	0	0	0	0	0	2	0	0	0	1	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	1	0
183	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
184	5	3	0	0	1	0	4	5	4	0	1	0	0	0	0	0	1	0	0	0	1	0	0	0	4	1	0	0
185	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
186	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0
188	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0

Sp.	A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A166	A17	A18	A19	A20	A21	A22	A23	A24	A25	A26	A27	A28
189	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
190	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0
191	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0
193	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
194	0	0	0	0	0	0	0	0	0	0	3	0	0	5	0	0	3	0	1	0	1	3	31	0	0	0	0	0
198	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	29	0	2
199	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
200	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	11	0	0	0	0	0	0	0
203	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	8	0	0
205	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0
207	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	18	0	0	0	0	0	2	0	0	0	0	0
208	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	1	0	0	0	0	0
209	9	0	0	0	0	0	0	30	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
213	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	4	0	0
215	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2
216	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	3	0	3
220	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	1	0	0	0	0	0	0	0	0	1	0	0
221	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
223	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
225	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	12	0	0	0
227	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
228	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	0	0	0
230	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
231	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
232	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
Sum	39	7	24	1	334	26	52	94	69	41	48	13	42	30	82	93	218	19	4	1	161	15	219	211	36	49	10	7

Additional material

Sp.	19-1	19-2	19-3	19-4a	19-4b	19-5a	19-5b	20-1	20-2	20-3	20-4	20-5	20-6	20-7	20-7a	20-8	20-9a	21-1	21-2	21-3	21-4	21-5	21-6	21-7	21-8	21-9	21-9b	21-10	21-11	21-13	21-14	22-1	22-2	22-3	22-4	22-5	22-6	22-7	22-7b	23-1	23-2	23-3	23-4	23-5	23-6	23-7	23-8	24-1	24-2
1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
4	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	9	0	0	1	0	0	4	0	0	2	1	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0
5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0
8	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	2	1	0
10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	1	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	0	0	0	0	0	0	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	1	0
20	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	2	0	0	2	0	0	0	0
24	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
25	0	0	0	0	0	0	3	1	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	2	0	0	0	0	0	0	0	0	1	2	0	0	0	1	2
27	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
28	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
30	0	1	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0
31	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	1	0	0
32	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0
33	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
34	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
35	0	0	0	0	0	0	11	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	5	0	0	1	0	0	12	0	16	4	0	0	0	0	0	0	0	1	0	40	6	19	0	3	4

Sp.	19-1	19-2	19-3	19-4a	19-4b	19-5a	19-5b	20-1	20-2	20-3	20-4	20-5	20-6	20-7	20-7a	20-8	20-9a	21-1	21-2	21-3	21-4	21-5	21-6	21-7	21-8	21-9	21-9b	21-10	21-11	21-13	21-14	22-1	22-2	22-3	22-4	22-5	22-6	22-7	22-7b	23-1	23-2	23-3	23-4	23-5	23-6	23-7	23-8	24-1	24-2
36	0	0	2	0	0	0	2	0	0	0	0	0	0	0	0	3	0	0	0	0	47	17	0	0	20	0	18	0	0	0	27	0	0	33	0	0	0	0	0	0	0	29	0	1	33	20	0	0	0
37	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	33	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
39	0	2	10	0	0	0	3	0	0	0	0	0	11	0	0	4	0	0	0	0	9	9	0	1	10	2	6	2	0	0	5	0	0	0	0	0	0	1	0	0	0	6	0	0	0	0	0	1	0
40	0	0	3	0	0	0	0	11	2	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	21	0	4	10	0	0	0	0	0	0	0	0	0	0	0	0	0	0	13	0	0	0
44	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	45	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
47	0	0	5	0	0	0	6	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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58	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	1	0	2	0	0	0	0	0	0	0
59	1	0	9	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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61	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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65	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0
67	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	1	2	0	0	0	0	1	0	0	0	2	3	0	0	0	0	0	0	0	1	0	7	1	0	0	1	0	0
68	0	0	1	0	2	1	0	0	0	4	0	0	11	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	16	0	0	0	0	0	0	0	0	0	0	0
69	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	2	2	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
70	0	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	3	0	4	0	0	1	0	0	2	0	0	0	4	0	0	0	0	0	0	0	0	3	4	2	0	0	0	0	0
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72	0	0	4	0	0	0	0	0	0	0	0	0	8	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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75	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0

Sp.	19-1	19-2	19-3	19-4a	19-4b	19-5a	19-5b	20-1	20-2	20-3	20-4	20-5	20-6	20-7	20-7a	20-8	20-9a	21-1	21-2	21-3	21-4	21-5	21-6	21-7	21-8	21-9	21-9b	21-10	21-11	21-13	21-14	22-1	22-2	22-3	22-4	22-5	22-6	22-7	22-7b	23-1	23-2	23-3	23-4	23-5	23-6	23-7	23-8	24-1	24-2
76	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0
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90	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
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92	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	6	0	16	0	2	0	0	0	0	0	0	0	0	6	0	0	0	0	0	0	0	5	0	3	0	8	0	0	0
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94	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
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Sp.	19-1	19-2	19-3	19-4a	19-4b	19-5a	19-5b	20-1	20-2	20-3	20-4	20-5	20-6	20-7	20-7a	20-8	20-9a	21-1	21-2	21-3	21-4	21-5	21-6	21-7	21-8	21-9	21-9b	21-10	21-11	21-13	21-14	22-1	22-2	22-3	22-4	22-5	22-6	22-7	22-7b	23-1	23-2	23-3	23-4	23-5	23-6	23-7	23-8	24-1	24-2
113	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	3	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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125	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
127	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
128	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
129	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
130	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
131	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
133	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
134	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
135	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0
136	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
137	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
138	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	6	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
139	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
140	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
141	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
144	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
145	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
146	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
149	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
151	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1

Sp.	19-1	19-2	19-3	19-4a	19-4b	19-5a	19-5b	20-1	20-2	20-3	20-4	20-5	20-6	20-7	20-7a	20-8	20-9a	21-1	21-2	21-3	21-4	21-5	21-6	21-7	21-8	21-9	21-9b	21-10	21-11	21-13	21-14	22-1	22-2	22-3	22-4	22-5	22-6	22-7	22-7b	23-1	23-2	23-3	23-4	23-5	23-6	23-7	23-8	24-1	24-2
154	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
155	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
156	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	1	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
159	0	0	0	0	0	0	0	0	0	0	2	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
160	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
161	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
164	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0
165	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
168	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
172	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
174	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
175	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
176	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
180	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0
184	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0
185	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
186	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
187	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
189	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
190	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
191	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0
192	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
194	0	0	0	0	0	0	49	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	5	1	0	1	2	0	0	0	0	0	0	1	0	0	0	0	0	0	0	3	0	41	0	0	0	0	17
195	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
196	0	0	0	0	1	0	2	0	0	5	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
197	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0
199	0	0	0	0	0	0	10	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	2	3	0	0	2	0
200	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
201	0	4	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3
202	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0

Sp.	19-1	19-2	19-3	19-4a	19-4b	19-5a	19-5b	20-1	20-2	20-3	20-4	20-5	20-6	20-7	20-7a	20-8	20-9a	21-1	21-2	21-3	21-4	21-5	21-6	21-7	21-8	21-9	21-9b	21-10	21-11	21-13	21-14	22-1	22-2	22-3	22-4	22-5	22-6	22-7	22-7b	23-1	23-2	23-3	23-4	23-5	23-6	23-7	23-8	24-1	24-2
203	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	10	0	0	0	0	0	0	0	0	0	0	0	0
204	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	5	0	0	0	0	0	0	0	0	0	0	0	0
205	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0
207	0	0	0	0	0	0	21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	13	0	0	0	0	2
208	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	1
209	0	0	0	0	0	0	0	0	0	11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
210	2	0	0	0	0	0	10	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
211	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0
212	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
213	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	4	0	0	0	0	0	0	0	0	0	0	0	0
214	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
215	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
216	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	2	0	0	0	0	0	0	0	0	0	0	0	0
217	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
218	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
219	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
220	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
221	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0
222	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	1	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
223	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0	0	0	0	0	0	0
226	0	0	0	0	0	0	0	0	0	0	15	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	0
227	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	1	0	0	0	0	0	1	0	0	0	0	0
229	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
230	0	0	0	0	0	0	0	0	0	0	8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
231	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3	0	0	0	0	0
Sum	3	23	54	1	6	5	146	48	18	60	35	10	47	4	1	21	9	26	49	1	114	51	38	5	100	6	39	39	10	12	79	24	106	132	2	9	44	24	3	14	7	100	64	127	56	85	16	16	37

Appendix D: Geographic distribution of bivalves

1 Bajocian

ser.	Egypt	Jordan	Ethiopia	Somalia	Kenya	Tanzania	India	Germany	France	Turkm.	Tibet
1	1	0	0	0	0	0	0	0	0	0	0
2	1	0	0	0	0	0	0	0	0	0	0
3	0	0	0	0	0	1	1	0	1	1	0
4	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	0	0
8	1	0	0	0	0	0	0	0	0	0	0
9	0	0	1	1	1	1	0	1	0	0	1
10	0	0	0	0	0	0	0	0	0	0	0
11	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	1	0
16	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0
18	1	1	1	0	0	0	0	0	0	0	0
21	1	0	1	1	1	0	0	0	0	0	1
23	0	0	0	0	0	0	0	0	0	0	0
24	0	0	0	0	0	0	0	0	0	0	0
25	1	0	0	0	0	0	0	0	0	0	0
29	1	0	0	0	0	0	0	0	0	0	0
30	1	1	0	1	0	0	0	0	0	1	1
32	0	0	0	0	0	1	1	0	1	0	1
33	0	0	0	1	0	0	0	0	0	0	0
35	1	1	0	0	0	0	1	1	0	0	0
36	1	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	1	0	1	0
39	1	0	0	0	0	0	0	0	0	0	0
40	1	0	0	0	0	0	0	0	0	0	0
41	1	1	1	1	1	1	0	0	1	0	0
42	1	0	0	0	0	0	0	0	0	0	0
44	1	0	0	0	0	0	0	0	0	1	0
46	0	0	0	0	0	0	0	0	0	0	0
48	1	1	0	0	0	0	0	0	0	0	0
49	0	0	0	0	0	0	0	1	1	1	1
53	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	0	0	0
57	1	0	0	0	0	0	0	0	0	0	0
58	1	0	1	1	1	0	1	0	0	0	0
59	0	0	1	1	1	1	0	1	1	1	1

2 Bathonian

ser.	Egypt	Jordan	KSA	Ethiopia	Somalia	Kenya	India	Germany	France	UK	Turkm.	Tibet
1	0	0	0	0	0	0	0	0	0	0	0	0
2	1	0	0	0	0	0	1	0	0	0	0	0
3	1	0	1	0	1	0	1	0	1	0	1	1
4	1	1	1	0	0	0	0	0	0	0	0	0
7	1	1	1	0	1	0	1	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0
9	1	0	0	0	0	0	1	1	0	1	0	1
10	0	0	0	0	0	0	0	0	0	0	0	0
11	0	0	1	0	0	0	0	0	0	0	0	0
12	1	1	0	0	0	0	1	0	0	0	0	0
13	1	0	1	0	1	0	0	0	0	0	0	0
14	1	0	0	0	0	0	0	0	0	0	0	0
15	1	0	0	0	0	0	1	0	0	1	0	0
16	1	0	0	0	0	0	0	0	1	0	0	0
17	1	0	0	0	0	0	0	0	0	0	0	0
18	1	1	1	1	0	0	1	0	0	0	0	1
21	1	0	0	0	0	0	0	0	0	0	0	1
23	1	0	0	1	1	1	0	0	0	0	0	0
24	1	0	0	0	0	0	0	0	0	0	0	0
25	1	1	0	0	0	0	0	0	0	0	0	0
29	1	0	0	0	0	0	0	0	0	0	0	0
30	1	1	0	1	1	1	1	0	1	0	1	1
32	1	1	1	1	0	0	1	0	1	1	0	1
33	1	0	0	0	1	0	0	0	0	0	0	0
35	1	1	1	0	0	0	1	1	1	0	0	1
36	1	0	0	0	0	0	1	0	0	0	0	0
38	1	0	0	0	0	0	0	1	1	1	1	0
39	1	0	0	0	0	0	0	0	0	0	0	0
40	1	0	0	0	0	0	0	0	0	0	0	0
41	1	1	1	1	0	1	1	0	1	1	0	0
42	1	0	0	0	0	0	1	0	0	0	0	0
44	1	0	0	0	0	0	0	0	1	0	1	0
46	1	0	0	0	0	0	0	0	0	0	0	0
48	1	1	0	0	0	0	0	0	0	0	0	0
49	1	0	1	0	0	0	1	1	1	1	1	1
53	1	0	0	0	0	0	0	0	0	0	0	0
54	1	0	0	1	1	1	0	0	0	0	0	0
55	1	0	0	1	1	1	1	0	1	0	0	0
56	1	0	0	0	0	0	1	0	0	0	0	0
57	0	0	0	0	0	0	0	0	0	0	0	0
58	1	0	0	0	1	0	0	0	1	0	0	0
59	1	0	0	0	0	0	0	1	1	1	1	1

3 Callovian

ser.	Egypt	Jordan	KSA	Yemen	Ethiopia	Somalia	Kenya	Madag.	India	Tunisia	France	Germany	UK	Turkme.	Tibet
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
2	1	1	0	0	0	0	0	0	1	1	0	0	0	0	0
3	1	1	1	0	0	0	1	1	1	1	1	0	0	1	1
4	1	0	0	0	1	1	0	0	0	1	0	0	0	0	0
7	0	1	1	0	1	1	1	1	1	1	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9	1	0	0	0	0	0	1	0	1	0	1	1	1	0	1
10	0	0	0	1	0	0	1	0	1	1	0	0	0	0	0
11	0	1	1	0	0	1	0	0	0	0	0	0	0	0	0
12	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	1	1	0	1	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
18	1	1	1	1	1	1	1	1	0	0	0	0	0	0	1
21	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1
23	0	0	0	0	0	0	0	0	0	0	0	0	1	0	0
24	0	0	0	0	0	0	0	1	1	0	0	0	0	0	0
25	1	1	0	0	0	0	0	0	0	0	0	0	0	0	0
29	1	0	0	0	0	0	0	0	0	1	0	1	0	0	0
30	0	1	0	0	1	1	1	0	1	1	0	0	0	1	1
32	1	0	1	1	1	1	0	1	1	1	1	0	0	0	1
33	1	0	0	0	1	1	0	0	0	1	0	0	0	0	0
35	1	1	1	1	0	1	0	1	1	1	0	1	1	0	0
36	0	0	0	0	0	0	0	0	1	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0
39	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
40	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
41	1	1	1	0	1	1	1	1	1	1	0	0	1	0	0
42	1	0	0	0	0	0	1	0	1	0	1	0	0	0	0
44	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0
46	1	0	0	0	0	0	0	0	0	0	0	0	0	0	0
48	0	1	0	0	0	0	0	0	0	0	0	0	0	0	0
49	0	0	0	0	1	1	1	1	1	0	1	1	1	1	1
53	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
54	1	0	0	0	0	0	0	0	1	0	0	0	0	0	0
55	0	0	0	0	1	1	1	1	1	0	0	0	0	0	0
56	0	0	0	0	0	0	0	0	1	1	1	1	0	0	0
57	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0	1	0	0	1	1	0	0	1	1	0	1	0	0	0
59	0	0	0	0	0	0	0	1	1	0	1	1	1	1	1

4 Oxfordian

ser.	Egypt	KSA	Ethiopia	Somalia	Kenya	Tunisia	Germany	Spain	France	UK	Madag.	Tanzania	India
1	0	0	0	0	0	0	1	0	1	1	0	0	0
2	0	0	0	0	0	1	0	0	0	0	0	0	0
3	1	0	0	1	1	0	0	1	1	1	0	0	1
4	0	1	0	0	0	1	0	0	0	0	0	0	0
7	0	1	1	0	1	0	0	0	0	0	0	0	0
8	0	0	0	0	0	0	0	0	0	0	0	0	0
9	0	0	0	0	0	0	0	0	0	0	0	0	0
10	1	0	1	1	1	1	0	0	0	0	0	0	0
11	1	1	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	1	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0
15	0	0	0	0	0	0	0	0	0	0	0	0	0
16	0	0	0	0	0	0	0	0	0	0	0	0	0
17	0	0	0	0	0	0	0	0	0	0	0	0	0
18	1	0	1	0	1	0	0	0	0	0	0	0	0
21	0	0	0	0	0	0	0	0	0	0	0	0	0
23	0	0	0	0	0	0	0	1	1	1	0	0	0
24	0	0	0	0	0	0	0	0	0	0	1	1	1
25	1	0	0	0	0	0	0	0	0	0	0	0	0
29	1	0	0	0	0	0	0	0	0	0	0	0	0
30	0	0	1	1	1	0	0	0	0	0	0	0	0
32	0	1	1	1	1	1	1	0	1	0	0	0	0
33	0	0	1	0	0	1	0	0	0	0	0	0	0
35	0	1	1	1	1	1	1	1	1	1	0	1	1
36	0	0	0	0	0	0	0	0	0	0	0	0	0
38	0	0	0	0	0	0	0	0	0	0	0	0	0
39	0	0	0	0	0	0	0	0	0	0	0	0	0
40	1	0	0	0	0	0	0	0	0	0	0	0	0
41	0	1	1	0	0	1	0	0	0	1	0	0	0
42	1	0	0	0	0	0	0	0	0	0	0	0	1
44	0	0	0	0	0	0	0	0	0	0	0	0	0
46	0	0	0	0	0	0	0	0	0	0	0	0	0
48	0	0	0	0	0	0	0	0	0	0	0	0	0
49	0	0	1	1	1	0	1	1	1	0	0	1	0
53	0	0	0	0	0	0	0	0	0	0	0	0	0
54	0	0	0	0	0	0	0	0	0	0	0	0	0
55	0	0	0	0	0	0	0	0	0	0	0	0	0
56	0	0	0	0	0	1	1	1	1	0	0	0	0
57	0	0	0	0	0	0	0	0	0	0	0	0	0
58	0	0	0	1	0	1	0	0	0	0	0	0	0
59	0	0	1	0	0	0	1	0	0	1	0	1	0