BIOFABRICS AS DYNAMIC INDICATORS IN NUMMULITE ACCUMULATIONS

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ABSTRACT: Biofabric interpretation of skeletal accumulations consisting of "biologically standardized" nummulite tests (larger foraminifera) is based upon (1) the ratio of small-bodied A-forms (megalogospheric) and large-bodied B-forms (microospheric), and (2) on their packing and imbrication features. In the Eocene Mokattam Formation of Egypt, Nummulites gizehensis occurs in limestones with four basic biofabrics. In wackestones, the nummulites "float" throughout the matrix, and A-forms strongly dominate over B-forms, approximating the ratio reported for undisturbed assemblages. Packstones, however, reflect various degrees of sedimentary reworking and winnowing of the original substratum by physical processes. For packstones with edge-wise imbrication and A-forms strongly dominating over B-forms, in situ winnowing of fine-grained matrix by waves can be inferred. In contrast, packstones composed of imbricated B-forms suggest hydraulic sorting and selective removal of A-forms by currents. Packstones composed almost entirely of A-forms represent transport-sorted allochthonous deposits.

Biofabric analysis thus allows us to understand better the dynamics of skeletal accumulations such as nummulite banks, whose commonly complex and extensive buildups can form hydrocarbon reservoirs.

INTRODUCTION

Many skeletal elements enter the sedimentation cycle of nature's laboratory as "standardized material" (Seilacher 1973) with predictable attributes. Thus the analysis of biofabric—orientation, packing, sorting of bioclasts—enables the reconstruction of the hydrodynamic and sedimentologic history of skeletal carbonates.

Accumulations of nummulites and other larger foraminifera are particularly suitable for hydrodynamic studies, since (a) the shape of foraminiferal bioclasts is relatively simple, and (b) the size and frequency distribution of the original nummulite population can be assumed with good confidence. This latter advantage is the consequence of the life cycle in larger foraminifera which produces two distinct size classes of a particular ratio in a single population (e.g., Blondeau 1972).

The purpose of this note is to illustrate the use of orientation, packing, and sorting of foraminiferal bioclasts ("biofabric") to interpret the hydrodynamics and the depositional environment of skeletal accumulations.

NUMMULITE BANKS

Larger foraminifera from various systematic groups form accumulations of considerable thickness and lateral extent. Fusulinid shoals in the Pennsylvanian of North America (e.g., Wilson 1975, p. 209) and nummulite banks in Eocene marginal shelves bordering the Tethys Sea (for literature review, see Aigner 1983) provide examples.

Accumulations composed almost exclusively of Nummulites gizehensis (tests up to 5 cm in diameter) are common in the Middle Eocene Mokattam Formation of Egypt (Said 1962). They can form nonreef buildups, or "banks," that may be distinguished from "fore-bank" and "back-bank" facies types (Arni 1965; see Fig. 1). These facies can be recognized in regressive succession within the Middle and Upper Eocene around Cairo (Fig. 2). Nummulite banks in the vicinity of Cairo are composed largely of nummulite packstones forming accumulations up to 30 m thick and approximately 1.5 × 1 km in area at the Giza Pyramids Plateau. These nummulite "gravel" contain a variety of sedimentary structures such as erosion surfaces, erosive ripples, scour-and-fill structures, pot casts, several types of imbrication, and so on (for detailed description see Aigner 1982, 1983). In some layers, the smaller A-forms of Nummulites gizehensis are dominant and from the "matrix" in which the larger B-forms are included, whereas A- or B-forms may be preferentially enriched and concentrated in other layers.

Although the large tests of N. gizehensis would provide an ideal substrate for various kinds of encrusting organisms, nummulites are only rarely to moderately encrusted by bryozoans, small oysters, and serpulids (Aigner 1983; Fig. 3). Other benthic organisms are relatively sparse in the bank environment and are restricted to burrowing echinoids, gastropods, and bivalves. In contrast to the "nummulite bank" packstones, the "back-bank" environment is dominated by lime mudstones and wackestones. A-forms always dominate over nummulite B-forms in the "back-bank" environment.

POPULATION DYNAMICS

Many modern larger foraminifera harbor endosymbiotic algae in their tests. The ecological success of extinct groups of larger foraminifera (mass occurrence and dramatic size increase) may be related to a similar association with symbiotic algae (e.g., Röttinger 1972; Lee et al. 1979; Hallock 1981, 1982). The life cycle of foraminifera is commonly complex and includes both sexual and asexual reproduction (Fig. 3) which is reflected in two distinct size classes of tests: smaller A-forms (megalogospheric generation) and larger B-forms (microospheric generation). Among modern populations of larger foraminifera with symbiotic algae, B-forms are scarce (Hallock 1982). Sim-

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ilarly, A-forms dominate in original, undisturbed assemblages: De la Harpe (1883) and Blondeau (1972) postulated an original A/B-ratio of approximately 10/1 (Fig. 3). Using this relationship as a basic premise, the A/B-ratio can be used as an indicator of processes causing burial of death assemblages.

**BIOFABRICS AS HYDRODYNAMIC INDICATORS**

Blondeau (1972) and Girgis and Hindy (1973) believe that nummulites probably lived scattered upon lime mud substrata rather than in nummulite "gravels" (packstones). Two lines of evidence suggest that the Eocene nummulite "gravel" of the bank facies does not represent a nummulite biocenosis in its original habitat:

(a) Appreciable encrustation of the tests is relatively uncommon. If the present nummulite "gravel" had served as a substrate for Nummulites colonization, a much higher degree of encrustation would be expected given the prolonged exposure of older (dead) tests. Instead, dead tests apparently were buried under fine material excluding epibions.

(b) The nummulite bank facies exhibits abundant examples of "high-energy" sedimentary structures (Aigner 1982). These sedimentary structures are evidence for episodic physical processes which would cause winnowing of fines and concentration of bioclasts.

Assuming that natural populations of larger foraminifera are dominated by the megalospheric A-forms (De la Harpe 1883; Blondeau 1972; Hallock 1982), biofabrics

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**FIG. 1.**—Nummulite facies model based on lateral facies succession in the Eocene of Libya, simplified after Arni (1965). Major environments are fore-bank, nummulite bank, back-bank, and littoral-lagoonal.

**FIG. 2.**—Location map and generalized vertical facies sequence in the Middle and Upper Eocene around Cairo, Egypt. In the Giza section, the nummulite bank facies is most prominent and developed on top of a paleo-high inherited from Late Cretaceous tectonic compression.

**FIG. 3.**—Life cycle of nummulites (above) and A/B-ratio in resulting population (below). After Blondeau (1972).
may be evaluated hydrodynamically in at least four ways (see Figs. 4 and 5):

(1) Relatively undisturbed assemblages are inferred when A-forms dominate (A/B-ratio 10/1 or more) in matrix-supported lithologies (mud- and wackestones). Although 10/1 ratios are rare in the nummulite bank facies, these ratios are very common in the back-bank environment of the Giza example (Fig. 4A).

(2) Parautochthonous assemblages. The dominance of A-forms (A/B average 7/1) is responsible for the poorly sorted nature of the N. gizehensis packstones throughout most of the bank facies. This pattern is expected for undisturbed nummulite accumulations, yet sedimentary structures indicate sea-floor disturbances by physical processes. This combination of features suggests that winnowing of the fines caused in situ concentration of nummulites. Winnowing was rigorous enough to remove fine carbonate mud but insufficient to remove many of the small A-forms selectively. The edge-wise imbrication in this assemblage (Fig. 4B) is similar to that produced in flume experiments by oscillatory rather than unidirectional currents (Futterer 1982). It is inferred that winnowing was caused by wave action.

(3) Residual assemblages can be inferred for layers enriched with larger B-forms but with A-forms still present (Fig. 4C). In extreme cases, the accumulation may consist entirely of B-forms (Fig. 4D). The dominance of imbricated B-forms suggests selective removal of the smaller A-forms, thereby enriching the larger B-forms to form a "residual lag."

(4) Allochthonous assemblages. A few layers that are composed almost entirely of A-forms suggest hydraulic sorting and separation of the bioclasts during lateral transport: the smaller A-forms are more easily transported than the B-forms (18–34 cm sec⁻¹ for A-forms versus 31–77 cm sec⁻¹ for B-forms, based on the flume experiments of Dr. E. Futterer), forming a pure, allochthonous A-form assemblage when redeposited. These accumulations imply a nearby assemblage of B-forms formed as a residual lag.

These principles should be valuable for understanding other accumulations of larger foraminifera. Furthermore, the regional distribution of various biofabrics could improve paleogeographic predictions and reconstructions of potential reservoir rocks. Biofabrics not only reflect hydrodynamics, but should also influence porosity/perme-
ability characteristics in rocks formed by larger foraminifera.

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