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DEEP-SEA MICROBIAL EUKARYOTES IN ANOXIC, MICROOXIC, AND SULFIDIC ENVIRONMENTS

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1. Introduction

Measuring the extent of eukaryotic microbial diversity is essential to our
understanding of eukaryotic evolution and the structure and function of micro-
bial food webs. In the past several years, molecular approaches have been used to
address an increasing interest in the diversity of microbial eukaryotes, particu-
larly that of protists from various marine environments. These have included
pelagic environments (e.g., Moon-van der Staay et al., 2001; Massana et al., 2002),
deep-sea environments (López-García, 2001), the ocean surface (Díez et al., 2001;
Moon-van der Staay et al., 2001), coastal environments (Massana et al., 2004),
and a river (Berney et al., 2004), as well as extreme environments, including acidic
and iron-rich rivers (Amaral Zettler et al., 2002), deep-sea hydrothermal vents
(Edgcomb et al., 2002; López-García et al., 2003), microoxic (<10 µM oxygen)
and anoxic waters and sediments in salt marshes (Stoeck and Epstein, 2003), per-
manently anoxic deep-sea waters (Stoeck et al., 2003, 2006), anoxic shallow
sediments of marine and freshwater (Dawson and Pace, 2002; Bernhard et al.,
2006). These studies have revealed an extraordinary diversity of previously unde-
tected eukaryotic lineages based on small-subunit ribosomal RNA (SSU rRNA)
sequences. For a recent overview of higher level classification of eukaryotes that
emphasizes the protists, see Adl et al. (2005). Anoxic (lacking dissolved oxygen)
environments have been present throughout Earth’s history, and sulfide-rich con-
ditions are likely to have existed in the deep oceans into the late Proterozoic
(Canfield, 1998; Shen et al., 2002), during the origin and early diversification of
eukaryotes when atmospheric oxygen concentrations were about 1% of present
day levels (Schopf and Klein, 1992). Indeed, the sulfur cycle has been implicated
in the origin of eukaryotes (e.g., Searcy, 1992; Martin and Müller, 1998; Moreira
and López-García, 1998; Gray et al., 1999). While the details of eukaryogenesis
remain debatable and it is impossible to re-enact the origin and early diversifi-
cation of Eukarya, additional insights into the origin and diversification of
eukaryotes can be gleaned from the study of extant anaerobic and microaerophilic