



Late Ordovician graptolite evolution: relationship to climate and environmental changes

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Many graptolite species became extinct during Late Ordovician environmental changes that were driven by global climate changes from “greenhouse” to “icehouse” to “greenhouse” states. Most planktic graptolites lived in hypoxic waters. Some species may have migrated into anoxic environments. During the Ordovician, the majority of hypoxic-anoxic environments in which graptolites lived developed in oxygen minimum zones that formed under ocean upwelling waters at shelf margins. Additionally, hypoxic-anoxic environments in which graptolites lived developed in certain basins within shelf areas. Potentially, certain sea level changes could have resulted in spread of oxygen minimum zone waters across shelves to allow formation of shelf sea hypoxic environments. Certain other graptolites lived in relatively oxic waters that extended across shelves from their margins into shallow inland seas. Graptolites living in inner shelf seas commonly include primarily locally endemic taxa. Glacio-eustatic sea level fall during “icehouse” state glaciation drained many shelf sea areas which resulted in habitat losses, including hypoxic environments. As well, shelf margin upwelling conditions appear to have become markedly reduced at the same time. Loss of hypoxic environments during these climate- change related environmental shifts resulted in many extinctions among graptolites that lived in hypoxic environments. Hypoxic environments established during the Late Ordovician in a shelf basin located in present-day South China persisted there throughout much, if not all, of the glacial episode. Many Ordovician graptolite taxa living there did not become extinct at the same time as species living in areas where hypoxic conditions were reduced markedly or were lost entirely. Instead graptolite species turnover appears to have been at about the same rate in that basin as in pre-extinction hypoxic environments. The area may be considered a refugium for those graptolites that preferred hypoxic en-

vironments. Those graptolites that lived in oxic waters continued to flourish in many areas throughout the interval during which those graptolites living in hypoxic environments became extinct.. Certain of these graptolites, notably the normalograptids, even underwent modest radiation in the Late Ordovician. Many normalograptid species appear to be endemic to the areas where they lived. Deglaciation and resultant sea level rise was followed by return of oxygen minimum zones and gradual renewal of the spread of hypoxic environments. Those graptolites that lived in these environments radiated markedly in areas in which hypoxic environments redeveloped. Global climate changes and resultant environmental changes led to significant evolutionary developments among graptolites during the Late Ordovician into Early Silurian.