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Structural and Geochemical Signatures of Mg-Calcite in Korean Crustose Coralline Algae: Proxy Potential for Multi-Year Seawater Temperature and Environmental Stress

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Crustose coralline algae (CCA) are important geochemical archives of past seawater environments. Their high-magnesium (Mg) calcite skeletons preserve temperature signals through the substitution of Mg for Ca; however, interpretation of skeletal Mg content requires consideration of physiological regulation, marine environmental conditions, and the integration of growth signals over multiple years. Along the Korean coast, rapid warming and rocky shore desertification have been reported, yet it remains unclear how these changes are reflected in the skeletal structure and chemistry of CCA. In this study, we analyzed 22 specimens collected from ten coastal sites around the Korean Peninsula using X-ray diffraction (XRD) and scanning electron microscopy with energy-dispersive spectroscopy (SEM-EDS). Long-term sea surface temperature (SST) records and 5-year moving averages were incorporated to evaluate multi-year environmental signals. All samples were dominated by Mg-calcite. The (104) diffraction peak shifted toward higher 2θ values relative to pure calcite, reflecting Ca^{2+} substitution by Mg^{2+}. Peak position showed strong negative correlations with lattice parameters and unit cell volume ($R^2 = 0.95$). XRD-derived Mg contents ranged from 9.0 to 14.5 mol% (mean 12.1 ± 1.5 mol%), consistent with regional SST gradients. EDS analyses revealed Mg/Ca ratios of 0.09–0.17 (mean 0.14 ± 0.02), with lower values in the northern East Sea and higher values along the southern coast and around Jeju Island. Mg-based temperature estimates agreed more closely with mean growth-season (May–October) SST than with annual means, based on comparisons with instrumental records from nearby monitoring stations. In some regions, discrepancies between estimated and observed growth-season temperatures were evident. These regional differences were partly associated with variations in seawater Mg/Ca ratios, as sites showing the largest temperature offsets were closest to the regression line of seawater Mg/Ca. Overall, Mg-derived temperatures from CCA are more appropriately interpreted as proxies for growth-season or summer SST rather than annual means. These results suggest that CCA skeletal chemistry reflects the combined influence of temperature and seawater Mg/Ca ratios. When growth-season bias and marine environmental factors are explicitly considered, CCA Mg-calcite provides a reliable archive for reconstructing multi-year to decadal coastal ocean warming.