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Integrating microscopy and Raman spectroscopy for characterization of conodont elements: a step toward paleoenvironmental reconstructions

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Reliable reconstruction of past climatic conditions is essential for understanding Earth's long-term environmental changes and predicting future trends. Organisms capable of biomineralization serve as valuable paleoenvironmental archives. A key example is conodonts – organisms whose hard jaw apparatus elements are primarily composed of fluorapatite and play a crucial role in reconstructing paleotemperatures through oxygen isotope analysis. Conodont elements commonly consist of three components – the albid crown, hyaline crown, and basal body – each characterized by unique compositional and structural properties that may carry different isotope signatures making interpretation challenging.

We conducted a study combining multiple instrumental techniques to identify intra-element heterogeneities in several taxa extracted from Ordovician and Silurian strata in Estonia. The specimens were embedded in epoxy, polished, and analyzed using polarized light and fluorescence microscopy, white light interferometry, scanning electron microscopy, and Raman spectroscopy. These methods provided detailed insights about compositional and structural variations that can be used for defining targets in future *in situ* oxygen isotope determinations.

The results show that conodont hard tissues, distinguished based on optical and scanning electron microscopy, exhibit distinct fluorescence properties, suggesting compositional changes, crystallinity variations, or structural defects. These observations correlate well with the results of Raman spectroscopy, which provide high-resolution structural and chemical insights about fluorapatite crystallinity (intensity and width of the symmetric stretching vibration of the P–O bond at ~960 cm^{-1}) and distribution of kerogen (intensity of the D1 band at ~1340 cm^{-1}). Variations in hard tissue crystallinity are also reflected in the polishing properties of conodont elements, as demonstrated by white light interferometry: the albid crown develops the most surface porosity, while the softer basal body exhibits more pronounced relief. The observed variations suggest a high degree of complexity in the compositional changes of the studied taxa and indicate that Raman mapping is a more effective tool than spot analysis in conodont research. Given the influence of orientation effects on the intensity of Raman spectra, further investigation using electron backscatter diffraction should complement the observations and conclusions from this part of our study.

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