

Quantifying Subjectivity in Geological Mapping: A Rock Identification Confusion Matrix for Uncertainty-Aware Geo-AI

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Geological maps are fundamental information layers used in mineral exploration, hazard assessment, land-use planning, and geoscientific research. However, the assignment of rock labels during geological field mapping is inherently interpretative. While field descriptions aim to document observations as objectively as possible, the final classification of a rock type represents a conceptual interpretation based on visual perception and expert judgement [1]. These interpretations introduce subjectivity that is rarely quantified. This subjectivity can be considered as uncertainty that becomes increasingly relevant when geological field observations or derived geological maps are integrated with large digital data sets using machine learning approaches. If the uncertainty associated to geological rock label assignments is not realistically quantified, reliable information retrieval from geological maps becomes impossible. Humans compensate for missing information, such as unquantified uncertainty, associated with data, using experience and intuition. AI systems cannot. For them, quantified data uncertainty is not optional: it is essential for correct information retrieval from data.

We present a structured methodology to quantify human-induced uncertainty in field-based rock identification through a crowd-based expert assessment [2]. Eleven geologists participating in a bedrock mapping project in the Trøndelag region of Norway evaluated the likelihood of confusing pairs of rock types using a five-level Likert scale. From these responses we construct a probabilistic rock identification confusion (RIC) matrix describing the collective uncertainty of the expert cohort across 35 lithological classes. The matrix captures the relational structure of classification ambiguity between rock types and provides a machine-readable representation of expert-derived uncertainty.

We further outline how the resulting probability distributions can be translated into stochastic misclassification cost matrices for loss-sensitive machine learning. Within a Monte Carlo framework, these cost matrices can be sampled during model training, enabling the propagation of expert-derived rock label uncertainty through geological data integration workflows and resulting in probabilistic geological maps.

The presented approach provides a practical pathway to incorporate tacit expert knowledge into uncertainty-aware geo-AI pipelines. While demonstrated for a regional bedrock mapping project, the method is scalable to larger geological surveys and transferable to other geoscientific field classification tasks that rely on human visual interpretation. It therefore contributes to bridging the gap between expert-driven geological mapping practice and emerging AI-based modelling workflows.

[1] Wilson, C.G., Bond, C.E., Shipley, T.F. (2019) How can geologic decision making under uncertainty be improved?. *Solid Earth* 10, 1469–1488.

[2] Ksienzyk, A.K., Asadi, J., Bingen, B., Bjerkgård, T., Ganerød, M., Gasser, D., Grenne, T., Gunleiksrud, I.H., Jakob, J., Meyer, G.B., Paulsen, H.-K., Svendby, A.K., Bleicher, A., Paasche, H. (submitted) Uncertainty in geological mapping: a rock identification confusion matrix for a bedrock mapping project in Trøndelag, Norway. *Norwegian Journal of Geology*.