A predictive and invertible model of fluvial sediment geochemistry

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Photo shows River Tilt at sampled locality near Blair Atholl. Credit Author

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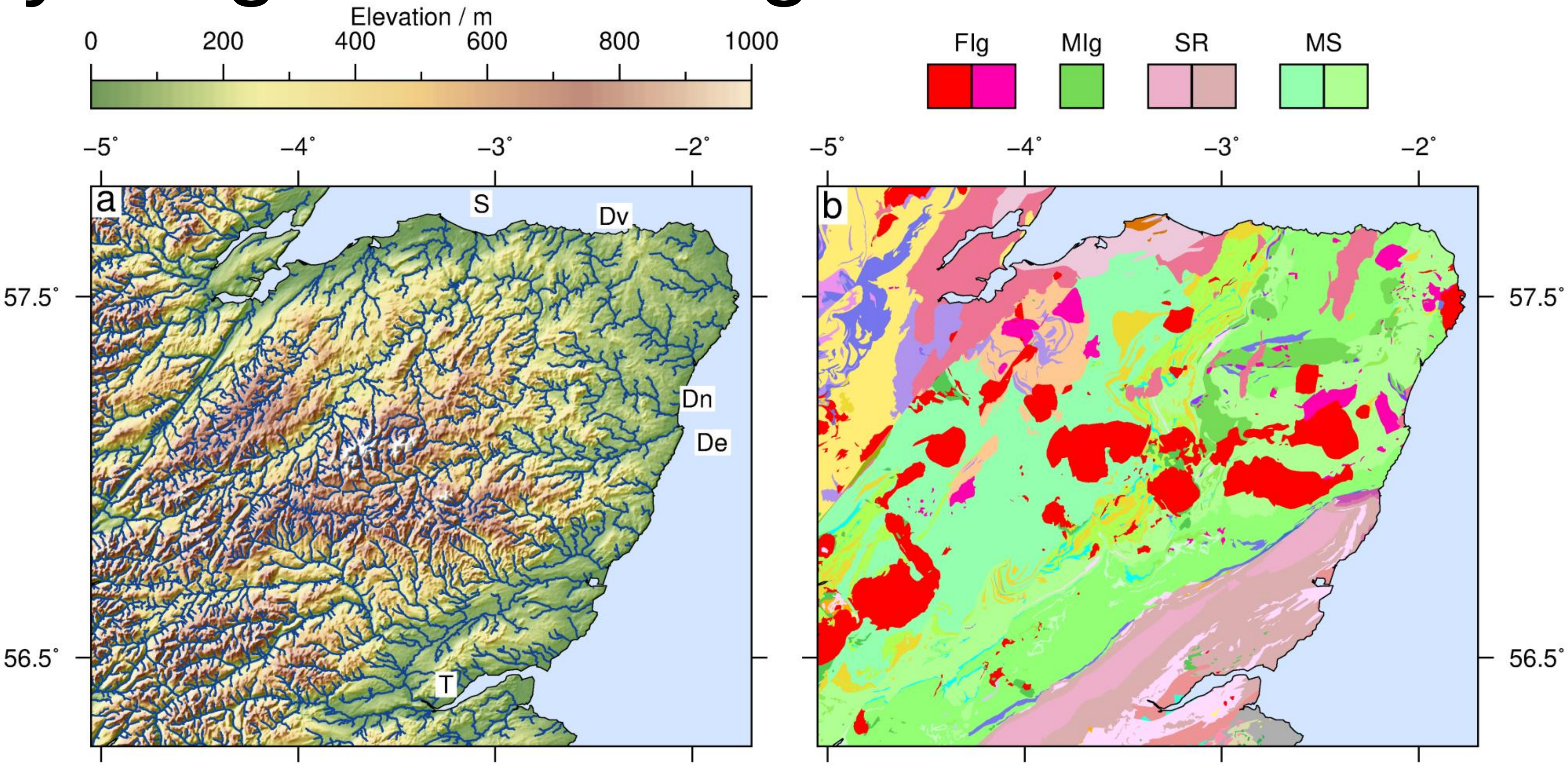
Introduction

- Models of fluvial erosion make predictions of sediment flux, e.g., the well known Stream Power Law
- They can also be adapted to predict properties of sediment which reflect provenance[1]
- Testing these predictions requires continuous maps of source region properties or geochemistry
- High-resolution geochemical surveys are a solution to this
- In this study we use the G-BASE geochemical survey of the UK to make predictions of higher order fluvial sediment geochemistry
- The success of these predictions is evaluated by analysing sediments sampled downstream

[1] Sharman et al. (2019), doi.org/10.1038/s41598-019-39754-6

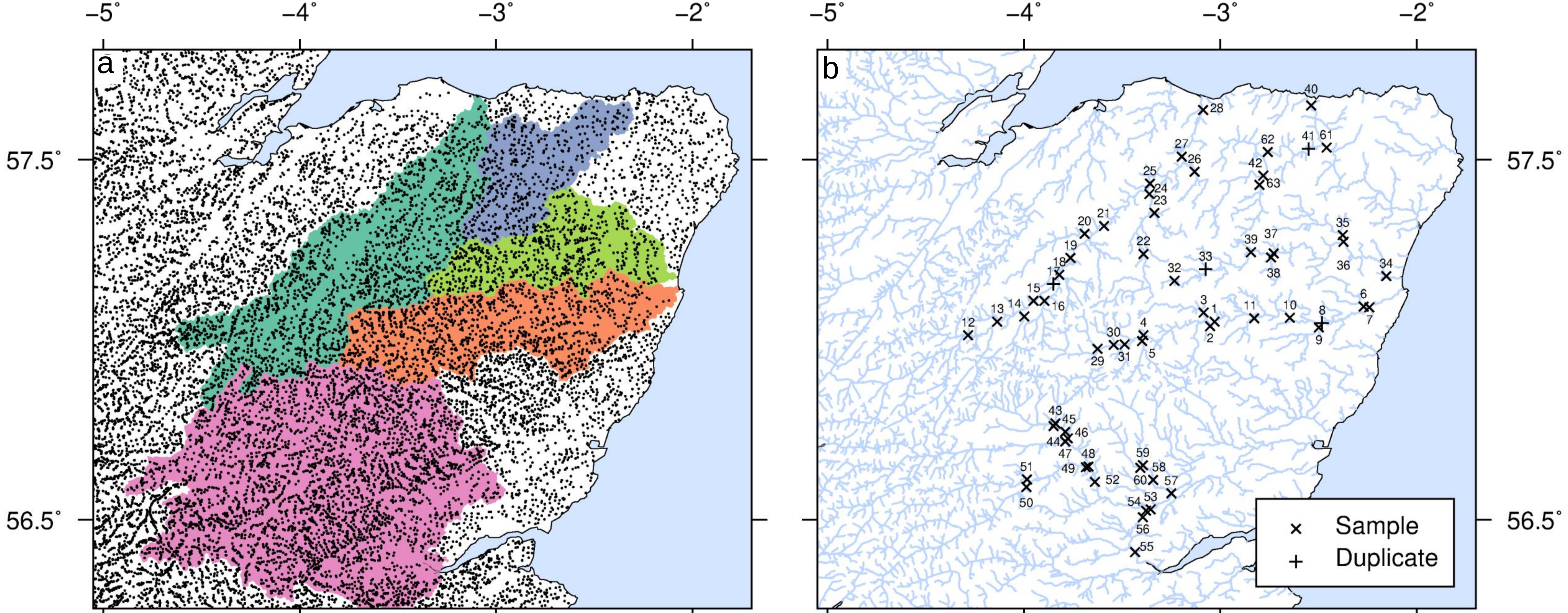
Study Region - Cairngorms



(a) Topographic map of study region with studied rivers labelled. S = Spey; Dv = Deveron; Dn = Don; De = Dee; T = Tay; (b) Simplified geological map of study region. FIg = Felsic Igneous; MIg = Mafic Igneous; SR = Sedimentary Rock; MS = Metasediments

- 5 Rivers draining Cairngorms, UK chosen for study
- Region has diverse geology and high relief
- This results in high signal to noise ratio

Study Region – Geochemical Sampling

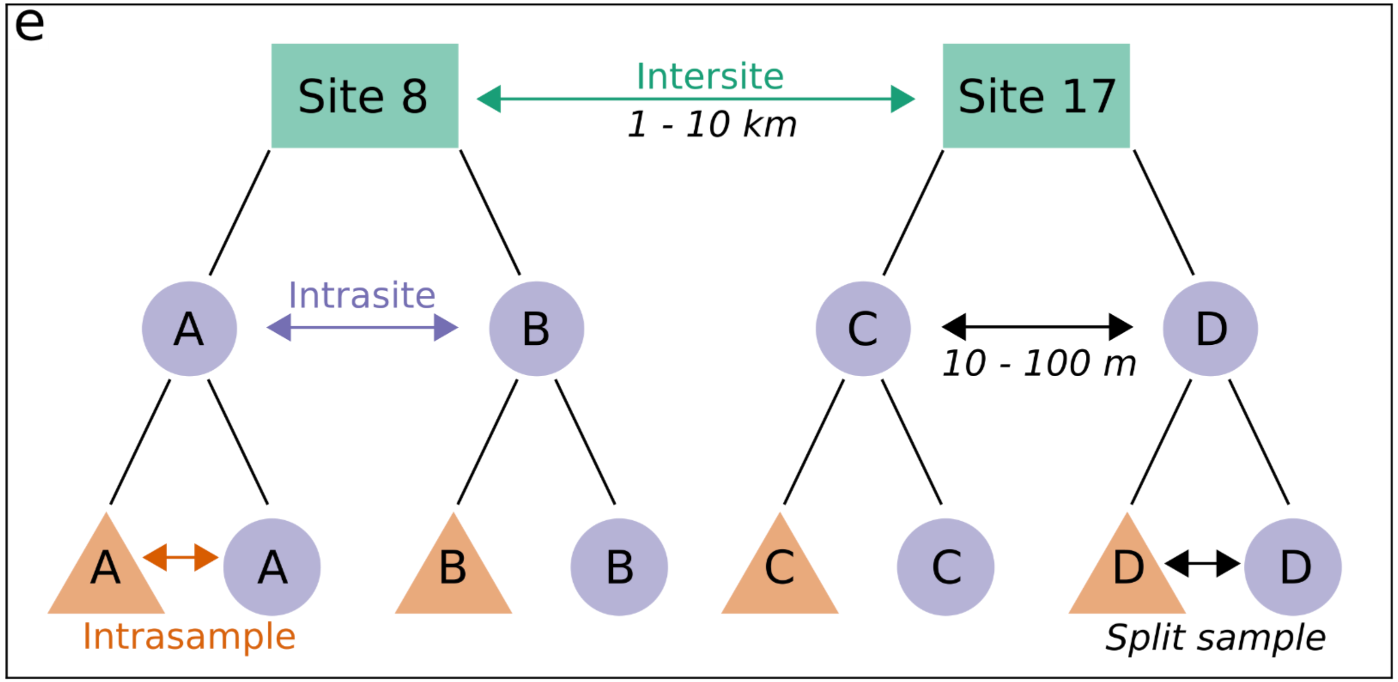


(a) Map of region with points indicating sample localities for G-BASE geochemical survey. Coloured polygons correspond to studied catchments. (b) Map of region with this study's higher order sample localities indicated. Cross indicates standard sample sites and plus indicates a duplicate site where two samples were taken.

- First order stream geochemistry is densely sampled by G-BASE survey[1]
- Our study samples 67 sites on higher order streams with 4 duplicated sites

[1] www.bgs.ac.uk/gbase/home.html

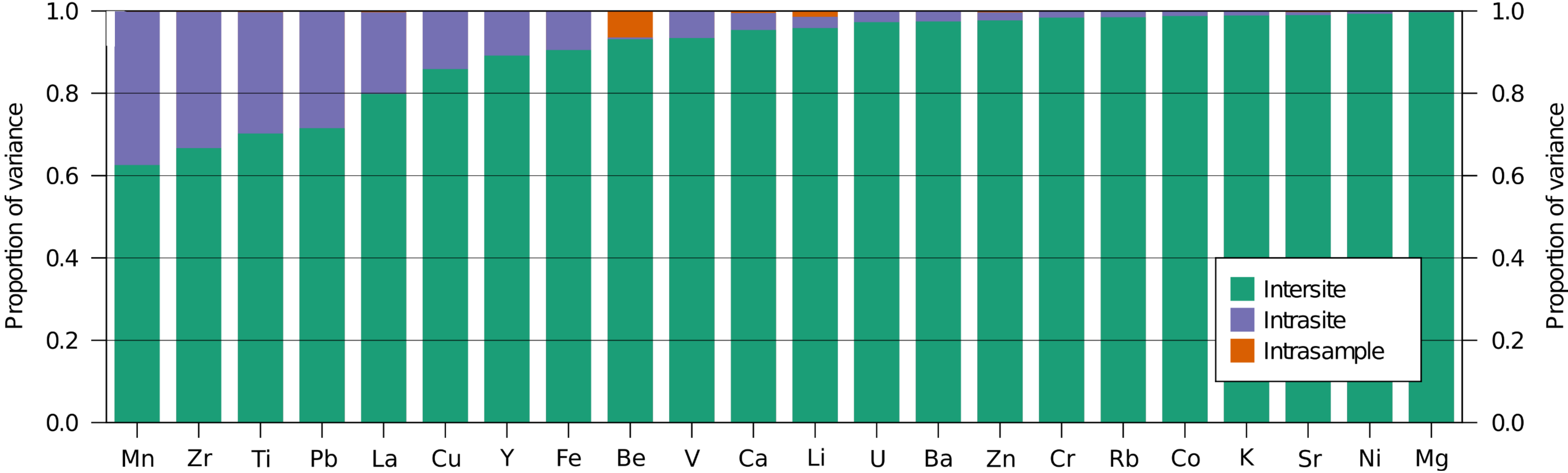
Sampling Methods



(a) Sampling kit; (b) Site 29 on Dee, arrow indicates flow direction; (c) Site 48 in Tay Catchment; (d) Site 55 on Tay; (e) Schematic of nested duplicate sample design for investigating sources of variance

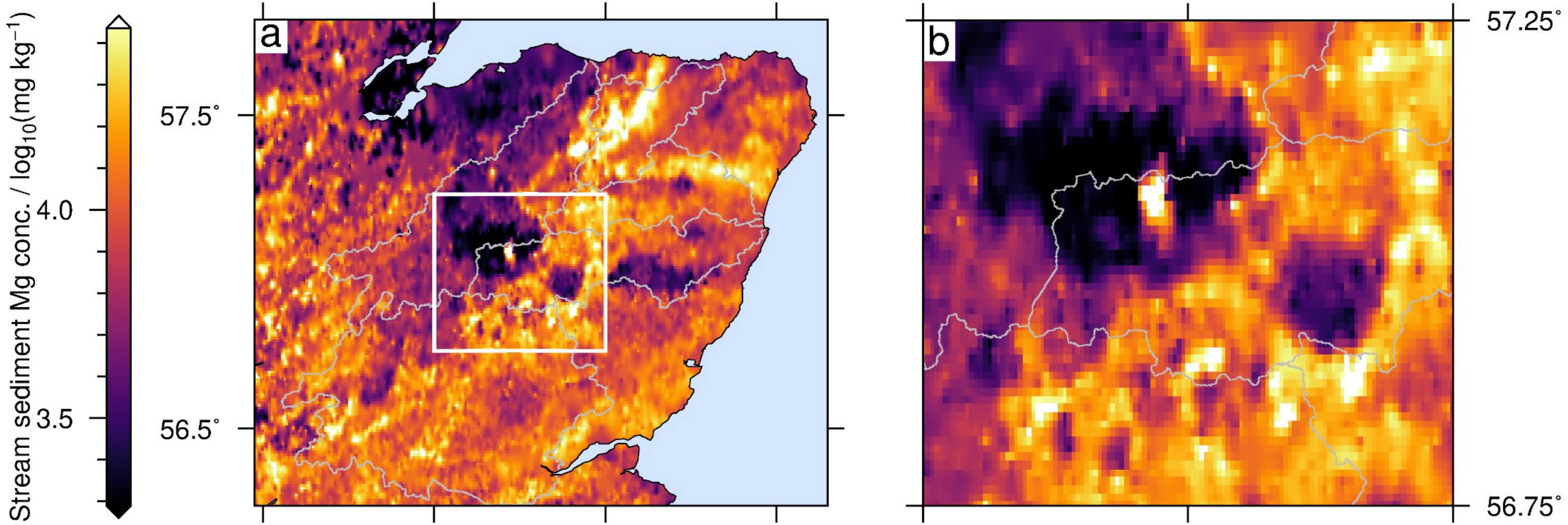
- < 150 µm fraction of bedload sampled by in situ wet sieving
- Duplicates taken at distances separated by ~100 m to investigate local heterogeneity
- Duplicates split in laboratory to create ‘replicates’ to investigate intrasample heterogeneity

Duplicates show large regional signals



- Results of a nested analysis of variance on duplicates and replicates show that most variance lies between sites for all elements
- Regional geochemical variability in river sediments dominates over local heterogeneity

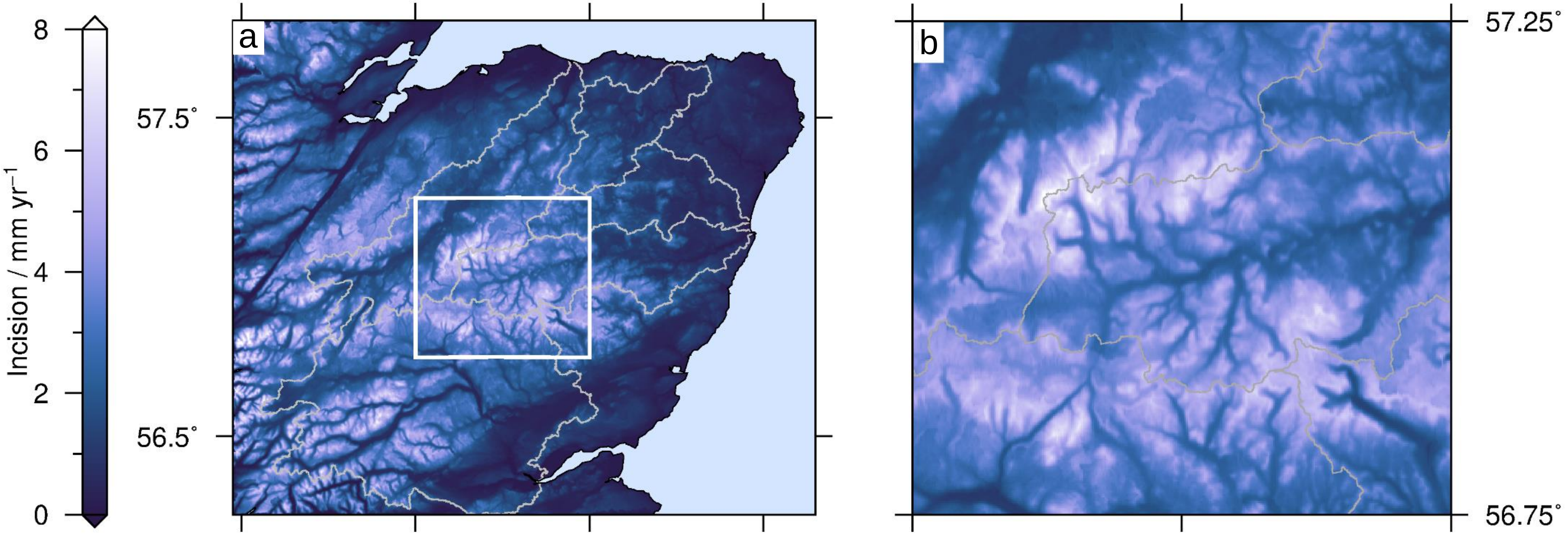
Landscape modelling - Inputs



(a) Interpolated G-BASE first order stream sediment Magnesium concentration; (b) Close up of upper reaches of Dee catchment for greater detail

- Interpolated G-BASE first order stream sediment geochemistry is used as a continuous map of source region geochemistry for making predictions in higher order streams.

Landscape modelling - Inputs

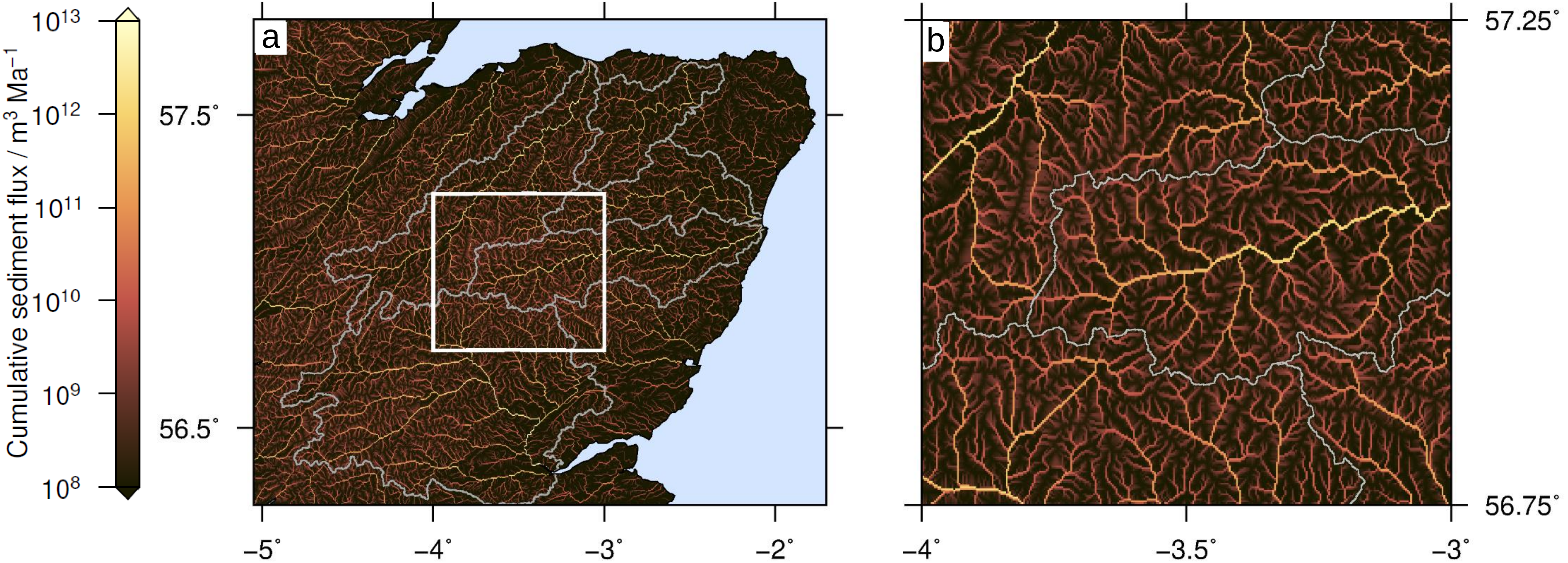


(a) Predicted incision assuming stream power law with k=3.37; n=1; m=0.35; (b) Close up of upper reaches of Dee catchment for greater detail

- SRTM1S topographic data is used to predict incision using stream power law implemented using LandLab[1]

[1] Hobley et al. (2017), doi.org/10.5194/esurf-5-21-2017

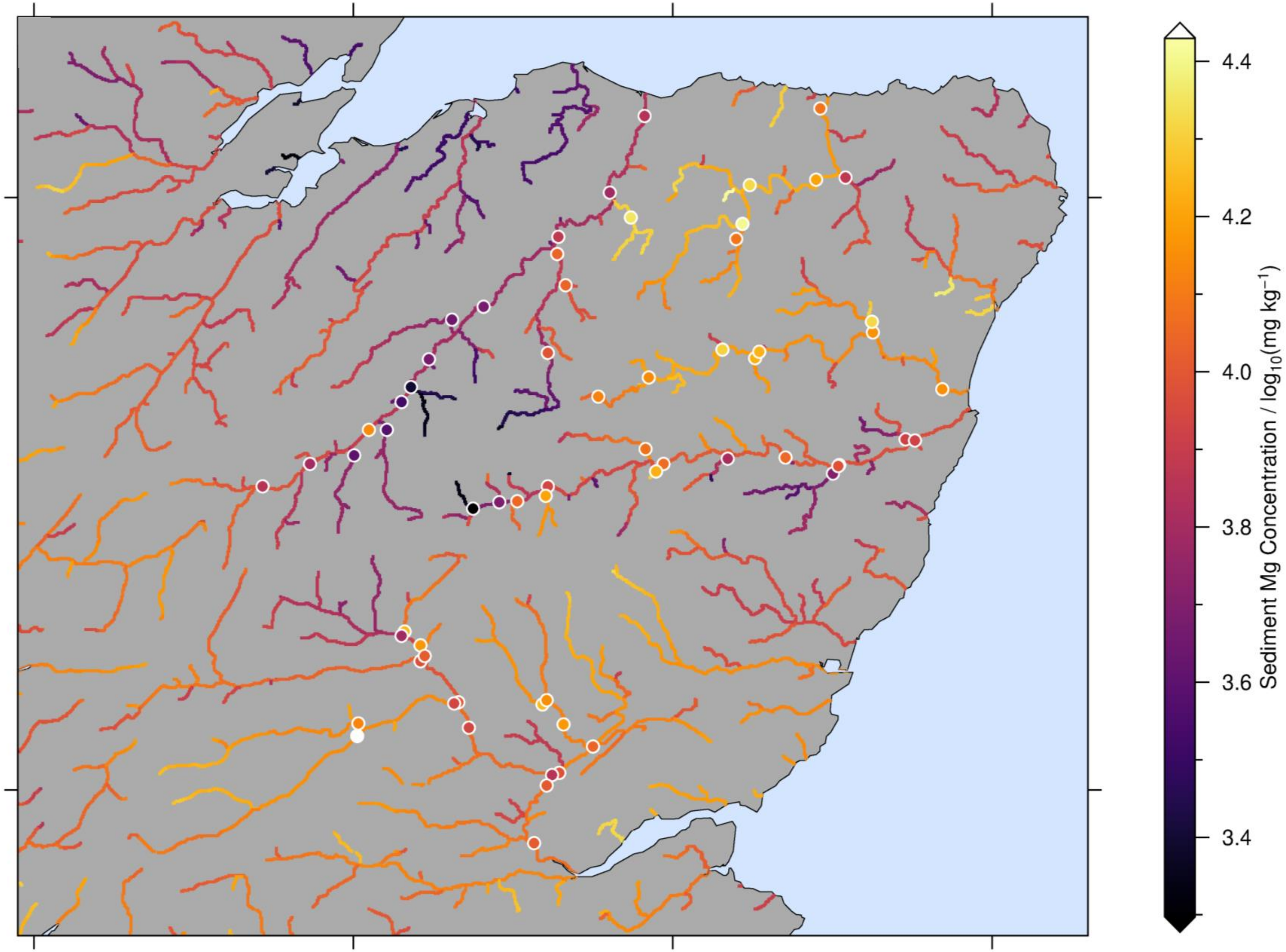
Landscape modelling - Inputs



(a) Predicted cumulative sediment flux assuming stream power law with k=3.62; n=1; m=0.35; (b) Close up of upper reaches of Dee catchment for greater detail

- Integrating predicted incision along flowpaths predicts total sediment flux
- This is used to predict composition of fluvial sediment at any point in the region

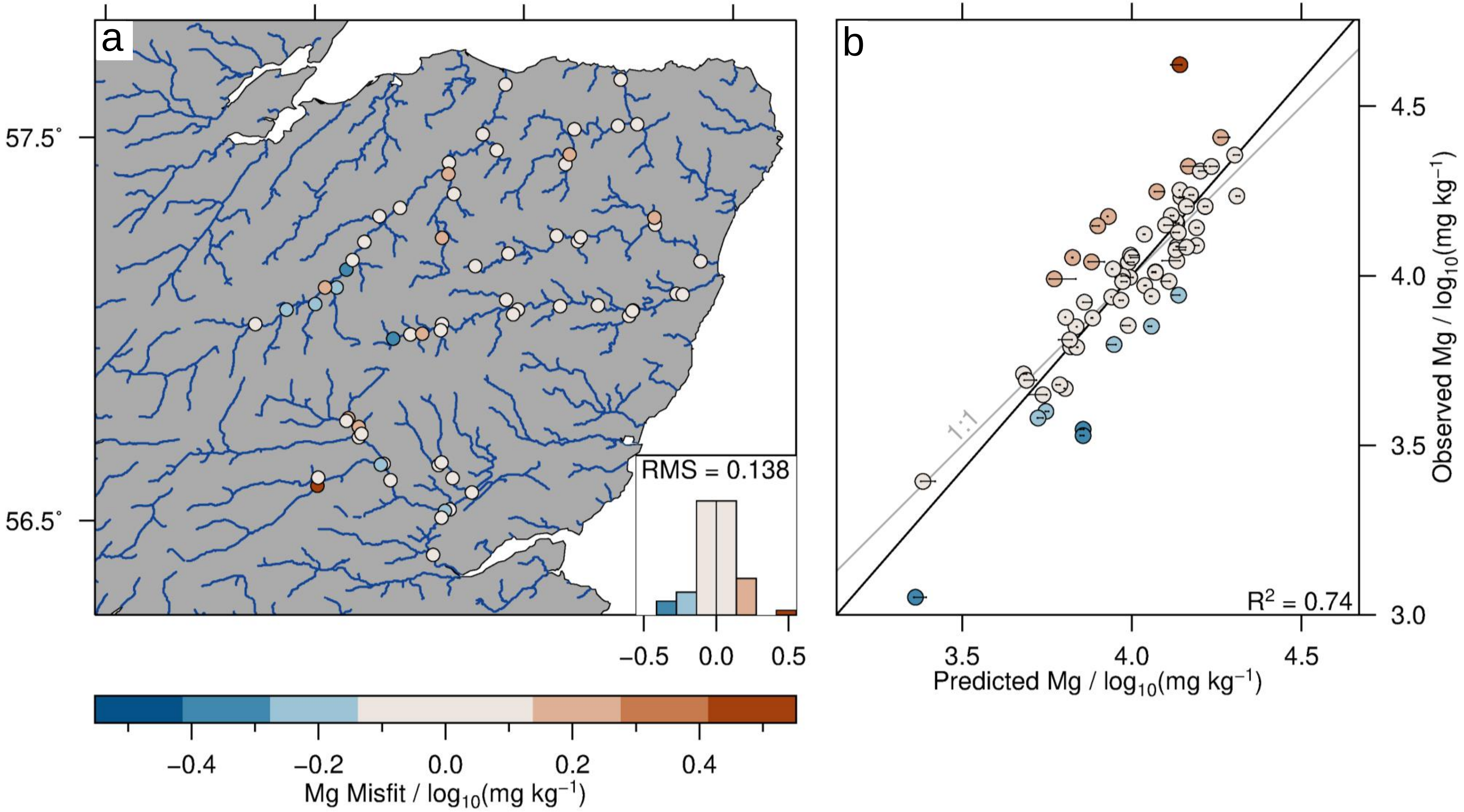
Predicting geochemistry - Results



Predicted sediment Mg concentration (continuous lines) overlain with observed values (filled circles)

- Predicted sediment geochemistry compared to observed geochemistry at sample sites
- Predictions successfully capture observed regional variability

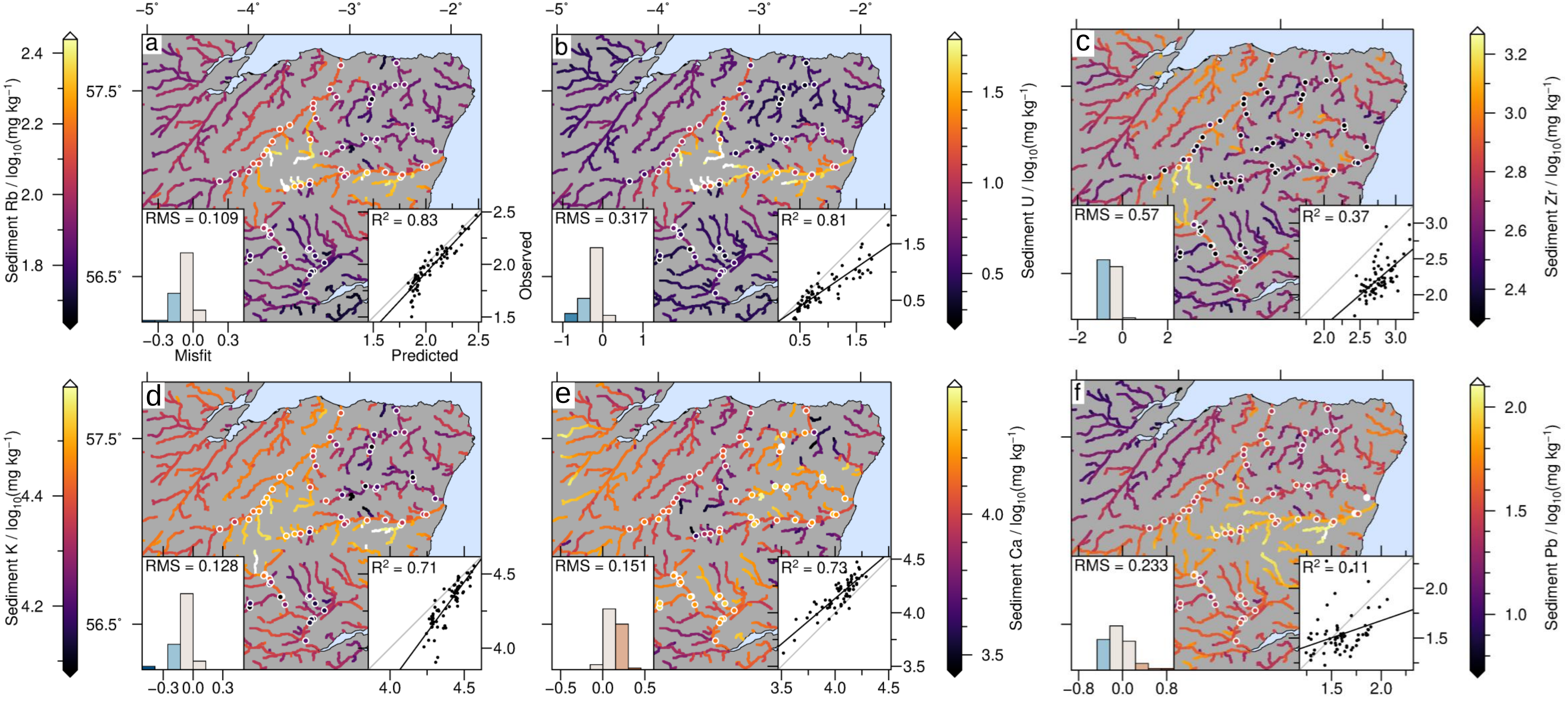
Predicting geochemistry - Results



(a) Misfit between predicted and observed Mg concentration. Inset histogram has binwidth = RMS misfit. (b) Cross-plot of predicted and observed Mg concentration colourised by misfit. Horizontal lines indicate range of predictions created by varying n in stream power law from 0.05 to 1.95

- Misfits show no geographic distribution nor significant bias for Magnesium

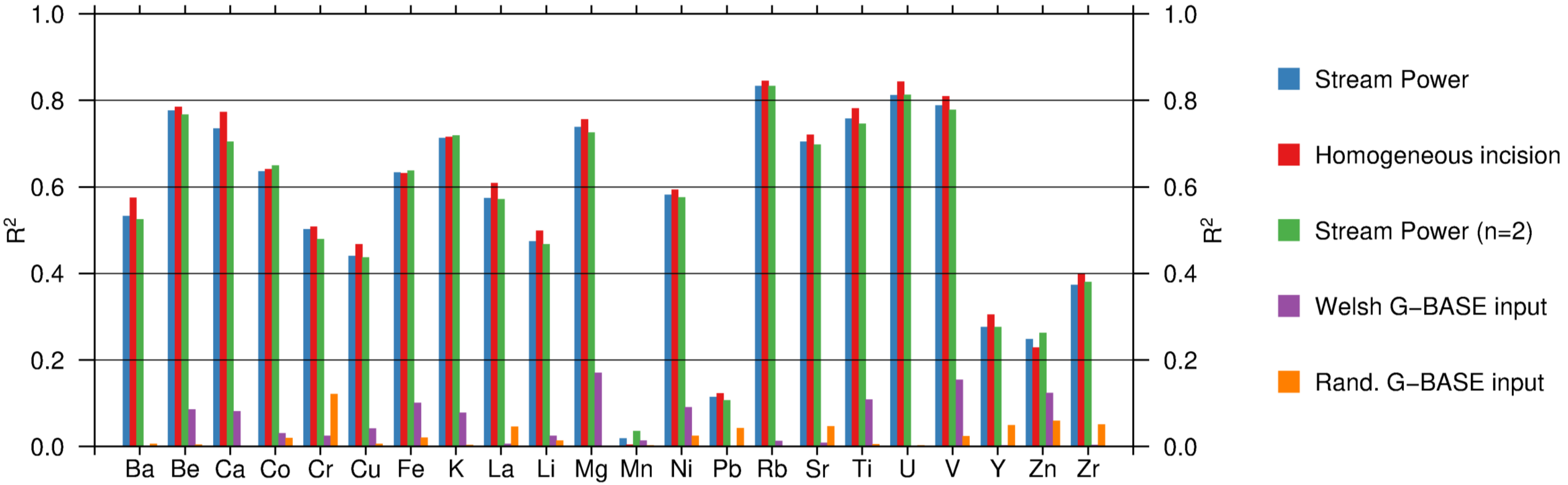
Predicting geochemistry - Results



(a) Comparison of predictions and observations for Rubidium concentrations. Inset histogram binwidth = RMS misfit, (b) Results for Uranium (c) Zirconium (d) Potassium (e) Calcium (f) Lead

- Most elements are well fitted by model although some (e.g., Zr, Pb) are not

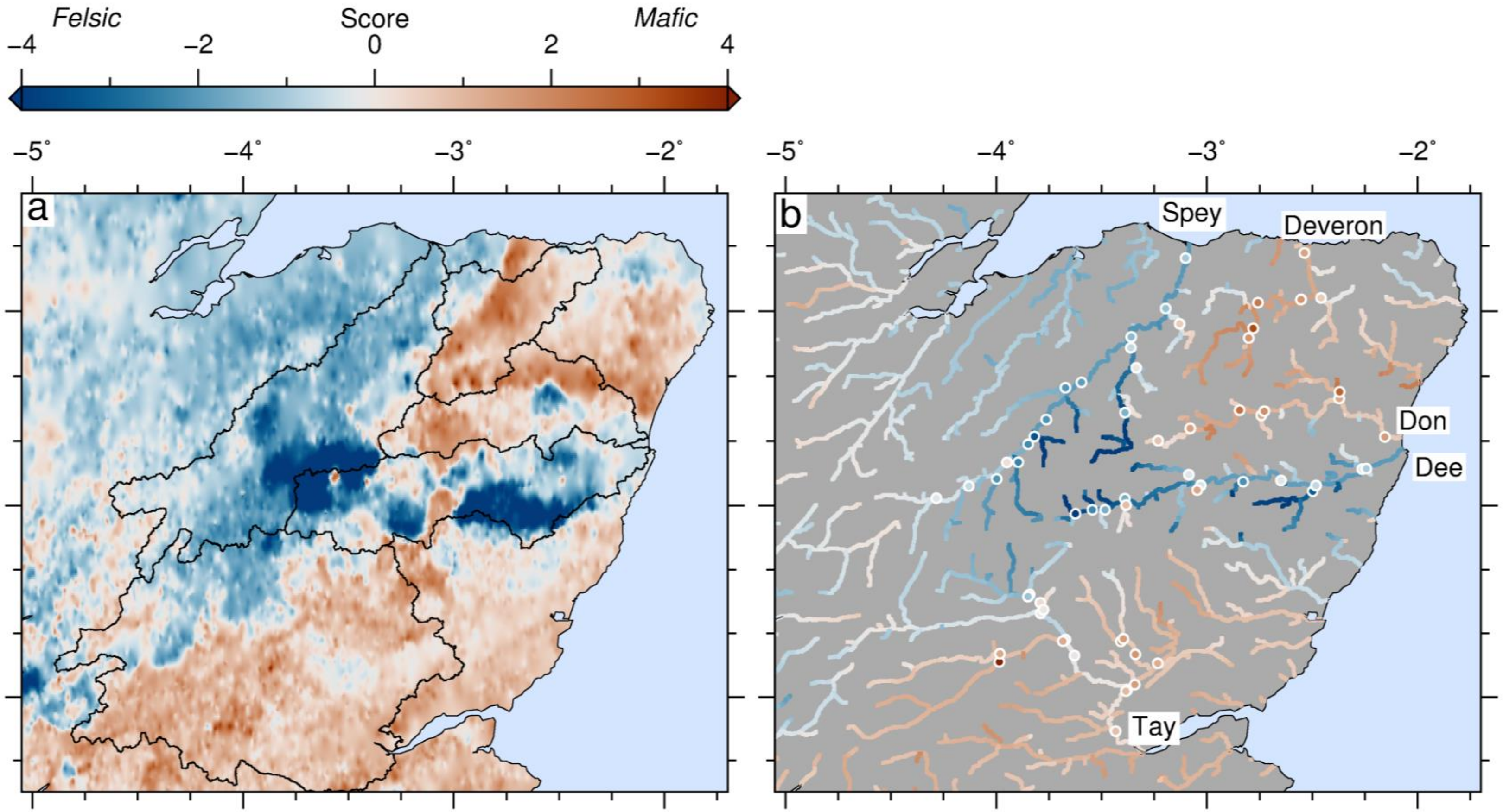
Changing erosion parameters



Model R^2 values for each element when different model parameters are changed, indicated by different colours. 'Welsh G-BASE input' refers to using a different quadrant of G-BASE geochemistry taken (arbitrarily) from Wales, UK; 'Rand. G-BASE' input refers to spatially randomising the original input G-BASE geochemistry. Only changing the geochemical input significantly affects model results.

- Different erosion parameters have a limited effect on model fit, including assuming homogenous incision
- Using different geochemical inputs has a strong negative effect on model fit

Geology sets fluvial composition



(a) G-BASE geochemistry projected onto loadings of first principal component of higher order stream sediment dataset. Note strong relationship to geology. (b) Scores of higher order stream sediment dataset for model predictions (continuous lines) and observations (filled circles). Blue indicates more felsic source region and red indicates more mafic source. First principal component contains 67 % of total variance.

- Principal Component Analysis indicates geology is the primary control on higher order sediment geochemistry
- Observations could therefore be inverted using stream power law to derive source region geology

Conclusions

- Stream sediment geochemical surveys can be combined with landscape evolution models to prediction fluvial sediment geochemistry.

- Testing model predictions in a case study in NE Scotland indicates a good fit between predictions and observations.

- Geology is major control on sediment geochemistry indicating sediments could be inverted for source region geology.

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