On the feasibility of detecting Rare Earth Element (REE) deposits using remote sensing

David A. Neave[a], Martin Black[b,c], Teal R. Riley[b], Sally A. Gibson[a], Graham Ferrier[c], Frances Wall[d] and Sam Broom-Fendley[d]

[a] *Department of Earth Sciences, University of Cambridge, United Kingdom, dan27@cam.ac.uk*
[b] *British Antarctic Survey, High Cross, Madingley Road, Cambridge, United Kingdom*
[c] *Department of Geography, Environment and Earth Sciences, University of Hull, United Kingdom*
[d] *Camborne School of Mines, University of Exeter, United Kingdom*

Rare Earth Elements (REEs) are crucial raw materials in a wide range of technological products and are consequently considered amongst the critical metals, i.e. they are of key economic importance and might be susceptible to future supply restrictions. Carbonatites (igneous rocks containing >50% carbonate) and alkaline silicate rocks are by the far the most significant hosts of REEs. Many REEs have unique spectral properties at visible and near infrared wavelengths (VNIR; 400–1400 nm) that make them directly detectable with reflectance spectroscopy: most lanthanide series elements undergo f-f electronic transitions caused by absorption of photons at specific wavelengths resulting in multiple diagnostic absorptions. Although previous generations of multispectral and hyperspectral instruments have been insufficiently sensitive to resolve the narrow absorption features associated with REEs, improvements in the sensitivity of upcoming instruments, such as HyspIRI and EnMAP, may enable REEs to be detected from satellite-based platforms for the first time. In order to ground truth future remote sensing data, we have acquired spectral reflectance and emissivity data from a range of REE-mineralised samples that contain the following REE-rich phases: monazite-(Ce), bastnäsite-(Ce), synchysite-(Ce), ancylite(-Ce), eudialyte and pyrochlore. VNIR reflectance and TIR (thermal infra-red) emissivity spectra were collected at the NERC Field Spectroscopy Facility (FSF) using an ASD FieldSpec® Pro field spectroradiometer and MIDAC field portable FTIR. Initial findings confirm the presence of strong REE absorbance features (particularly Nd) in the VNIR reflectance spectra of carbonatites and syenites from locations including Bayan Obo, China and Mountain Pass, USA. By resampling our spectra to the spectral responses of various instruments we demonstrate that REE absorption features should be detectable in high quality hyperspectral datasets of high grade deposits.

On the feasibility of detecting rare earth element (REE) deposits using remote sensing

David A. Neave*,[a], Martin Black[†,b,c], Teal R. Riley[b], Sally A. Gibson[a], Graham Ferrier[c], Frances Wall[d] and Sam Broom-Fendley[d]

*Corresponding author: dan27@cam.ac.uk; [†]Presenting author; [a]University of Cambridge; [b]British Antarctic Survey; [c]University of Hull; [d]Camborne School of Mines

UNIVERSITY OF CAMBRIDGE · British Antarctic Survey · NATURAL ENVIRONMENT RESEARCH COUNCIL · UNIVERSITY OF Hull · UNIVERSITY OF EXETER · NERC SCIENCE OF THE ENVIRONMENT

Abstract

Carbonatites and their alkaline associates are the primary hosts for global reserves of rare earth elements (REEs). Many REEs have unique spectral properties at visible and near infrared wavelengths (VNIR; 400–1400 nm) that make them directly detectable with reflectance spectroscopy. Previous studies indicated that neodymium (Nd) has the most diagnostic spectral features of the REEs[1]. Although various studies have demonstrated that carbonatite complexes can be mapped using remote sensing techniques[2,3], current satellite-based multispectral instruments have rarely been able to resolve the narrow absorption features associated with REEs because of their coarse spectral resolutions[4]. However, the improved spectral resolution in planned hyperspectral instruments, such as EnMAP[5], may enable REEs to be detected directly from satellite-based platforms in future.

In order to ground truth future remote sensing datasets, we have acquired spectral reflectance data from a range of petrologically-characterised REE-rich samples that contain the following REE-rich phases: *monazite-(Ce)*, *bastnäsite-(Ce)*, *parisite-(Ce)*, *synchysite-(Ce)*, *ancylite-(Ce)*, *eudialyte* and *pyrochlore*. Our findings confirm the presence of strong Nd^{3+} absorbance features in the VNIR reflectance spectra of REE-rich rocks from locations including *Bayan Obo, China*; *Mountain Pass, USA*; *Kangankunde, Malawi*; and *Qeqertaasaq, Greenland*. Resampling (i.e convolving) our laboratory spectra to the spectral response functions (SRFs) of a range of remote sensing instruments shows that while REEs cannot be detected by multispectral instruments, REEs absorptions can be resolved by both aircraft- and satellite-based hyperspectral platforms at realistically achievable signal-to-noise ratios. Challenges facing REE detection by remote sensing are thus dominantly geological rather than instrumental in nature, i.e relate to deposit size, lithological heterogeneity and style of outcropping.

Sample sources & characteristics
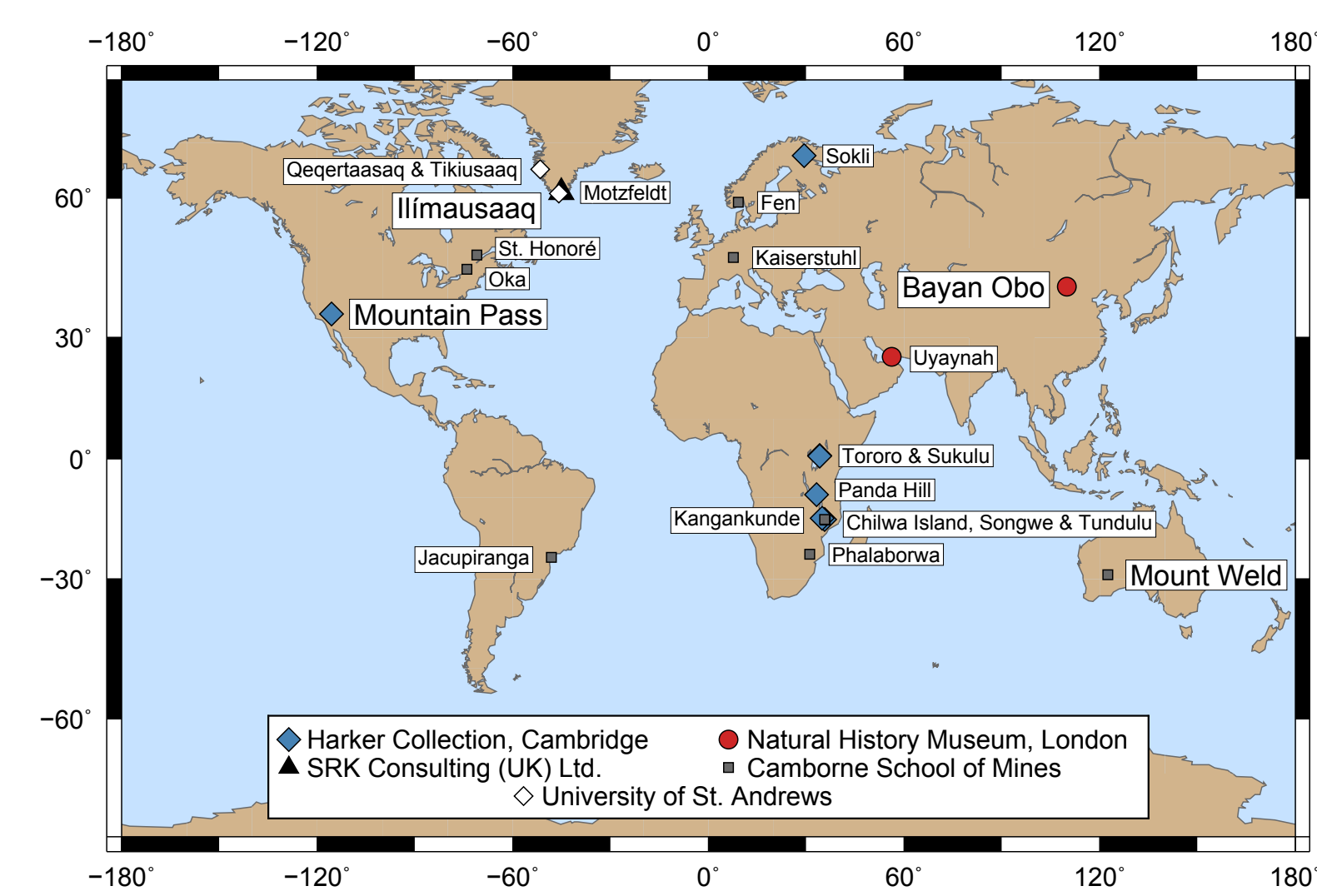
Map showing the geographical distribution of samples used in this study, as well as the collections from which they were sourced. Whole-rock analyses indicate that samples contain ~100-100000 ppm Nd.

Samples were selected to cover a diversity of carbonate mineralogies, whole-rock REE contents, and styles of REE mineralisation.

Samples include calciocarbonatites, such as *Oka, Canada*, ferrocarbonatites, such as *Kangankunde, Malawi*, REE ores, such as the Banded Ore from *Bayan Obo, China*, and extrusive carbonatites from *Uyaynah, UAE* and *Fort Portal, Uganda*.
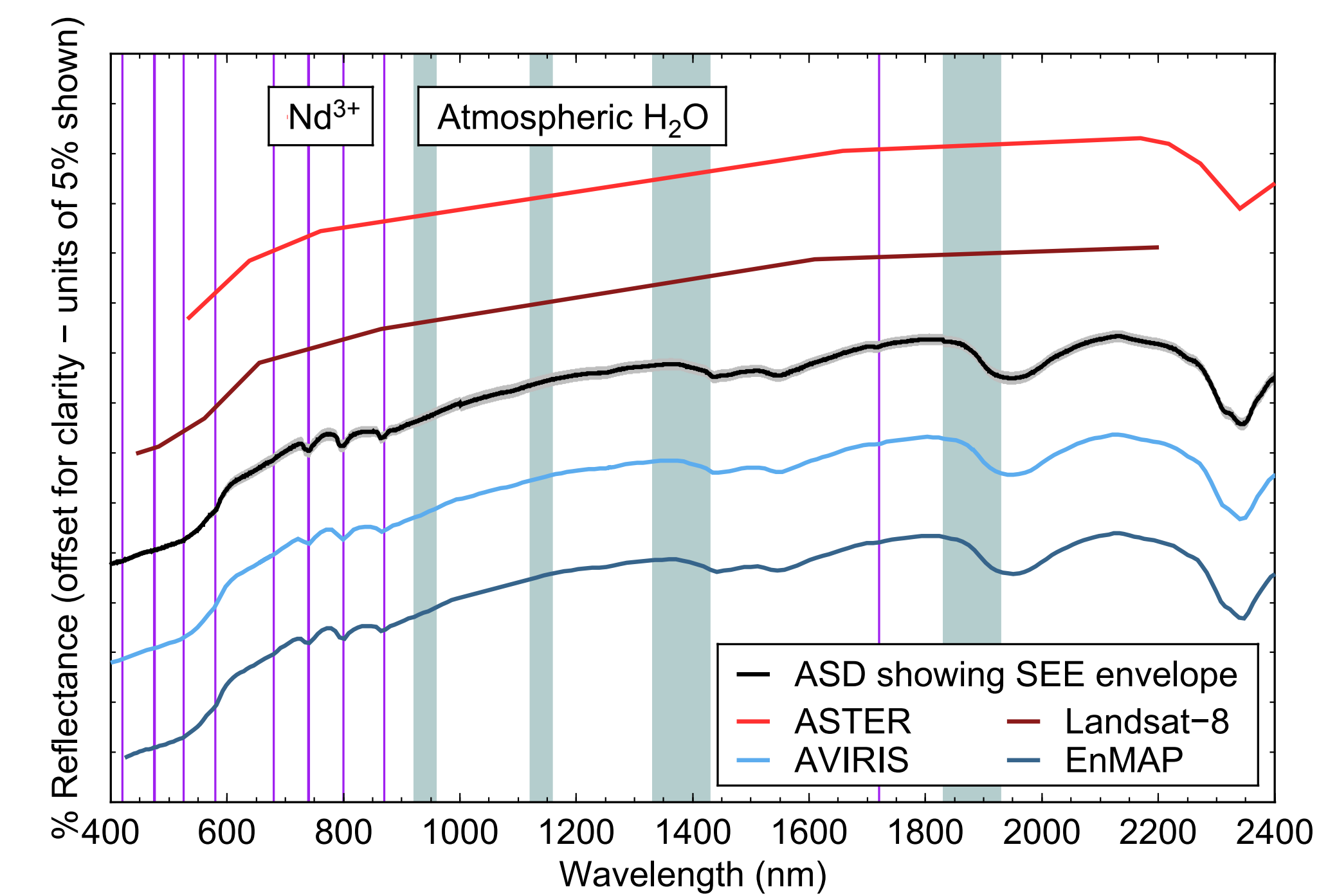
Pyrochlore- and *eudialyte*-bearing alkaline rocks from the *Motzfeldt* and *Ilimaussaq* centres in *Greenland* that represent Nb, Ta and REE prospects were also investigated.

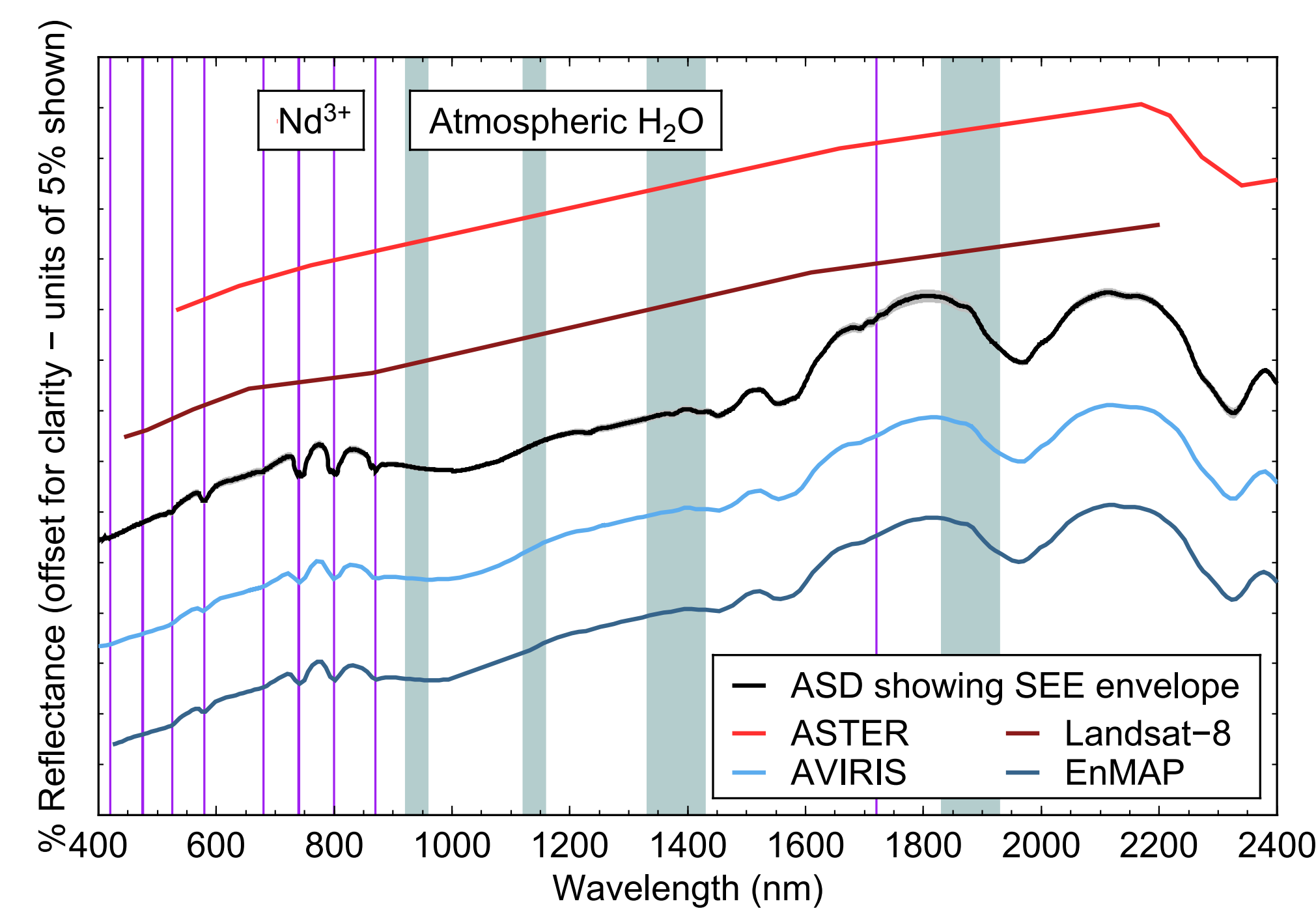## Measured and resampled visible & near infrared (VNIR) spectra

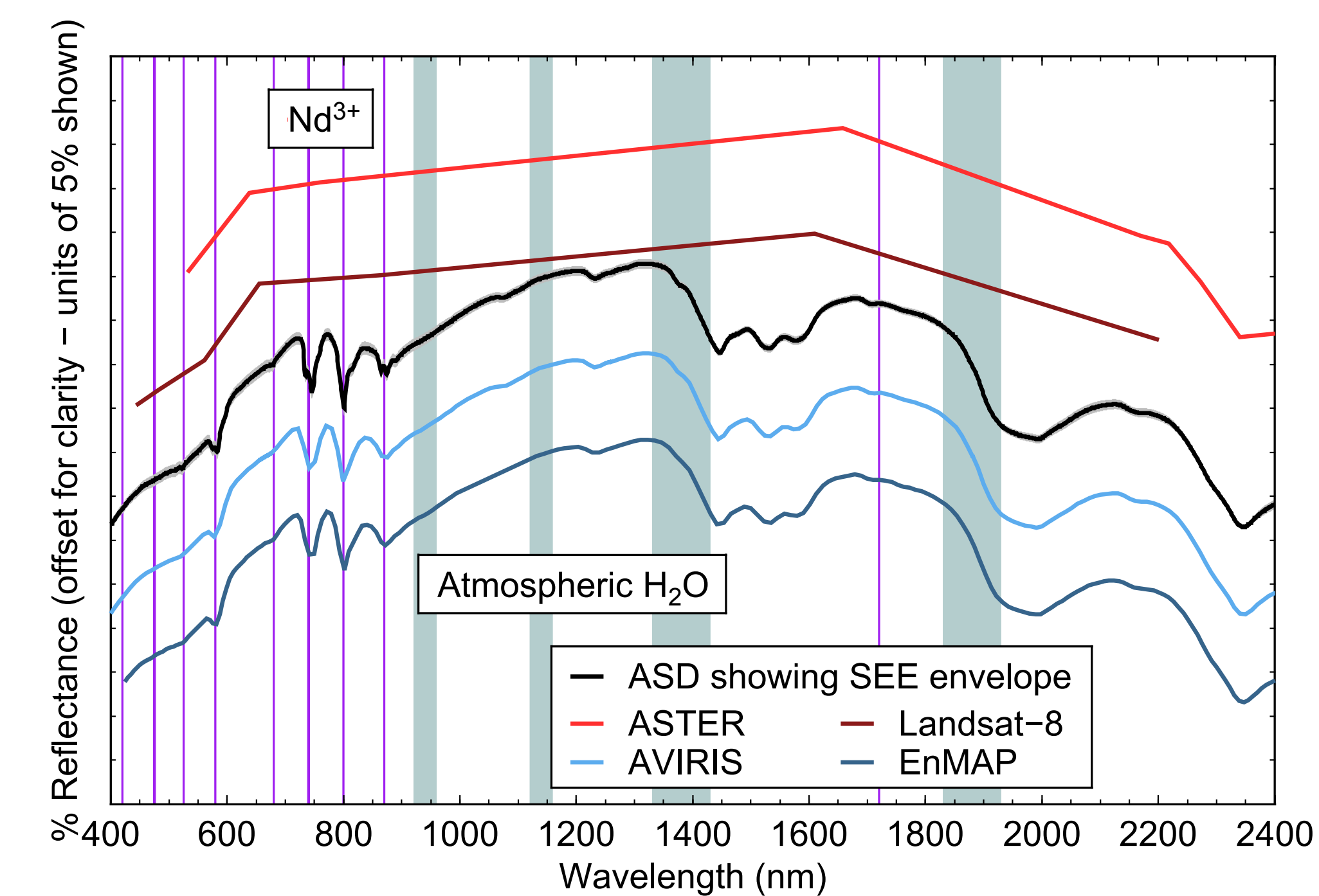*Bastnäsite*- & *monazite*-bearing Banded Ore from *Bayan Obo, China*
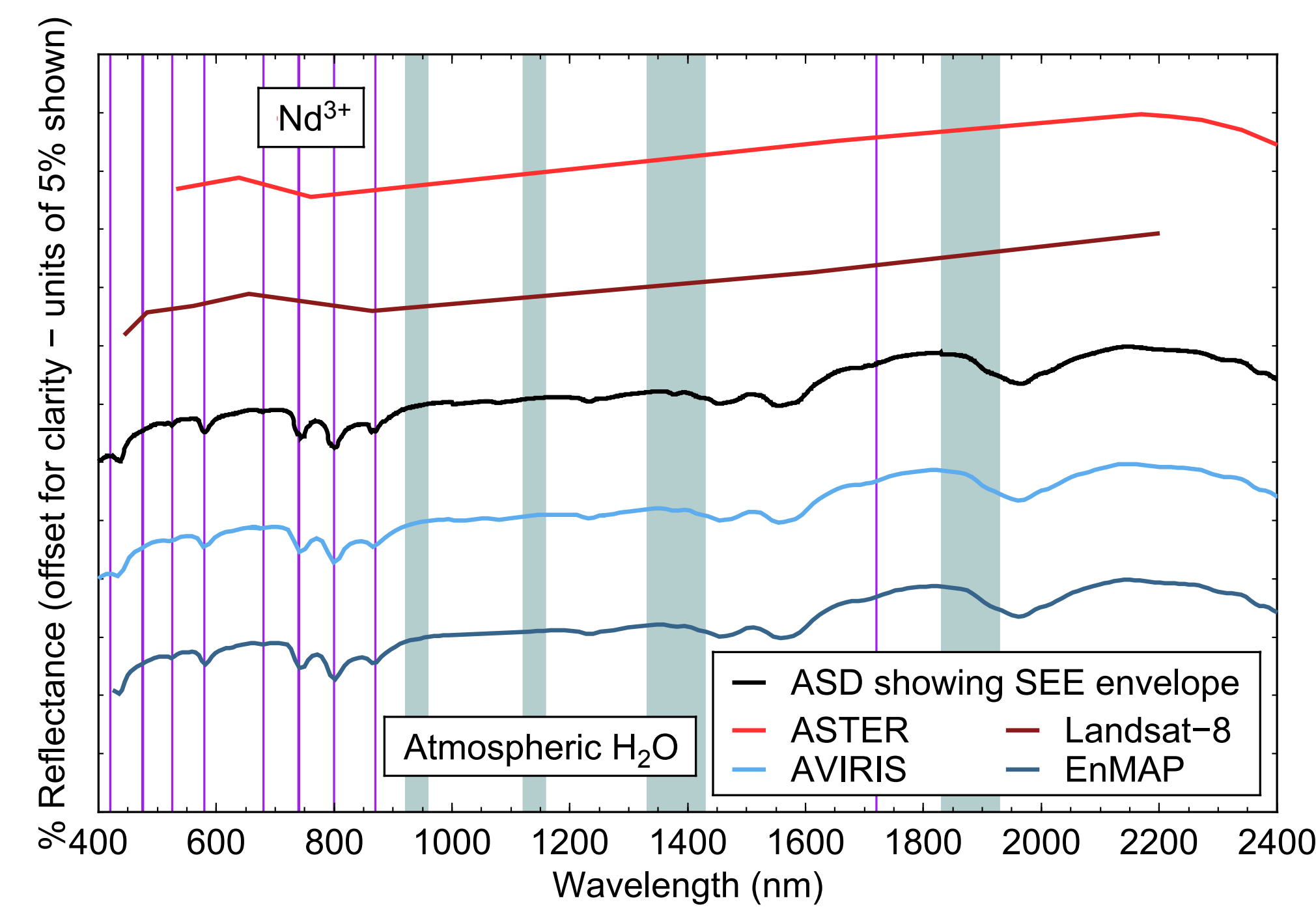
Bastnäsite-bearing calciocarbonatite from *Mountain Pass, USA*

Monazite-bearing ferrocarbonatite from *Kangankunde, Malawi*

Ancylite-bearing calciocarbonatite from *Qeqertaasaq, Greenland*

Remote sensing instruments

Multispectral instruments

ASTER – Advanced Spaceborne Thermal Emission and Reflection Radiometer

ASTER is a Japanese multispectral instrument on the Terra satellite that was launched in 1999. The instrument collects images at 14 visible and infrared wavelength bands with a spatial resolution of 15–90 m. Although ASTER has been used for mapping carbonatites with some success[3,4], it's spectral resolution is insufficient to detect narrow REE absorption features.

Landsat–8

Landsat–8 is an American multispectral satellite that was launched in 2013. The instrument collects images at nine visible and shortwave infrared, and two thermal infrared wavelength bands with resolutions of 30 m and 100 m respectively. As with ASTER, the spectral resolution of Landsat–8 is insufficient to detect narrow

Hyperspectral instruments

**EnMAP** – Environmental Mapping and Analysis Program

EnMAP is a German satellite-based hyperspectral instrument planned for launch in 2015. The instrument is planned to image 244 adjacent spectral bands at 420 –2450 nm with a spatial resolution of 30 m. EnMAP is likely to represent a new baseline in satellite-based hyperspectral remote sensing imagery.

AVIRIS – Airborne Visible/InfraRed Imaging Spectrometer

AVIRIS is an airborne hyperspectral instrument designed by the Jet Propulsion Laboratory (JPL) in the USA that has been in use since 1987. The instrument uses four spectrometers to image 244 adjacent spectral bands at 400–2500 nm. AVIRIS has been succesfully used to undertake lithological mapping of carbonatites[6], including possible identification of REE-rich material[7].

Methods

Measuring visible & near infrared (VNIR) spectra
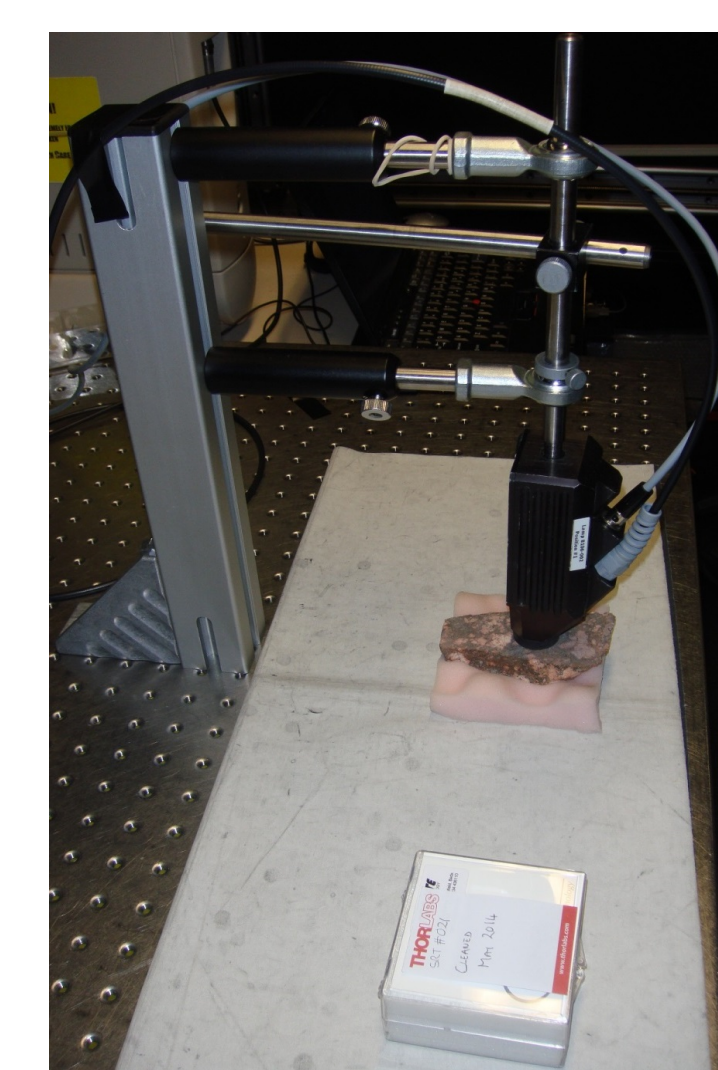
Collecting VNIR spectra from the *Mountain Pass* sample using an ASD FieldSpec® Pro spectroradiometer at the NERC Field Spectroscopy Facility.
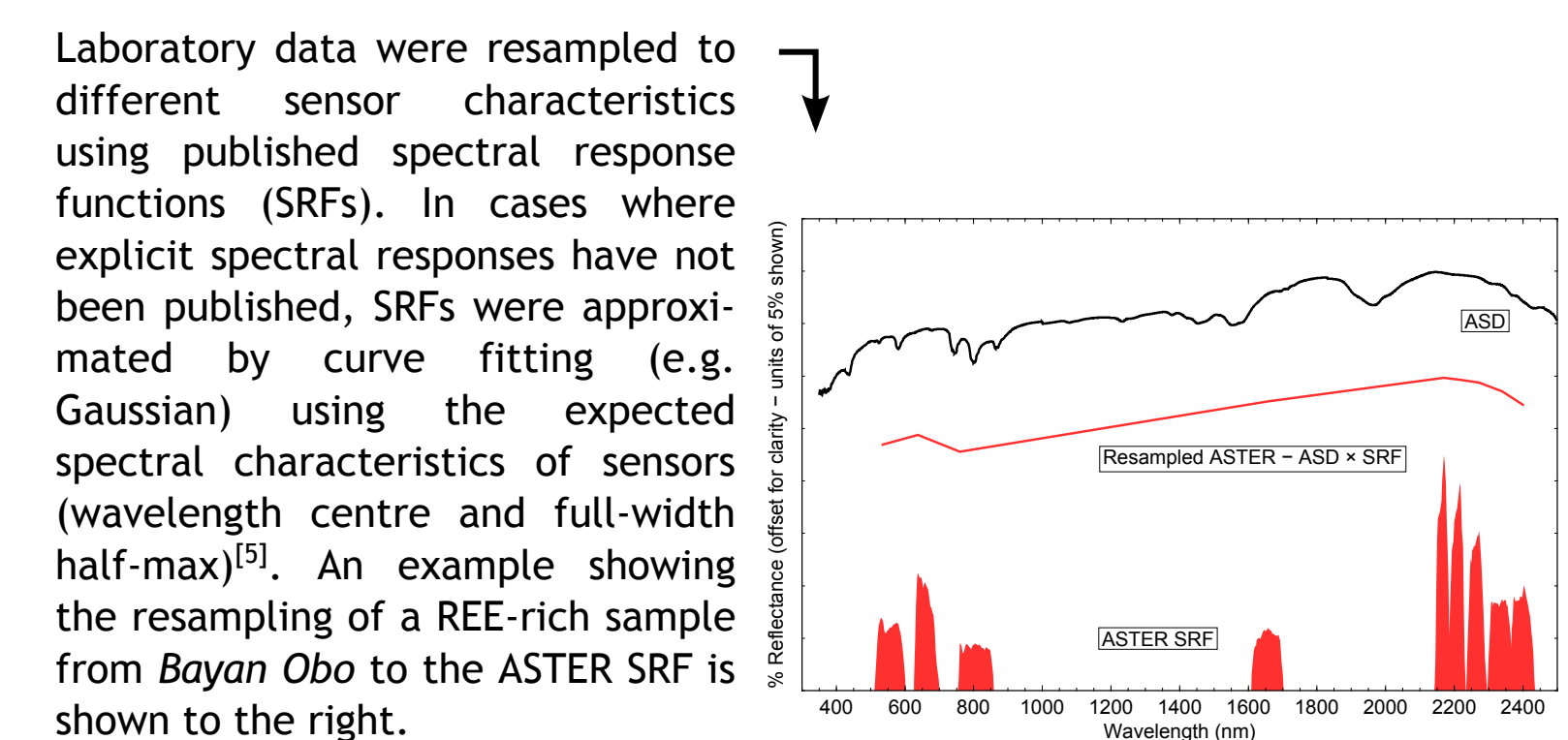
Measurements were made in a darkroom using a contact probe, and calibrated against a Spectralon white panel.

The sampling interval is 1.4 nm at λ=350–1000 nm, and 2 nm at λ=1000–2500 nm, where λ is wavelength.

The spectral resolution is 3 nm at λ=700 nm, 10 nm at λ=1400 nm and 12 nm at λ=2100nm.

Simulating remote sensing data – spectral convolution

Spectral data were spectrally resampled (convolved) in order to simulate acquisition by a number of airborne and spaceborne multispectral and hyperspectral sensors. It is thus possible to assess whether various instruments would theoretically be able to detect the narrow absorption features generated by REEs. Details of the chosen sensors are provided in the pink box to the right.

Laboratory data were resampled to different sensor characteristics using published spectral response functions (SRFs). In cases where explicit spectral responses have not been published, SRFs were approximated by curve fitting (e.g. Gaussian) using the expected spectral characteristics of sensors (wavelength centre and full-width half-max)[5]. An example showing the resampling of a REE-rich sample from *Bayan Obo* to the ASTER SRF is shown to the right.


Sensitivity analysis

The sensitivity of hyperspectral remote sensing instruments to REE absorption features was tested by adding random Gaussian noise to a number of resampled spectra using the method of Biocuas-Dias & Nascimento[8].

Synthetic noise was generated at a range of signal-to-noise ratios (SNRs) relevant to remote sensing applications: AVIRIS has been shown to achieve SNR>350 at λ~700 nm. EnMAP is expected to achieve SNRs up to 450 at λ~700 nm under ideal conditions[5].

REE absorption features remain resolvable at SNR=100 in REE-rich samples that have been resampled to the EnMAP SRF, such as the Banded Ore example from *Bayan Obo, China* that is shown to the right. A SNR of 100 should be routinely achievable during hyperspectral imaging campaigns.
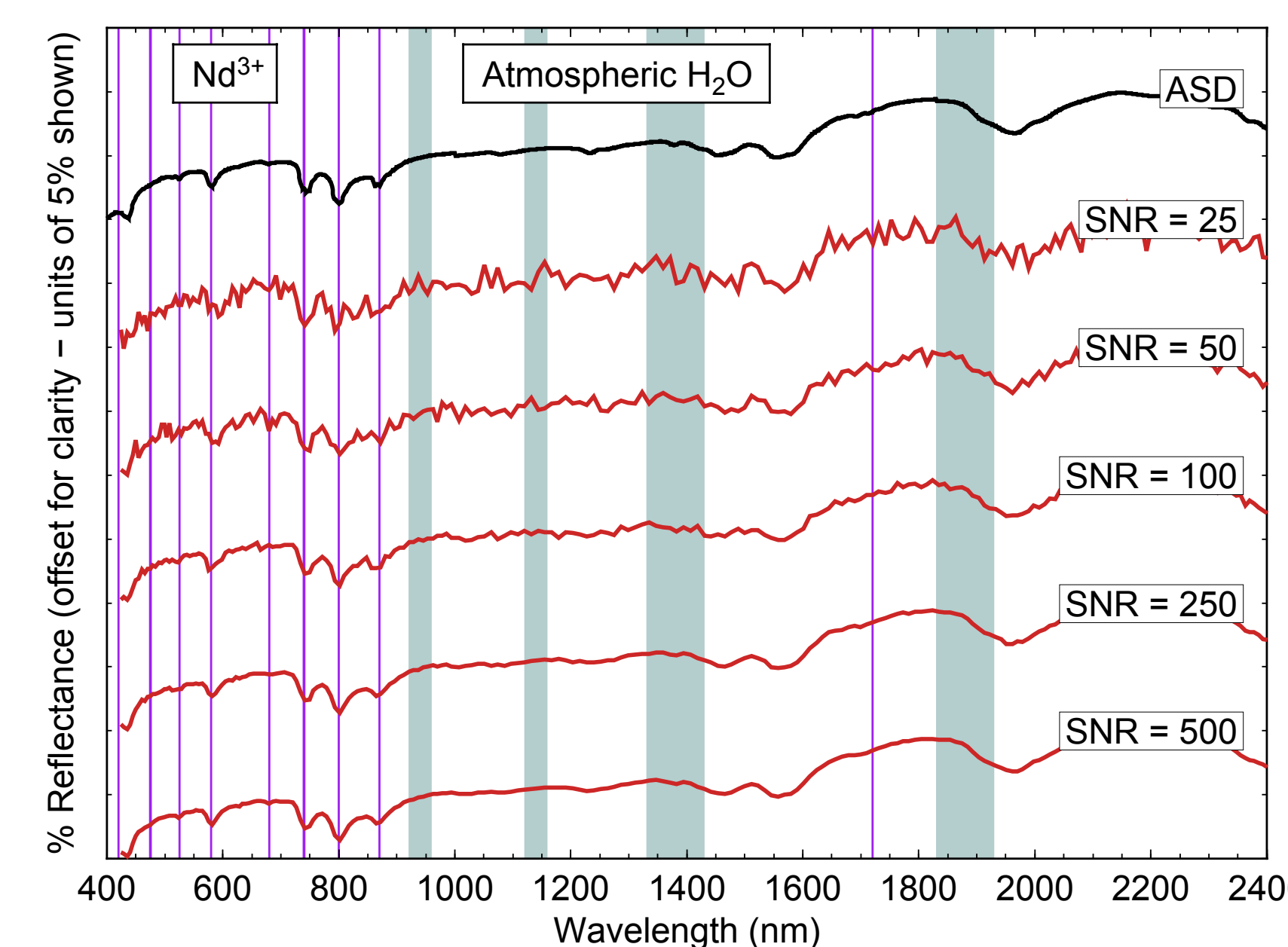
Conclusions

REE absorption features can be identified in VNIR spectra from a number of REE-rich carbonatites using a field-portable spectroradiometer.

Nd^{3+} absorption features are independent of REE mineralogy.

Simulating remote sensing data by resampling (convolving) lab spectra to a range of intrument SRFs indicates that REE-spectra can theoretically be detected by hyperspectral sensors on both aircraft- and satellite-based platforms. REEs are not unambiguosly identifiable using current multispectral sensors.

Sensitivity analysis indicates that REE absorption features, such as the diagnostic Nd^{3+} absorptions centred at 740 nm and 800 nm, are reproduced in resampled spectra of high grade rocks at signal-to-noise ratios as low as 100.

Petrographic and geochemical analyses are currently underway in order to quantify relationships between spectral features, mineralogy and whole-rock geochemistry.

References

[1] Rowan, L. C., Kingston, M. B. Crowley, J. (1986). Economic Geology 81, 857–871.
[2] Bedini, E. (2009). Remote Sensing of Environment 113, 1208–1219.
[3] Rowan, L. C. & Mars, J. C. (2003). Remote Sensing of Environment 84, 350–366.
[4] Mars, J. C. & Rowan, L. C. (2011). Geosphere 7, 276-289.
[5] www.enmap.org/sites/default/files/pdf/Table_EnMAP_Specs.pdf
[6] Rowan, L. C. & Bowers, T. (1995). Economic Geology 90, 1966–1982.
[7] Crowley, J., Rowan, L. & Podwysocki, M. (1988). Proceedings of the Airborne Visible/infrared Imaging Spectrometer (AVIRIS) Performance Evaluation Workshop, JPL publication 6-8.
[8] Bioucas-Dias, J. M. & Nascimento, J. M. P. (2008). IEEE Transactions on Geoscience and Remote Sensing 46, 2435-2445.