Vol. 46 — N° 4 12 22 p. 753–759

GEOSTANDARDS and GEOANALYTICAL RESEARCH

Geostandards and Geoanalytical Research Bibliographic Review 2021

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This GGR Bibliographic Review is a survey of approximately 5200 geoanalytical publications for the year 2021. Selected articles, numbering over 340, containing measurement results for relevant geological and environmental reference materials are listed with individual summaries of target analytes, relevant reference materials and producers. A brief summary of a selection of these publications is included that highlights notable developments in geoanalytical studies, newly developed or characterised RMs, and new datasets of established reference materials that have been re-analysed using improved or state-of-the-art measurement techniques.

Keywords: review, analytical geochemistry, geochemical reference materials, reference material data, GeoReM database, environmental reference materials.

Received 24 Oct 22 – Accepted 26 Oct 22

The Geostandards and Geoanalytical Research Bibliographic Review 2021 comprises a survey of a broad selection of scientific publications released in 2021 that contain analytical data for geoanalytical and environmental reference materials (RMs). The research includes journals specializing in classical geochemistry as well as journals for a wide range of related topics such as biogeochemistry or environmental chemistry. As a result of this a huge spectrum of RMs ranging from natural minerals such as zircon or biogenic samples such as corals to synthetic glasses or pressed powder pellets is represented in this review.

The 2021 Review is the result of a survey of more than 5000 publications of about twenty scientific journals from various publishers. Unfortunately, the Max Planck Society had only access to a single journal from Elsevier. Therefore, many Elsevier journals which were covered by the Geostandards and Geoanalytical Research Bibliographic Review in former years are not included in this review, with the exception of "Lithos". As a consequence, for 2021 the total quantity of publications incorporated in this outline is significantly lower than in recent years (e.g., Weis *et al.* 2022). In almost 350 papers, which are equivalent to nearly 7% of the surveyed papers from 2021, there are published analytical data for RMs (Table 1, Figure 1). Many well established RMs such as those of the USGS or NIST are represented, as well as numerous recently developed or characterised RMs. Figure 2 demonstrates that the governmental organisations USGS, NIST, IRMM and GSJ provide the most frequent used RMs. The share of publications with analytical results for RMs from USGS, NIST, IRMM and GSJ is 43%, 37%, 23% and 22% respectively. The importance of these RMs is also confirmed by the number of queries within the GeoReM database (Jochum *et al.* 2005). Figure 3 shows eleven RMs with the highest number of requests in GeoReM. Most of them are geological materials provided by the USGS, the others are two synthetic glasses from NIST. All of them are well characterised with certified and reference values for numerous elements (Jochum *et al.* 2011, 2016). Because of a recent internal reorganisation, the USGS materials have been not available in the last few years, but now they can be ordered again via the USGS homepage (https://www.usgs.gov/centers/gggsc/science/usgs-geochemical-and-microanalytical-reference-materials-distribution).

Hereafter, some newly introduced RMs and some broad studies using improved analytical methods are emphasised. All data of publications that are part of this review are incorporated in the GeoReM database, which is available on a free access basis (http://georem.mpch-mainz.gwdg.de). GeoReM is a database for RMs of geological and environmental interest. The recent Application Version 34 of GeoReM (as of November 2022) contains more than 3900

doi: 10.1111/ggr.12466

Table 1.
Number of papers in listed journals with data for relevant reference materials

Journal	Number
Analytical Sciences	5
Aquatic Geochemistry	1
Biological Trace Element Research	26
Bulletin of Environmental Contamination and Toxicology	6
Contributions to Mineralogy and Petrology	11
Environmental Geochemistry and Health	10
Environmental Monitoring and Assessment	12
Geochemistry Geophysics Geosystems	21
Geochemical Journal	6
Geochemical Perspective Letters	3
Geochemistry International	2
Geostandards and Geoanalytical Research	24
Holocene	1
International Journal of Earth Sciences	3
JAAS	55
Journal of Petrology	42
Journal of Radioanalytical and Nuclear Chemistry	12
Lithos	100
Lithosphere	4

RMs from numerous providers worldwide, from commercial providers with hundreds of different RMs to distributors of few specific RMs.

Appendix S1 contains the full list of publications surveyed for 2021 that are the topic of this review and also are included in the GeoReM database. The GeoReM reference citation in Appendix S1 is preceded by a key code: the first two digits stand for the year of publication (here: 21) followed by the serial number for the specific year and the GeoReM-ID, which enables rapid and straightforward queries to be made within the database. An overview on the names and abbreviations of RM providers is given in Appendix S2.

The Geostandards and Geoanalytical Research Bibliographic Review 2021 expands the spectrum of the research compared to the last years by adding some journals with geochemical topics for the first time to this survey (Weis *et al.* 2022). All of them contribute publications with analytical results of RMs: "Geochemical Journal" (6 papers), "Geochemical Perspective Letters" (3 papers), "Geochemistry International" (2 papers) and "Lithosphere" (4 papers; Table 1, Figure 1).

The largest quantity of papers with analytical results of RMs can be found in "Lithos" (100 papers), "Journal of Analytical Atomic Spectroscopy" (55) and "Journal of Petrology" (42). "Geostandards and Geoanalytical Research" again has the leading role regarding the percentage with more than 60%, followed by "Journal of Petrology" with 42 % and "Journal of Analytical Atomic Spectroscopy" with 20%. In "Geochemical Journal", which is part of the survey for the

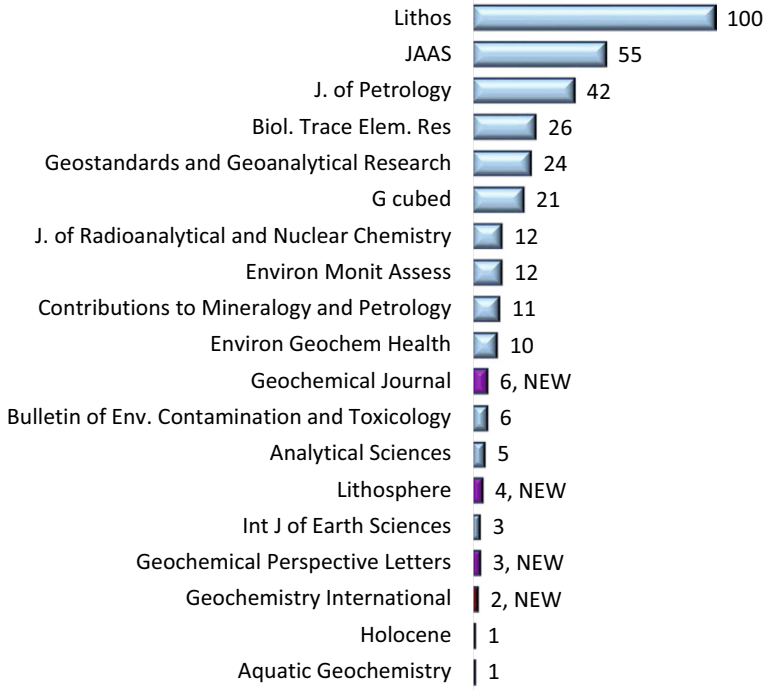

Figure 1. Bar chart showing the number of papers from surveyed journals containing relevant reference material information.

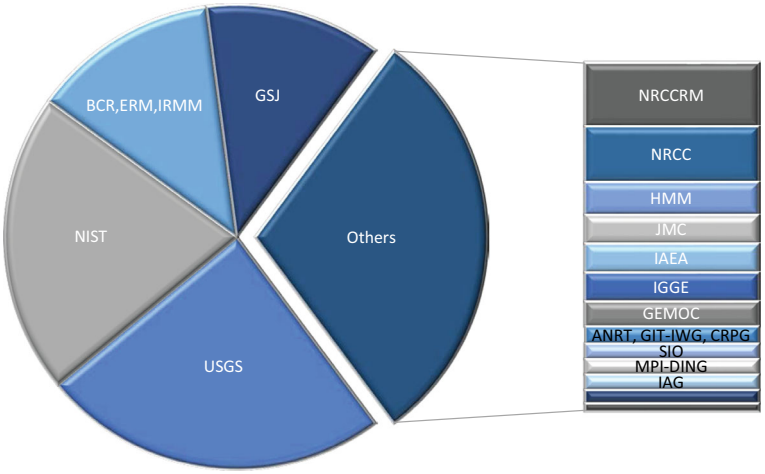

Figure 2. Pie chart illustrating the proportion of publications containing analytical data for RMs of specific providers.

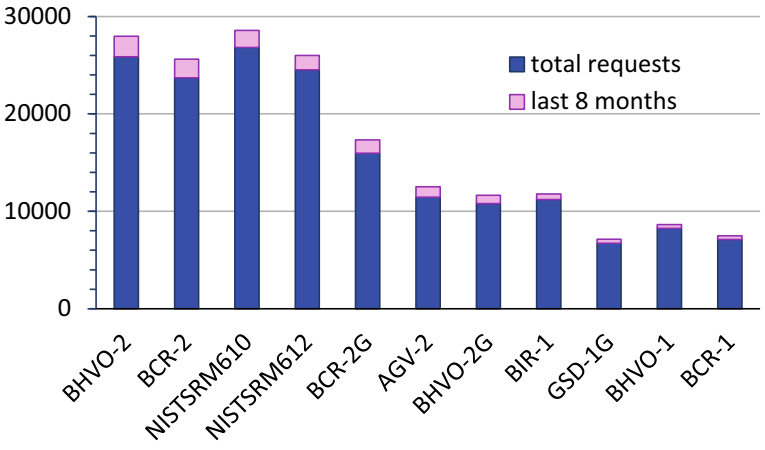

Figure 3. Bar chart showing the total requests and those for the last 8 months to the GeoReM database for the top eleven reference materials.

first time, 19% of the annual publications in 2021 present analytical data of RMs (Figure 4, Weis *et al.* 2022).

The significance of isotopic systems within geosciences and related fields is reflected by the high share, both, of published isotopic values and of new characterised isotopic RMs compared to the share of data for major and trace elements (Figure 5). Some 56% of publications address isotopic systems, whereas only 20% address major elements, 32% trace elements and 28% are focused on only a few elements.

In the following, we refer to several publications of special interest: either they present newly developed or characterised RMs, or they provide substantial data sets for established RMs following improved analytical methods. Some minerals are proposed as RMs especially for specific isotopic systems to broaden the selection of matrix-matched RMs. For example, a new natural chalcopyrite reference material – TC1725 – has been prepared for *in situ* Cu isotope measurement by Bao *et al.* (2021). Chen *et al.* (2021) introduced natural pyrrhotite (JC-Po) and pentlandite (JC-Pn) from the Jinchuan Ni-Cu-PGE massive sulfide ores (China) which have been evaluated as S and Fe isotope RMs. Li *et al.* (2021) analysed a new natural calcite specimen (NJUCal-1) to investigate its potential as a reference material for microbeam oxygen isotope measurement. Stewart *et al.* (2021) assigned $\delta^{11}B_{SRM951}$ and trace element compositions to two new synthetic marine carbonate RMs – NIST RM 8301 (Coral) and NIST RM 8301

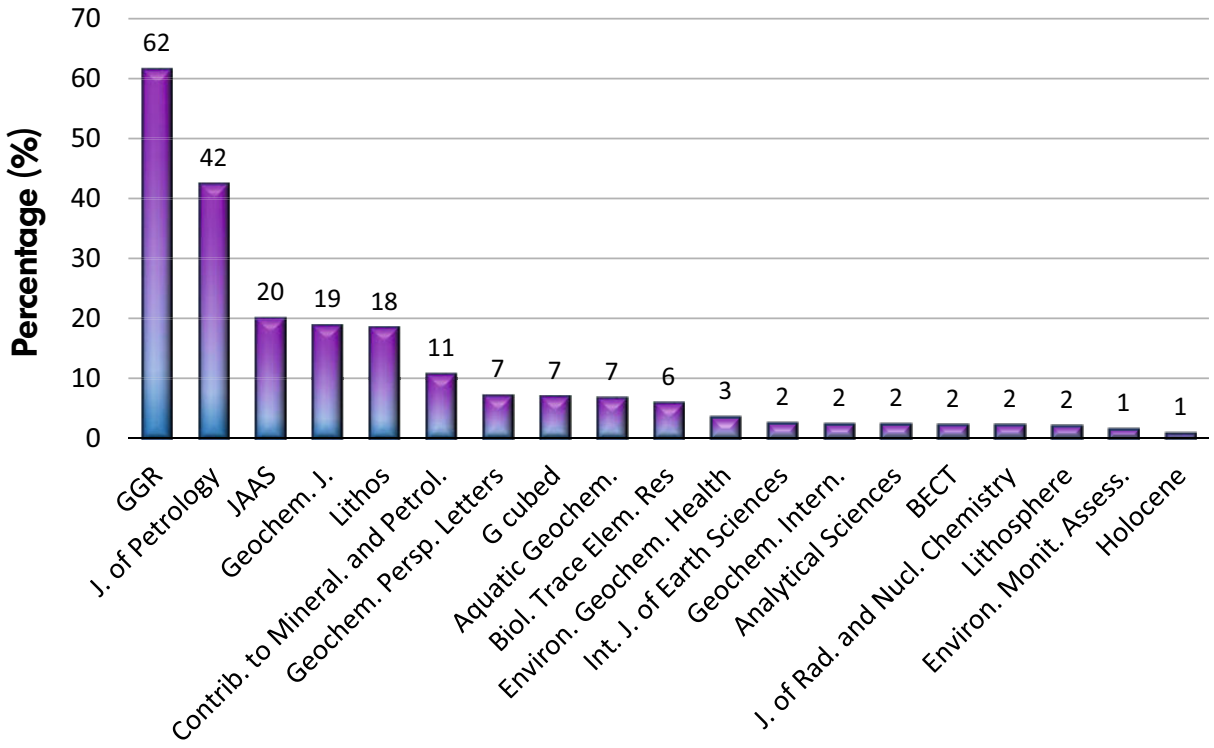

Figure 4. Bar chart illustrating the ratio (in per cent) of articles containing analytical data for RMs compared with the total number of articles published in specified journals in 2021.

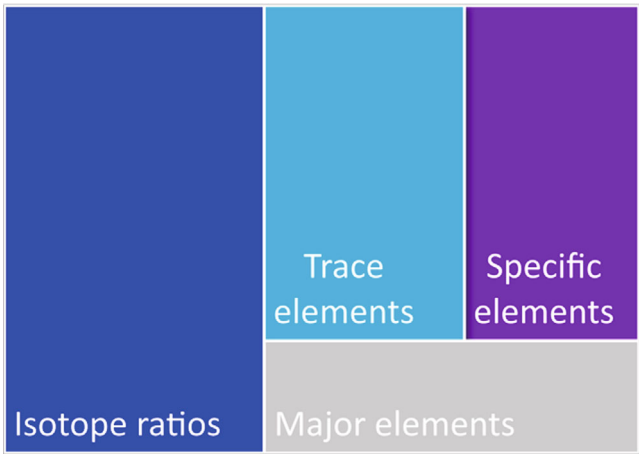

Figure 5. Area diagram expressing the proportions of type of target analyte derived from the 2021 literature survey.

(Foram). Wudarska *et al.* (2021) reported on a set of six apatite reference materials (chlorapatites MGMH#133648, TUBAF#38 and fluorapatites MGMH#128441A, TUBAF#37, 40, 50), which they have proposed as RMs for chlorine isotope ratios. Wiedenbeck *et al.* (2021) have further investigated three tourmaline RMs from the Harvard Mineralogical and Geological Museum (schorl 112566, dravite 108796 and elbaite 98144), which have already been widely used for the calibration of *in situ* boron isotope measurements. These samples have now been additionally characterised for their oxygen and lithium isotope d-values or isotope ratios. The variety of zircon RMs has been enlarged by the Tanz zircon megacrysts, which are suitable as microanalytical RMs for the determination of

U-Pb ages, Zr isotopes, Hf isotopes, O isotopes and trace element mass fractions. They have been described by Hu *et al.* (2021).

The preparation and characterisation of three new sediment-based reference materials SdAR-L2 (blended sediment), SdAR-M2 (metal-rich sediment) and SdAR-H1 (metalliferous sediment) has been conducted by a collaboration between the United States Geological Survey (USGS) and the International Association of Geoanalysts (IAG) (Wilson *et al.* 2021). Also, some new synthetic RMs have been introduced. The development, uncertainty evaluation and certification of eleven newly developed zinc isotope ratio RMs (GBW04465-04475) have been performed by gravimetrically preparing enriched isotopic materials (Lu *et al.* 2021). Three molybdenum isotopic reference materials have been developed by the National Institute of Metrology (China), including one natural-abundance CRM (GBW 04504) and two isotopically enriched RMs (GBW 04505 and GBW 04506), (Song *et al.* 2021).

2021 also saw the publication of many considerable data sets for established RMs obtained by new or improved analytical methods. In what follows we present some examples. A remarkable feature is the high number of publications that deal with isotopic data. This confirms the increasingly important role of many different isotopic systems for scientific research. For boron isotopes there are new data for different rock matrices, e.g., marine carbonates amongst others (Cai *et al.* 2021, Gutjahr *et al.* 2021, Zhu *et al.* 2021). Wu *et al.* (2021) published a wide study on many isotopic systems (Li, B, Si, O, Mg, Sr, Nd, Hf, Pb) for three andesitic microanalytical RMs (ARM-1,-2,-3 glasses). Xu *et al.* (2021) present Fe isotope ratios for fourteen reference materials from the USGS, MPI-DING and CGSG. Potassium isotopic compositions of seven biological reference materials were measured by Moynier *et al.* (2021). A new procedure to determine δ^7Li values was applied to nineteen silicate rocks and one natural water by Navarro *et al.* (2021). High precision cadmium isotopic compositions for seven geological RMs are provided by Peng *et al.* (2021). The Rb isotopic compositions of several geological RMs have been determined by Nie *et al.* (2021). Antimony isotopes are important as geochemical tracers for archaeological and environmental purposes. Colin *et al.* (2021) present Sb isotopic data for fourteen RMs of various matrices. A combined dataset of Cu, Zn and Pb isotope values for thirty-three geological and biological reference materials RMs was published by Jeong *et al.* (2021). The biological RMs GSB-14 and GSB-19 have been characterised for the first time for Mg isotopes by Liu and Han (2021).

Furthermore, there are examples for new major and trace element data: Instrumental neutron activation analysis (INAA) has been applied for the determination of twenty-eight element mass fractions in seven geological reference materials from the USGS Marques *et al.* (2021). The range of applications for CRM ERM-CZ120 has been broadened by the publication of analytical data for twenty-nine elements by Honda (2021).

This outline of just a selected few materials demonstrates that there is an on-going process of characterising more RMs, some of them suitable for very specific applications or matrix-matched for specific materials, others suitable for many different scientific topics and analytical methods. This development of new RMs is crucial for applications where the stock of established RMs is nearly depleted and replacements are urgently needed. Also, numerous studies have shown refinements of analytical methods to improve accuracy and precision, and therefore to enhance the quality of analytical measurements. Both the preparation of new RMs and the improvement of reference values is a huge benefit for scientific research.

Acknowledgement

Open Access funding enabled and organized by Projekt DEAL.

Data availability statement

The data that support the findings of this study are available in the supplementary material of this article and in the GeoReM database (http://georem.mpch-mainz.gwdg.de/).

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Supporting information

The following supporting information may be found in the online version of this article:

Appendix S1. Full list of publications surveyed for 2021.

Appendix S2. List of the names and abbreviations of RM providers.

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