GEOSTANDARDS and GEOANALYTICAL RESEARCH

Geostandards and Geoanalytical Research Bibliographic Review 2019

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This bibliographic review gives an outline of publications in 2019 focusing on reference materials (RMs) used in geochemistry and related fields, such as palaeoclimate and environmental research.

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This bibliographic review gives an outline of publications in 2019 focussing on reference materials (RMs) used in geochemistry and related fields, such as palaeoclimate and environmental research. The survey has included 6850 individual publications from more than twenty scientific (i.e., peer-reviewed) journals. Nearly 700 of these articles include published analytical results for RMs (Table 1, Figure 1). All of these data are freely available in the GeoReM database (Jochum *et al.* 2005; http://georem.mpch-mainz.gwdg.de). GeoReM allows various queries to find suitable RMs for specific analytical methods and presents compilations of certified and measured values. The most recent Application Version 28 (as of December 2020) contains more than 3700 RMs. All publications of 2019 included in GeoReM are also listed in Appendix S1. The reference citation is preceded by a key code: the first two digits stand for the year of publication (here: 19) followed by the serial number for the specific year and the GeoReM-ID, which allows easy access to the GeoReM database. An overview on the names and abbreviations of RM providers is given in Appendix S2.

An unprecedented challenge for this year's review was the limited access to some publishers (e.g., Elsevier) for the Max Planck Society and many German universities. Thus, several journals, which provided many analytical data or RMs in previous years, could not be investigated by us and therefore have not been included in this review (Figure 2, Weis *et al.* 2020). To accommodate this shortfall, the survey was extended to journals from other publishers, which were incorporated into this year's survey (Table 1, Figure 2) to broaden the spectrum of this study. Some of these journals delivered numerous results for RMs, such as 'Environmental Monitoring and Assessment' (15 publications in 2019) and 'Bulletin of Environmental Contamination and Toxicology' (12 publications, Figure 2). 'Lithos', 'Geochimica et Cosmochimica Acta' and 'Chemical Geology' supplied the most papers to the present array with 100 or more publications each and are, thus, similar to numbers obtained in 2018 (Weis *et al.* 2020, Figure 2). In terms of percentage of papers on RMs, 'Geostandards and Geoanalytical Research' still leads with 78% as in previous years (Figure 3).

Splitting into different categories illustrates the increasing importance of various radiogenic and stable isotopic systems in geochemistry and related fields: 55% of the relevant papers presented data for isotope ratios, whereas only 13% contained major element data and 19% wide-ranging trace element data sets. Single elements or specific groups of elements (e.g., highly siderophile elements) contributed 13% of the data (Figure 4).

Figure 5 shows the distribution of the most important providers for RMs in 2019 surveyed publications. In more

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Table 1.
Scientific journals from which relevant articles were reviewed

Journal	No. of papers
Analytical and Bioanalytical Chemistry	5
Analytical Sciences	10
Biogeosciences (Copernicus)	7
Biological Trace Element Research	23
Bulletin of Environmental Contamination and Toxicology	12
Chemical Geology	99
Climate of the Past	1
Contributions to Mineralogy and Petrology	12
Earth and Planetary Science Letters	49
Environmental Chemistry Letters	0
Environmental Geochemistry and Health	8
Environmental Monitoring and Assessment	15
Frontiers in Earth Science	1
Geochemistry, Geophysics, Geosystems	22
Geochimica et Cosmochimica Acta	130
Geostandards and Geoanalytical Research	32
International Journal of Earth Sciences	8
International Journal of Mass Spectrometry	1
Journal of Analytical Atomic Spectrometry	42
Journal of Geoscience and Environment Projection	1
Journal of Metamorphic Geology	3
Journal of Paleolimnology	0
Journal of Petrology	30
Journal of Quaternary Science	2
Journal of Radioanalytical and Nuclear Chemistry	17
Lithos	151
Marine Pollution Bulletin	1
Microchimica Acta	6
Paleoceanography and Paleoclimatology	1
Science Advances	1
The Holocene	2

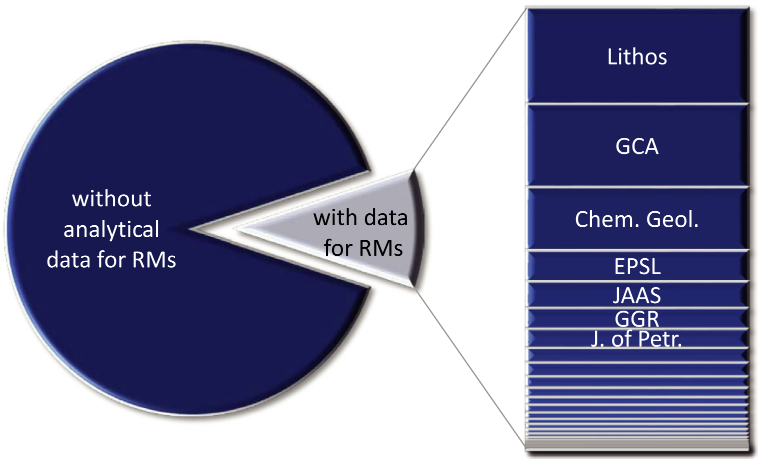

Figure 1. Number of publications of specific journals in 2019 containing analytical data for RMs, which are included in GeoReM, compared with the total number of researched publications.

than 50% of the publications, RMs of United States Geological Survey (USGS) (28%) and National Institute of Standards and Technology (NIST) (25%) have been cited, followed by Geological Survey of Japan (GSJ) with 15% and several providers with 3% or less, shown in decreasing order. Numerous providers with an amount of less than 1% are not shown for reasons of clarity. It has to be noted that USGS provides about 135 different RMs, NIST even several

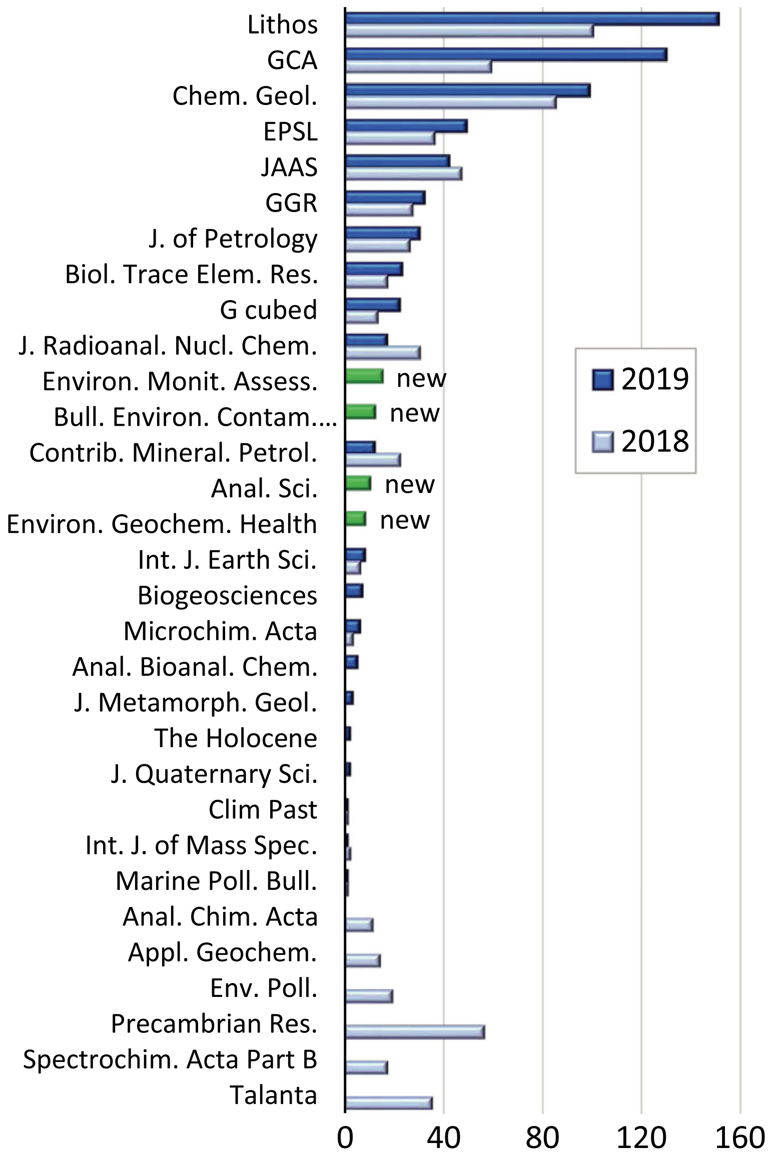

Figure 2. Bar chart showing the number of publications of specific journals containing analytical data for RMs in 2019 in comparison with 2018. Highlighted are some journals, which are researched for the first time (marked 'new').

hundreds (currently 418 in GeoReM) and GSJ about fifty, while MPI-DING offers only eight RMs (Jochum *et al.* 2006).

In the following, we choose to highlight certain publications that present recently characterised RMs or new analytical techniques that we rate to be of particular interest to the geochemical community. Several articles in 2019 addressed the determination of lithium isotopes: (a) Li *et al.* (2019a) reported a new dual-column system for lithium purification to achieve accurate and precise analysis of lithium isotopic compositions using a multi-collector inductively coupled plasma-mass spectrometer (MC-ICP-MS). (b) Lin *et al.* (2019) proposed an improved procedure and provided δ^7Li values for eleven carbonate reference materials. (c) Liu and Li (2019) showed in their study that lithium element mass fraction and lithium isotope composition can be routinely measured using a single-collector ICP-MS. (d) Steinmann *et al.* (2019) suggested a new method for *in situ* measurements of lithium (Li) isotope ratios at low lithium concentration levels using UV-femtosecond laser ablation coupled with MC-ICP-MS.

In 2019, several new RMs have been prepared and introduced: natural olivine, clinopyroxene and orthopyroxene RMs have been assessed for their oxygen isotope

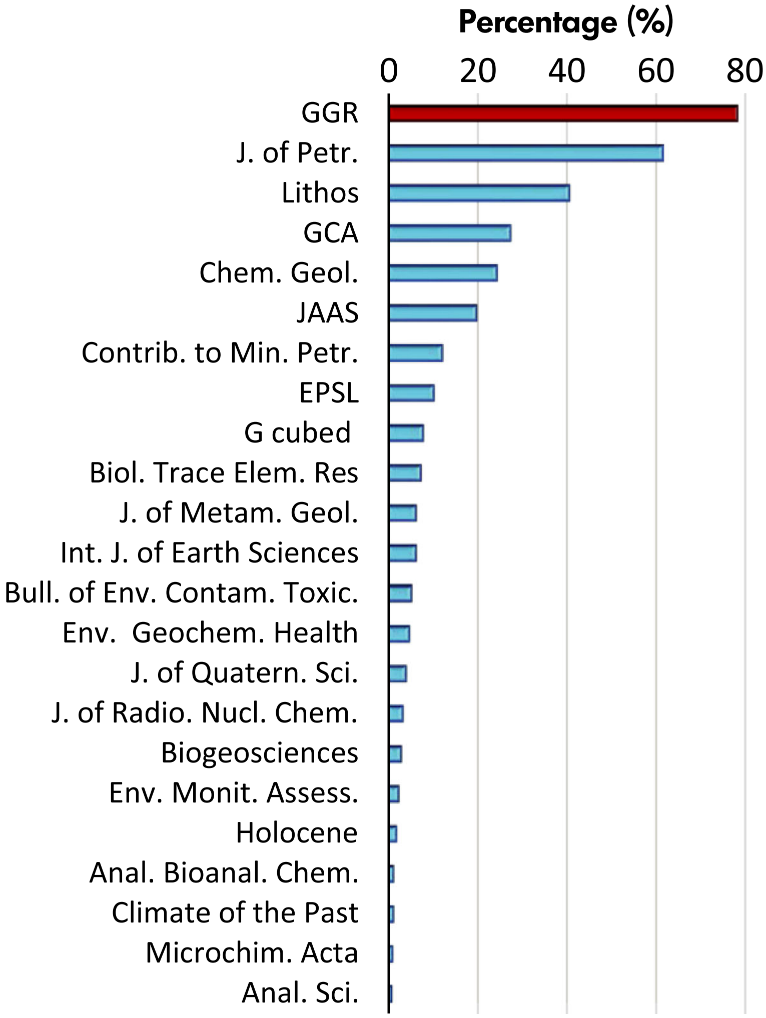

Figure 3. Bar chart illustrating the ratio (in per cent) of articles containing analytical data for RMs compared with the total number of articles published in specified journals in 2019.

homogeneity and proposed as *in situ* RMs for SIMS measurements by Tang *et al.* (2019). Another new olivine RM for *in situ* measurement of major, minor and trace elements has been characterised using various analytical methods including isotope dilution ICP-MS by Batanova *et al.* (2019). Also, a set of new natural white mica RMs (UNIL_WM1 to UNIL_WM5) was developed for *in situ* H_2O content determinations by SIMS (Luisier *et al.* 2019). Another approach to improve microanalysis such as LA-ICP-MS is the development of RMs based on nanoparticles. Jochum *et al.* (2019) presented a study on nano-powdered calcium carbonate reference materials in comparison with the original RMs, because well-characterised homogeneous reference materials (RMs) for calibration at the nanometre to micrometre scale are essential for microanalytical methods such as LA-ICP-MS. For *in situ* (U-Th)/He dating, a new apatite RM (MK-1 apatite) has been introduced by Wu *et al.* (2019a). A set of synthetic andesitic glasses for microanalytical purposes (ARM-1, ARM-2, ARM-3) with reference and information values for fifty-six elements was presented by Wu *et al.* (2019b).

To address the shortage of reference materials certified for carbon isotope ratios traceable to the SI, a new reference material LGC171-KT was produced by Malinovsky *et al.* (2019).

Since there are very few RMs with certified Pb isotopic composition available, Vogl *et al.* (2019) have produced and certified one bronze RM and one high-purity solution of lead within the natural lead isotopic variation for the validation and verification of analytical procedures.

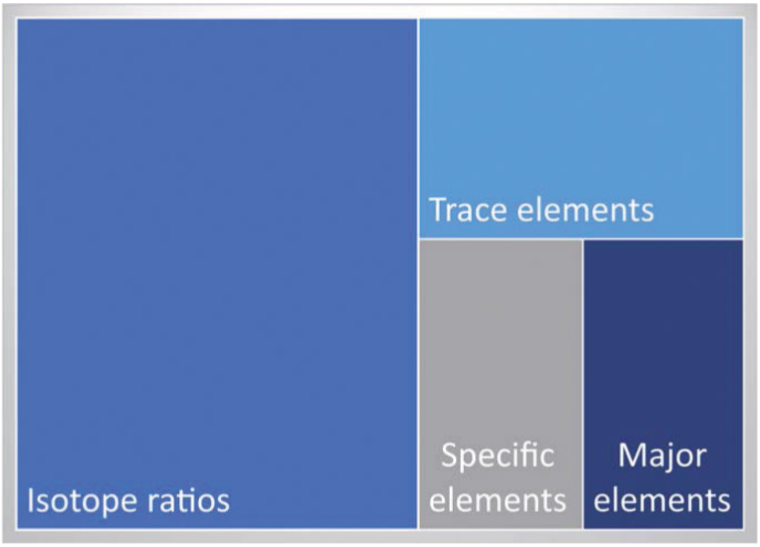

Figure 4. Proportion of papers that present analytical data of special geochemical categories such as isotope ratios, major element sets, substantial trace element sets and few selected elements.

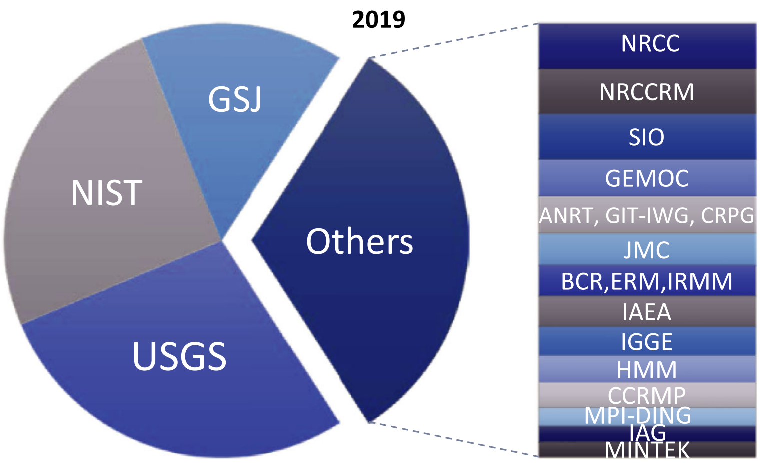

Figure 5. Number of publications containing analytical data for RMs of specific providers.

Linge *et al.* (2017) pointed out that ongoing progress in analytical instrumentation and techniques enables higher analytical performance and precision and also the development of new applications such as recently considered isotopic systems. For example, Bonnand *et al.* (2019) have calibrated a new cerium isotopic RM (CeLMV) using TIMS equipped with 10^{13} Ω amplifier resistors. Chen *et al.* (2019) have developed a new method for measuring K isotopes at high precision using MC-ICP-MS in cold plasma. They report K isotopic compositions of twenty geological reference materials determined by an interlaboratory comparison. Gallium isotopic compositions of several geological RMs have been analysed by Feng *et al.* (2019). Geng *et al.* (2019) have synthesised two sodium sulfate samples (S-MIF-1 and S-MIF-2) enriched in ^{33}S with different magnitudes. The sulfur isotopic composition has been provided in this publication. Additionally, these RMs are artificially enriched in ^{17}O and the calibration of the oxygen isotopic composition is still in progress. Li *et al.* (2019b) presented basaltic and solution RMs for Fe, Cu and Zn isotope measurements. For highly precise measurements of Ni isotope ratios, Wu *et al.* (2019c) developed a procedure using MC-ICP-MS, which is applicable to various matrices, and they provided Ni isotope data for different geological

RMs. For the first time, Zhang *et al.* (2019) proposed a high-precision method to measure stable Zr isotope ratios in zircons using LA-MC-ICP-MS.

Environmental and climate research has a huge need for natural water RMs, which have to be replaced by new batches frequently. Yeghicheyan *et al.* (2019) have presented an interlaboratory characterisation of many trace elements in natural river water reference material SLRS-6 (NRCC).

Hoang *et al.* (2019) have introduced a complementary method for the determination of abundances of fifty-two elements in natural waters, which combines freeze-drying pre-concentration (FDC) and isotope dilution internal standardisation (ID-IS). These are just a few examples for interesting publications addressing RMs chosen from the almost 700 publications, which are content of this study and which can be studied in Appendix S1 and GeoReM.

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Supporting information

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

Appendix S1. Reviewed publications from 2019.

Appendix S2. Abbreviations used for reference material providers.

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