A Natural Reference Material OOID for Calibrating In Situ Trace Element Measurements in the Carbonate Matrix

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ABSTRACT: In situ elemental analysis of carbonate matrices at the microscale is a rapidly developing and promising area of research with significant implications for fields including geology, environmental science, and biology. However, applications in these fields have been inhibited by the lack of appropriate analytical reference materials and the ongoing need for improvements in analytical methods. This study used pure ooid sands from the modern Schooner Cays in the Bahamas as raw material due to their nearly consistent mineralogical compositions and uniform elemental distributions. A wet milling process was employed, and the Tyndall effect was used to isolate ultra-fine colloidal particles (most <1 μm). These particles underwent high-pressure compression, and the resulting pellets, namely OOID, were subsequently embedded in epoxy resin to ensure their long-term preservation and utility. Over a four-year study period, we confirmed that at least 28 elements remained homogeneously distributed within the reference material OOID. These results were achieved through rigorous relative standard deviation and Horwitz tests. The findings of this study underscored the crucial role of natural reference materials in ensuring quality control of in situ carbonate elemental analyses. Simultaneously, the study provided valuable new guidelines for preparing carbonate reference materials and improved the accuracy of in situ microanalytical methods for carbonate samples.

INTRODUCTION

Carbonate rocks are one of the most widely distributed lithologies and continue to form at an approximate rate of three billion tons annually, representing the largest carbon reservoir on the Earth’s surface. Due to their profound implications for global environmental dynamics, carbonate rocks are frequently employed as proxies to elucidate both modern and ancient geological processes from multiple perspectives, including oceanic and fluid chemistry variations, environmental fluctuations, and biological evolution. Numerous instantaneous and high-fidelity signatures are often preserved within specific mineralogical and crystallographic structures at the microscale. Consequently, the high-resolution extraction and quantification of elemental and isotopic compositions from carbonates represents a pivotal and promising analytical approach that may prove invaluable to disciplines requiring the study of carbonate microstructures. However, the in situ analysis of the carbonate matrix differs from that of most other materials because, except for the major elements (e.g., Ca in calcite and Ca and Mg in dolomite), other elements occur predominantly at concentrations below 0.1% by weight and have non-uniform distribution within the mineralogical and crystallographic structures. This complexity
renders accurate localization and measurement using conventional chemical analytical techniques challenging.

With ongoing technological and methodological advances, laser ablation–inductively coupled plasma–mass spectrometry (LA-ICP-MS) has emerged as an important tool capable of meeting the requirements of analytical precision and spatial resolution for *in situ* microanalysis of carbonates. Currently, two main calibration methods are widely used to quantify elemental concentrations in carbonates. One involves normalizing all measured elements (expressed as oxides) in carbonates to 100%, while the other utilizes calibration with external standards alongside internal standard elements (typically Ca). Both methods require carbonate standards for quality control or data calibration, but only a limited number of such standards are available. One widely used carbonate reference material is MACS-3, which was developed by the United States Geological Survey (USGS). This synthetic standard has trace element concentrations that can be up to hundreds of times higher than actual carbonate samples. The particles that compose the MACS-3 standard are predominantly concentrated in the 10 to 30 μm range (Certificate of Analysis, updated 12-5-2012), which can lead to non-uniform particle ablation. Other reported reference materials for carbonate analysis include biogenic carbonates such as JCP-1 (coral), JCt-1 (clam), and NFHS (foraminifer), along with limestone powder ECRM-752-1, and all their reground nanoparticulate pressed (NP) powder pellets. The MACS-1 and GP-4 standards have also been utilized, although they have received relatively less attention in recent studies than the aforementioned reference materials.

Despite these advancements, several concerns remain to be addressed in carbonate microanalysis. Given the scarcity of available reference materials, the development of new and reliable carbonate standards is still important. Although nano-pellets have improved analytical repeatability, their homogeneity needs further enhancement, particularly for low mass fractions (e.g., < 0.1 μg/g). In addition to carbonate reference materials, non-carbonate glasses have been widely used as external standards for data calibration. However, the accuracy of the measured elements remains uncertain and requires independent validation. Furthermore, the lack of natural carbonate reference materials for quality control during the analytical process, with and without the use of matrix-matched external standards, raises concerns about the consistency of material ablation and mass fractionation. These concerns are particularly relevant with pending biotic and abiotic carbonates, which generally contain very low trace element concentrations.

This study aims to evaluate the homogeneity of OOID, a newly developed, naturally sourced carbonate material (Fig. 1A), across both short- and long-term temporal scales and providing a reference for accurately measuring the carbonate matrix. To this end, this paper delineates the material source, outlines the preparation methods, and details the validation results for the reference material OOID, providing reference values for 28 elements and corresponding isotopes for the measurements. Additionally, we assess potential matrix effects and molecular interferences on elemental quantification by comparing carbonate and non-carbonate external standards. We propose optimized measurement and calibration strategies tailored to the carbonate matrix in LA-ICP-MS analyses based on our findings. These methodological advancements can potentially improve the accuracy of *in situ* microanalytical techniques for carbonate measurement.

**EXPERIMENTAL**

**Material source.** The carbonate reference material was developed using surficial carbonate sediments collected in July 2018 from an
Producing the carbonate reference material. A six-step process was involved in the production of the carbonate reference material, OOID, at the School of Geoscience and Technology, Southwest Petroleum University (SWPU) in March and April 2021 (Fig. 2). The process is detailed as follows:

1. The ooid sands were initially screened in the laboratory to remove obvious non-ooid particles (Fig. 2A).

2. The raw material was ground in a grinder (Shanghai Jingxin Industry) for 2 h, with a 30-min break before resuming grinding for an additional 2 h. Polytetrafluoroethylene (PTFE) grinding jars and balls were used in a level 10,000 clean room to prevent contamination from metallic or siliceous processing (e.g., agate grinding) during material preparation (Fig. 2B). Simultaneously, the ooid sands and grinding balls (diameters of ~3 mm) were added in an approximate 1:1 ratio to four individual 0.1 L grinding jars (Fig. 2C), followed by the addition of an appropriate amount of Milli-Q water (Fig. 2D).

3. The ground powder was transferred to a beaker containing 250 mL of Milli-Q water in a level 1,000 clean room and allowing it to settle for ~2 h (Fig. 2E). The floating debris were removed with a pipette (Fig. 2F). This step was repeated twice.

4. The settled powder was subsequently transferred to a new beaker containing 250 mL of Milli-Q water and stirred with a PTFE rod for 3 min. The mixtures were then allowed to settle for a period of 15 min or even longer. The colloidal and still-
suspended materials were then transferred to a new 250 mL beaker and allowed to settle for 24 h (Fig. 2G). The supernatant was discarded, and the remaining material was oven-dried at 40°C for 24 h (Fig. 2H). The time required for settling and trapping colloidal particles was not constant and depends on the occurrence of the Tyndall effect in beakers when illuminated by a light source.

(5) A portion of the dry powder pieces (~2 mm thick) was placed in a custom-made high-pressure circular mold of 1-inch-diameter in a manually operated hydraulic press (PrepP-01M, Ruishenbao Analytical Co. LTD). The pressure was gradually increased to a range of 5 to 10 tons and maintained for 1 min before removal.

(6) The produced pellets (~1 mm thick) (Fig. 2I) were next embedded in epoxy resin to make 10 1-inch mounts (Fig. 1A), ensuring that the pressed surface would face up without the need for polishing and washing.

**Instrumentation and test conditions.** The use of a field emission scanning electron microscope (FE-SEM; MIRA 3, TESCAN) was implemented to examine surface topographic features in the backscattered electron (BSE) mode at the ZKKY GeoAnalysis Laboratory in Beijing, China. Further high-resolution flatness and particle size observations were made using an atomic force microscope (AFM; NX10, Park) at the Chengdu Geological Center, China Geological Survey. An examination of major-element homogeneity and particle size range was performed using an electron probe micro-analyzer (EPMA; JXA-8230, JEOL) at the School of Geoscience and Technology, SWPU.

Two laboratories in Chengdu were used to verify the homogeneity of trace element distribution in the prepared OOID reference material utilizing the LA-ICP-MS method over the past four years (August 2021 to January 2024; 2022 was omitted due to the epidemic). The first of these laboratories was the Department of Key Laboratory of Carbonate Reservoirs of CNPC, SWPU (ESI NWR 193UC and Agilent 7800), and the other was Sichuan Chuangyuan Microspectrometry Technology Co., Ltd. (ASI RESolution LR S155 and Thermo iCAP TQ). A “squid” device (ChenLab, Shanghai) was used in the SWPU laboratory to provide smoother signal performance. Detailed operating parameters for the two LA-ICP-MS instruments are shown in Table S1. We optimized certain experimental parameters during the long-term measurements, including adding of a pre-ablation process (3 pulses) and adjusting the laser energy. These modifications could affect the evaluation results, which are underlined in the Results section.

A verified, more homogeneous microanalytical reference glass NIST 612, provided by the National Institute of Standards and Technology, was subsequently used to calibrate the measurements with Ca as the internal standard element. NIST 612, MACS-3, and OOID were measured in an orderly sequence after every fifth sample of each measurement session. MACS-3 and OOID used in this study were encapsulated in 1-inch epoxy mounts to ensure long-term usability, and both were dry-polished with 10,000-grit sandpaper during the four-year measurement period. The trace element concentrations of the carbonate reference material OOID were double-corrected using MACS-3 and NIST612 as external standards (reference values from the GeoReM database) and its own Ca content as the internal standard. Unless otherwise stated, our recommended reference values were calculated using MACS-3 as the external standard. All raw data processing and calculations were performed by the first author of this study using Iolite v. 4, following a consistent data reduction scheme and custom.

**Data evaluation.** The homogeneity of the carbonate reference material OOID was evaluated according to the methodology of Jochum et al., whereby the raw data were calibrated against NIST 612 (external standard) and their respective calcium contents (internal standard element; using Ca\(^{44}\))\(^{9,19,22}\). Relative standard deviations (RSDs), expressed as the percentage of the standard deviation (1σ) divided by the average concentration, were calculated for the measured mass fractions in MACS-3 and OOID after each analytical session to assess the short-term homogeneity. The long-term stability of MACS-3 and OOID was also evaluated in this study based on the RSD values of the measured mass fractions during ten batches within four years. The Horwitz test\(^{22}\) was applied in this study to verify the reliability of OOID for short-(RSD in each session) and long-term (RSDs in ten sessions) trace element measurements. This was done by comparing our results with the predicted RSD (PRSDs; Equation 1), a widely used test of homogeneity that is independent of matrix and methodological differences.\(^{22}\) It has recently been applied to evaluate the reproducibility of a carbonate reference material.\(^{22}\)

$$\text{Predicted RSD (PRSDs, %)} = 2 \times C^{0.15}$$

where C is expressed as a dimensionless mass fraction. The measured RSD values of certain mass fractions that are less than 0.5 times the predicted RSDs (0.5 × PRSDs) indicate excellent performance of the tested mass fractions in the reference material. The values below the predicted RSDs (lower side of PRSDs) indicate good performance of the tested mass fractions.\(^{22}\) Conversely, values that are significantly higher than the predicted RSDs (upper side of PRSDs) indicate poor homogeneity of the tested mass fractions in the reference material (see the discussion in reference\(^{22}\)).

**RESULTS**

**OOID surface flatness.** Observations under the BSE imaging mode of the FE-SEM revealed a uniform surface with no apparent
compositional differences at five separate locations on the OOID surface (Fig. 3A). The particle size distribution within the OOID tablet is primarily in the range of 1 to 1000 nm, as indicated by the Tyndall effect, with an estimated upper particle size limit of approximately 3 μm (n = 566) based on the results of an EPMA image particle-size analysis. Atomic force microscope observations of the surface of OOID-2 (second generation) also revealed indistinguishable individual grains due to their diminutive size (Fig. 3B and 3D). The aggregated particles have diameters of less than 1 μm and exhibit the characteristics of compression under pressure. The surface roughness of the reference material was minimal, typically not exceeding 100 nm (Fig. 3B and 3C). In addition, some pores with diameters not exceeding 1 μm (Fig. 3C) and a maximum depth of 193 nm were observed on the OOID surface (Fig. 3D).

**Homogeneity evaluation.** In this study, the major element Ca content in the carbonate reference material OOID was investigated using EPMA, and the results are presented in Table S2. The average weight percentage of Ca was determined to be 37.546%. The distribution of Ca on the surface of OOID was remarkably homogeneous, with an RSD of 1.1%. Al and Si are two major element proxies for non-carbonate impurities (e.g., dust and agate mill), and both are below the detection limit of EPMA in OOID (Table S2).

The RSDs of 36 trace elements (43 isotopes) in OOID calibrated against the NIST 612 standard over a four-year period are shown in Fig. 4A, and their values are given in Table S3, exhibiting that most elements have RSDs of less than 10% in both short- and long-term measurements. However, a minority of elements, including Mg, Sc, Ti, Mn, Zn, Ga, and Mo, exhibit remarkably higher RSDs, mostly exceeding 15% (Fig. 4A). Most of the RSDs of the measured mass fractions are below the curve of PRSD<sub>5</sub>; these values are roughly distributed along the curve of 0.5 × PRSD<sub>5</sub> (Fig. 4A). In contrast, the RSDs of Mg, Sc, Ti, Mn,
Table 1. Comparison of measured mass fractions in the reference material OOID, calibrated against both MACS-3 and NIST 612 reference materials. The reference element contents and isotopes used for the carbonate LA-ICP-MS measurements are denoted in bold. The mean values and standard deviations (σ) of the measured elements were calculated as the means of the values reported in Tables 2 and 3. The deviation of the measured element is expressed as a percentage, calculated as [(Mean_{NIST612}−Mean_{MACS-3})/Mean_{MACS-3}] × 100%. Deviations not reported indicate that the numbers used for the calculation were insufficient. The pre-ablation process significantly affected the analytical results for Fe and Th. Therefore, data obtained without pre-ablation were excluded from the mean and σ calculations for Fe and Th. These elements are marked with an asterisk (Fe* and Th*) to indicate the exclusion of non-pre-ablation data.

<table>
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<tr>
<th>Isotope</th>
<th>MACS-3 Mean</th>
<th>MACS-3 σ</th>
<th>NIST612 Mean</th>
<th>NIST612 σ</th>
<th>Deviation (%)</th>
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<tr>
<td>Na</td>
<td>23</td>
<td>1663</td>
<td>52.5</td>
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<td>Mg</td>
<td>25</td>
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<td>266</td>
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<td>Al</td>
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<td>119</td>
<td>8.00</td>
<td>8.09</td>
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<td>0.040</td>
<td>0.109</td>
<td>0.035</td>
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<tr>
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<td>6.02</td>
<td>0.952</td>
<td>5.69</td>
<td>0.806</td>
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<tr>
<td>V</td>
<td>51</td>
<td>0.401</td>
<td>0.018</td>
<td>0.387</td>
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<tr>
<td>Cr</td>
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<td>Mn</td>
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<td>57</td>
<td>175</td>
<td>29.4</td>
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<tr>
<td>Co</td>
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<tr>
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<td>Ga</td>
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<td>7971</td>
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<td>Sr*</td>
<td>88</td>
<td>7134</td>
<td>59.7</td>
<td>7027</td>
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<tr>
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<td>Zr</td>
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<td>0.096</td>
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<td>0.112</td>
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<td>0.011</td>
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<tr>
<td>Ba</td>
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<td>6.52</td>
<td>0.153</td>
<td>6.28</td>
<td>0.389</td>
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Co, Zn, and Mo are generally distributed along the curve of 2 × PRSD (Fig. 4A). In addition, the RSDs of trace elements in OOID calibrated against MACS-3 show similar characteristics (Table S4), except for the more pronounced RSD deviations of Fe and U (Fig. 4B). On the other hand, the comparative analysis between the two laboratories used (i.e., SWPU and Chuyangyan Microspectum) shows similar patterns in RSD variations (Tables 2 and 3). In particular, the RSD results for elemental measurements are either simultaneously high or low in both laboratories (Tables 2 and 3). However, with the incorporation of a pre-ablation process at the beginning of the sixth session in the Chuyangyan Microspectum laboratory, there was a noticeable reduction in the RSD values for certain elements (e.g., Al, Fe, and Ni) compared to those observed in the SWPU laboratory without this pre-ablation process (Fig. 4A and B).

Compared to OOID, MACS-3 calibrated against NIST 612 has a much better performance (Table S5), with RSD values below 5% for most of the measured trace elements (Fig. 4C). Notably, only a few RSDs of Fe, Al, and U in MACS-3 are markedly above the curve of PRSD after excluding the sessions without pre-ablation (Sessions 1-5) during the long-term measurements (Fig. 4C).

Trace element compositions. The results of measured trace element concentrations of OOID, calibrated with NIST 612 and MACS-3 are given in Tables 2 and 3, respectively. In addition, the measurement results of MACS-3 calibrated against NIST 612 are shown in Table S5. We compared the results of OOID trace element measurements, employing NIST612 and MACS-3 as external standards, and the results reveal that most elements that contain low RSDs (below the curve of PRSD; Fig. 3A and B) exhibit low deviations (<10%) (Table 1). For elements with larger RSDs (above the curve of PRSDs) in OOID, including Mg, Sc, Fe, Co, Zn, and U, the deviations were also typically more significant (> 10%) (Table 1). The OOID measurements did not show significant differences for a few elements (e.g., Ga and Th) with extremely low concentrations despite larger RSDs (Table 5). The element content correlation of measured OOID and MACS-3 was compared using NIST612 as the external standard; significant correlations were found for 23Na, 31V, 52Cr, 56Fe, 59Co, 60Cu, 68Sr, 88Y, 90Zr, 137Ba, REEs (rare earth elements; excluding the 139La and 151Eu), 208Pb, and 232Th isotopes used in element measurements (Fig. 5).

**DISCUSSION**

Homogeneity evaluation on the developed carbonate reference material OOID. In the process of analyzing the concentration...
of 36 elements (43 isotopes) in the carbonate reference material OOID, we found that 23 elements including Na, V, Cr, Ni, Cu, Sr, Y, Ba, REEs, Pb, and U exhibited excellent short- and long-term stability, with RSDs falling below the curve of PRSDs (Fig. 4A). The RSDs of REE mass fractions ranging from -0.01 to 0.3 μg/g were well below 10% and roughly distributed along or even below the curve of 0.5 × PRSDs (Fig. 4A), representing an excellent performance in reproducibility estimation. Only a few RSD values of Al, Fe, Ga, Zr, and Th were slightly above the curve of PRSDs (including data from sessions without pre-ablation), but the other RSDs of these five elements were below the curve of PRSDs, indicating acceptable reproducibility during the long-term measurements. In contrast, the RSD values for Mg, Sc, Ti, Mn, Co, Zn and Mo are markedly higher than the curve of PRSDs in both the NIST 612 and MACS-3 calibration results (Fig. 4B and C), indicating insufficient reproducibility of these elements in OOID during production. For these reasons, OOID can be considered a reliable carbonate reference material for at least 28 elements in this study.

**Homogeneity and measurement accuracy of the carbonate reference material MACS-3 used in this study.** MACS-3 is the most suitable reference material currently available for carbonate analysis. The measured data of MACS-3 calibrated against NIST 612 in this study show a high homogeneity (Fig. 4C, except for Fe and U) and have extremely high similarity in trace element contents to most of their recommended reference values, indicating the high validity and comparability of Nb in MACS-3. Although some studies have questioned the homogeneity of MACS-3, the short- and long-term measurement data in this study supported the relatively high homogeneity of MACS-3, which was consistent with the work of Chen et al., Jochum et al., and Tabersky et al.

**Elemental reference values of the reference material OOID and the recommended isotopes for the in situ analysis.** After excluding the inhomogeneous elements in the carbonate reference material OOID, the concentrations of 28 elements that show small deviations between the NIST 612 and MACS-3 calibration data are shown in Table 5 for reference. Since the distributions of Fe and U in MACS-3 are inhomogeneous in this study (Fig. 4C) and have affected the RSDs of these elements in OOID (Fig. 4B), the contents of Fe and U in OOID are presented as the results calibrated with NIST 612 (Table 5). Although previous studies have provided a series of suitable isotopes for carbonate LA-ICP-MS analyses, measurements on the carbonate reference material OOID have indicated that some of these recommended isotopes may result in significant deviations during actual in situ measurements of the carbonate matrix. The measurement of OOID reveals that while the 60Ni and 62Ni results in MACS-3 were nearly identical, the RSD values of 60Ni were much greater than those of 60Ni in OOID during long-term measurements (Table 5). Moreover, the elemental results for 62Ni were variable compared to those of 60Ni, potentially due to the interference of [61NiO]+ on 62Ni* in this study (carrier gas of mixed He and N2) (Table 1). In some cases, similar interference has been observed by 151Gd (from 139LaO4*) and 157Gd (from 169PrO4*) in OOID,
considering the result of the solution ICP-MS measurement on Gd (Fig. 6). This suggests that $^{150}$Gd is likely to be an alternative isotope for carbonate measurements when interferences on the isotopes of interest are intense. More importantly, this Gd interference cannot be detected in MACS-3 with high Gd values (Table S5). The measurement of the element Cr has also presented some puzzles. The reference content of Cr in MACS-3 is as high as 157 μg/g,19 and when the isotopes $^{52}$Cr and $^{53}$Cr were used for measurement, there was no significant difference in the results (Table S5). However, for natural carbonate samples with low concentrations, such as OOID, the results differ significantly when using $^{52}$Cr and $^{53}$Cr (Table 1). We have tentatively chosen to use $^{54}$Cr as the reference isotope for elemental content analysis (Table 1) for the following reasons: (1) $^{52}$Cr may have more interference from the more abundant $^{12}$C in carbonate rocks ($^{40}$Ar$^{12}$C and $^{40}$Ca$^{12}$C), although $^{13}$C will also interfere with $^{53}$Cr ($^{40}$Ar$^{13}$C and $^{40}$Ca$^{13}$C); (2) the measurement result of $^{54}$Cr in MACS-3 is closer to its recommended value (Table S5). In addition, the commonly occurred $^{135}$Ba$^{18}$O/$^{137}$Ba$^{16}$O interference on $^{151}$Eu/$^{153}$Eu is negligible as their consistent measuring data approach the published solution ICP-MS analytical result,7 as well as the relatively low contents of Ba in OOID (Table 1).

Reference materials for carbonate trace-element measurements. While NIST 612 can be used for carbonate analysis under certain conditions, it is not considered the optimal solution. This is because the analytical data for several elements (e.g., Cu and REEs) may be inaccurate when calibrated against NIST 612. For example, the deviations of the measured results on ooids between LA-ICP-MS (NIST612 calibration) and solution-ICP-MS methods exceeded 10% for Gd (Fig. 6). However, the MACS-3 calibrated results did not have such large deviations (Fig. 5). Additionally, the measured REE data calibrated against NIST 612 were almost lower than those calibrated with MACS-3, with some deviations reaching 5% (Table 1), which may have affected the accurate calculation of total REE concentrations and La, Ce, Eu and Gd anomalies. Moreover, many elements showed a strong correlation between OOID and MACS-3 results when calibrated against NIST 612 (Fig. 5), suggesting that the use of the matrix-matched reference material as an external standard for data correction could provide consistent performance for elemental measurements in carbonates. We are inclined to interpret this consistency as an indication of the importance of matrix-matched reference materials. However, further evaluation is needed to determine if this is true. The strategy of using NIST 612 for data calibration and MACS-3 for quality control may also suffer from shortcomings, as natural calcium carbonate generally contains many extremely low mass fractions that are more sensitive to interferences and matrix effects,8 which cannot be identified in MACS-3 measurement results (Fig. 4C) (see Section Elemental reference values of the reference material OOID and the recommended isotopes for the in situ analysis).

Considering the relatively high elemental mass fractions8 and the excellent short- and long-term precision and accuracy of MACS-3 (Fig. 4C), as well as the limitations of OOID in terms of applicable elements and concentration ranges (Fig. 4A and Table 1), we recommend using MACS-3 as the primary external standard and OOID or other natural carbonate NP pellets,19,22 as secondary external standards for quality control in carbonate trace element analysis. Further improvements, such as the use of NP powder preparation (reduced particle size),19 encapsulation (minimizes air exposure and improves surface stability) (Fig. 1A), and pre-ablation (reducing the adherence of dry-polishing materials and contaminants) (Fig. 4B), can enhance the precision and accuracy of the carbonate reference material during measurements.

CONCLUSION AND IMPLICATIONS

We have developed OOID, a carbonate reference material utilizing natural ooid sediments, for in situ carbonate trace element measurements. Our results showed that at least 28 commonly used trace elements have good short- and long-term stability; their values are provided for reference. Given the potential matrix effects and other interferences in carbonate trace element measurements, we recommend using the MACS-3 reference material as the primary external standard and an additional natural carbonate reference material (e.g., OOID) for quality control during in situ elemental analysis of carbonates. This strategy can help ensure the accuracy and reliability of analytical data.

The LA-ICP-MS technique offers higher spatial resolution, and its analytical precision has improved significantly in the past few years, allowing for a clearer understanding of the source of the acquired data. Therefore, this technique holds great analytical potential for carbonate trace element measurements. It is clear that pure ooid sands have the potential to develop other in situ analytical standards, such as those for Sr and Ca isotopes, and halogen elements, as well as imaging analytical standards (e.g., time-of-flight ICP-MS).26 Since most of our co-authors are sedimentologists, we are willing to consider sharing the raw materials and procedures with specialized, experienced, scientific or commercial laboratories for standardization development according to ISO guidelines,28 serving the geoscience and other communities.

ASSOCIATED CONTENT

Supporting information (Tables S1-S5) is available at www.at-spectrosc.com/as/home
AUTHOR INFORMATION

Fei Li received his BSc in 2007 and PhD in 2016, from China University of Geosciences (Wuhan). He currently holds the position of professor in Sedimentology at Southwest Petroleum University. His primary areas of expertise include carbonate sedimentology, geochemistry, paleoceanography, and in situ carbonate microanalysis. He hosted several projects funded by the National Natural Science Foundation of China and other organizations and developed a suite of methods and reference materials applied to in situ carbonate microanalysis using LA-ICP-(ToF)-MS. He has contributed extensively to the fields of carbonate sedimentology and sedimentary geochemistry with over 50 publications.

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Notes

The authors declare no competing financial interest. Making procedures and products of the carbonate reference material OOID are protected by Chinese patents (CN Patent No. ZL202210066350.2; CN Patent App. 202211356635.6).

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