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Research paper

Where did the lower Paleozoic rocks of Yucatan come from? A U–Pb, Lu–Hf, and Sm–Nd isotope study

Bodo Weber [a,*], Erik E. Scherer [b], Uwe K. Martens [c], Klaus Mezger [d]

[a] *Departamento de Geología, Centro de Investigación Científica y de Educación Superior de Ensenada (CICESE), Carretera Ensenada-Tijuana 3918, 22860 Ensenada B.C., Mexico*
[b] *Institut für Mineralogie, Westfälische Wilhelms Universität, Corrensstr. 24, D-48149 Münster, Germany*
[c] *Tectonic Analysis Inc., 1315 Alma Ave, Ste 134, Walnut Creek, CA 94596, USA*
[d] *Institut für Geologie, Universität Bern, Baltzerstrasse 1-3, CH-3012 Bern, Switzerland*

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ABSTRACT

Detrital zircon grains from Lower Paleozoic sedimentary rocks in the Yucatan Peninsula have an age distribution characterized by major probability peaks at ~1.0, ~1.2, and ~1.5 Ga (Martens et al., 2010). Here, we present new Lu–Hf data (MC–ICPMS) paired with U–Pb ages (ID-TIMS) for additional zircon grains from the same rocks. This analytical approach yields precise information about the time and geochemical environment of zircon growth, which in turn helps to distinguish between different crustal source regions that just happen to host zircon populations of similar age. In addition, single zircon grains from granitoids that intruded the sedimentary rocks were dated by U–Pb laser ablation MC–ICPMS and ID-TIMS, and their Hf-isotope compositions were determined by solution MC–ICPMS. The zircon data are complemented by Sm–Nd analyses of the sedimentary and igneous whole rocks.

The Yucatan Peninsula, which forms part of the Maya block of Central America, includes lower Paleozoic rocks in the Maya Mountains of Belize. The pre-Mesozoic geologic history of the Maya block is related to the evolution of the mid-Proterozoic basement in Mexico (Oaxaquia), other Paleozoic peri-Gondwanan terranes, and the Pan-African–Brasiliano type basement of Florida. The initial $^{176}Hf/^{177}Hf$ values of ~1.0 Ga detrital zircon grains lie on a crustal evolution trajectory similar to that defined by older, ~1.2 to ~1.5 Ga grains. This trajectory is consistent with those that would be produced by crustal reservoirs that separated from the depleted mantle between 1.70 and 2.05 Ga. However, some grains have significantly less radiogenic $^{176}Hf/^{177}Hf_{(t)}$, indicating influence from even older cratonic crust. Zircon grains from granitoids that intruded the Early Paleozoic sedimentary rocks of the Yucatan Peninsula yielded Late Silurian to Early Devonian (~415–400 Ma) crystallization ages. More radiogenic Hf isotope ratios indicate anatexis of a crustal reservoir that is distinct from that of the Early Paleozoic sedimentary rocks. The Sm–Nd systematics of whole rock samples further support the results from the Hf isotopes in zircon grains. The data suggest a more continental provenance for the sedimentary rocks from Yucatan as compared to typical ca. 1.3 to 1.0 Ga outcrops in southern and central Mexico. The results indicate that sediments were shed either from mid-Proterozoic complexes of NW Amazonia or from similar continental sequences that were thrust over Oaxaquia during the Grenville orogeny and subsequently eroded in the early Paleozoic. Integrating the data into a new model for early Paleozoic times, the southern Maya block is inferred to have formed during the opening of the Rheic Ocean along the western margin of Amazonia adjacent to Oaxaquia. The paucity of Ediacaran (Pan African–Brasiliano) signatures implies that before the Silurian, the southern Maya block evolved geographically separated from NW Yucatan and Florida, where Pan African–Brasiliano crystalline rocks have been reported.

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1. Introduction

Global orogenic cycles occurring within relatively short time intervals (<50 Ma) are characteristic for the assemblage of supercontinents such as Pangea and Rodinia (e.g., Li et al., 2008, and references therein). During orogenies, new zircon populations can crystallize over similar time intervals within distinct, unrelated crustal reservoirs. The erosion of such orogens leads to the deposition of widespread siliciclastic sediments containing detrital zircon grains that record a narrow range of crystallization ages irrespective of their provenance. Therefore, provenance analysis of global orogeny sources based solely on detrital zircon geochronology by laser ablation multicollector inductively coupled plasma mass spectrometry (LA–MC–ICPMS) is not always conclusive. Provided that the internal structures of the detrital zircon grains are

* Corresponding author at: CICESE, Earth Science Division, P.O. Box. 434843, San Diego, CA 92143-4843, USA. Tel.: +52 646 1750500x26329; fax: +52 646 1750557.
E-mail address: bweber@cicese.mx (B. Weber).

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simple, the relatively high precision U–Pb ages obtained by isotope dilution thermal ionization mass spectrometry (ID-TIMS) may provide more resolving power than lower precision LA–MC–ICPMS ages. However, additional provenance information is necessary to discriminate among different crustal domains of similar age.

These objectives can be accomplished by tying the geochronology to the geochemical record of the dated zircon grains and their host rocks. Samarium–Nd analyses of sedimentary whole rocks provide integrated crustal residence ages (e.g., Allègre and Rousseau, 1984; Arndt and Goldstein, 1987) that correspond to the mean time of separation from the depleted mantle of all participating crustal components. The Lu–Hf system can be applied in a similar way as Sm–Nd, and the two systems tend to be correlated (e.g., Patchett and Tatsumoto, 1980; Vervoort and Blichert-Toft, 1999). In sedimentary rocks, however, the Lu–Hf isotope system offers outstanding advantages over the Sm–Nd system because Lu–Hf systematics of individual detrital zircon grains can be determined. Thus, in addition to U–Pb crystallization ages, initial $^{176}Hf/^{177}Hf$, and initial εHf values provide valuable information about the geochemical environment in which the zircon crystallized (e.g., Patchett et al., 1981; Amelin et al., 2000; Kemp et al., 2006). If these reservoirs have different crustal residence ages (times since their extraction from the mantle), then the initial εHf values of zircon, the two-stage crustal residence ages (from Lu–Hf in zircon), and the T_{DM} model ages (Sm–Nd in whole rocks) may be able to distinguish between sediment provenances even if they yield identical zircon ages. Furthermore, high Hf concentrations and low Lu/Hf values in zircon facilitate Hf isotope analyses and make age corrections on $^{176}Hf/^{177}Hf$ almost unnecessary. Although detailed information about the evolution of crustal reservoirs can be obtained from the Lu–Hf systematics of individual U–Pb dated zircon grains, such information is generally biased toward felsic (zircon-bearing) crustal sources. In contrast, the Sm–Nd systematics of whole rocks integrate crustal evolution information from all source components whether they are mafic (zircon-free) or felsic, but without the benefit of being able to precisely date magmatic or metamorphic events. Hence, the two kinds of data are complementary.

This study presents high precision Lu–Hf isotope data obtained by solution MC–ICPMS and high precision U–Pb analyses obtained by ID-TIMS on individual detrital zircon grains from early Paleozoic sedimentary rocks of the Yucatan Peninsula. Both Lu–Hf and U–Pb methods were performed on the same individual zircon grains. The average external reproducibility of $^{176}Hf/^{177}Hf$ of the analyses was typically ± 0.3 ε-units, which is three to five times better than the typical precision of in-situ LA–MC–ICPMS analyses (ca. ± 1.0–1.5 ε-units; e.g., Griffin et al., 2006). The ID-TIMS analyses yielded average 2σ age uncertainties of $\pm 0.4\%$ (Table 1), or a factor ten better than the $\pm 4\%$ average uncertainty obtained for individual LA–MC–ICPMS analyses (based on 243 zircons from the same samples analyzed in this study, calculated from Martens et al., 2010).

The age uncertainty is of particular importance when basing provenance interpretations on initial εHf values, which are strongly age dependent. With an uncertainty in the age of about 4%, an additional ± 1.0 εHf unit has to be propagated into the uncertainty of the initial εHf for a 1 Ga zircon. This amounts to a total average uncertainty in the Hf-isotope compositions of ± 2.0–2.5 epsilon units if both Lu–Hf and U–Pb systems are analyzed with laser ablation techniques. Hence, high precision U–Pb ID-TIMS dating and Hf-isotope determination by solution MC–ICPMS have the potential to reveal provenance information that cannot be resolved by less precise laser ablation techniques.

Age spectra of detrital grains from the sedimentary rocks analyzed in this study were previously obtained by LA–MC–ICPMS analyses and published in Martens et al. (2010). Most 1.0 Ga grains and a few ca. 1.2 Ga grains are consistent with their derivation from the nearby Oaxaquia terrane of southern Mexico (Fig. 1; Weber and Köhler, 1999; Lawlor et al., 1999; Solari et al., 2003; Cameron et al., 2004; Gillis et al., 2005), which is widely accepted as being a former part of the Rodinia supercontinent (e.g., Ortega-Gutierrez et al., 1995; Keppie et al., 2003; Keppie and Ortega-Gutiérrez, 2010). On the other hand, the previous zircon analyses by Martens et al. (2010) also yielded a minor age peak at ~1.5 Ga that is not characteristic of Oaxaquia. Therefore, other provenances such as Amazonia or Baltica, where rocks with ~1.0, ~1.2, and ~1.5 Ga ages are common, were considered (Martens et al., 2010). However, U–Pb ages alone cannot discriminate these provenances from each other. We therefore targeted zircon grains from the early Paleozoic sedimentary rocks of Yucatan for an integrated isotope study in hopes of shedding light on the geologic evolution of NW Gondwana. To further investigate differences in age and source composition, well characterized samples were revisited. The chief goal of this study was to isotopically characterize zircon grains from the most prominent populations. To use initial εHf versus age space as a provenance determination tool, we compiled existing data from potential source regions of similar age and defined fields that can discriminate terranes and provinces.

On the basis of the new data presented here and the first zircon Hf data from Oaxaquia (Weber et al., 2010), the present study provides important constraints on possible provenance sources of Mesoproterozoic zircon grains present in the early Paleozoic sedimentary rocks of Yucatan. To complement these new data from detrital grains, Sm–Nd systematics of whole rock samples, as well as U–Pb ages and Lu–Hf isotope data of zircon grains from granites that intrude the sedimentary sequences are reported. The new data are integrated into a new model for the sedimentary and tectonic evolution of the related peri-Gondwanan terranes in early Paleozoic times that addresses the following questions: (1) Where was the ancient position of Yucatan with respect to Oaxaquia and mainland Gondwana? (2) Do Yucatan sediments record the evolution of Oaxaquia's tectonic cover? (3) Under what circumstances did igneous rocks intrude the early Paleozoic sedimentary rocks of Yucatan?

2. Geologic setting

2.1. The Maya block (Yucatan block)

The Yucatan Peninsula forms part of the Maya block, also known as the Yucatan block, which includes the coastal plain of the western Gulf of Mexico, the Tehuantepec Isthmus, the Mexican state of Chiapas, and northern Guatemala, and it is separated from the Caribbean plate by the Motagua–Plochic fault system (M–P, Fig. 1, Dengo, 1969; Donnelly et al., 1990). The presence of Early Paleozoic to Late Precambrian sedimentary rocks in the Yucatan Peninsula was suggested by Dixon (1955) and ultimately confirmed by Martens et al. (2010), who reported the only-known occurrence of well preserved and relatively unmetamorphosed sedimentary rocks of early Paleozoic age of the Yucatan Peninsula. These were found in the Maya Mountains of Belize in an area of ~4000 km^2 (Fig. 1).

Late Paleozoic sedimentary rocks of the Maya block are exposed in Belize, Chiapas, and Guatemala (Santa Rosa Group, Fig. 2; Bohnenberger, 1966; Hernández-García, 1973; Weber et al., 2006, 2009). Paleozoic–Triassic crystalline basement of the Maya block forms the Chiapas Massif Complex (Fig. 1; e.g., Schaaf et al., 2002; Weber et al., 2007, 2008) and several outcrops are known from Guatemala north of the Motagua fault system (Ortega-Gutiérrez et al., 2007; Ortega-Obregón et al., 2008; Ratschbacher et al., 2009; Solari et al., 2010). Mesoproterozoic granulite exposures of the Guichicovi Complex constitute the oldest basement of the southern Maya block west of the Tehuántepec Isthmus (Ruiz et al., 1999; Weber and Köhler, 1999; Weber and Hecht, 2003). At the NW edge of the Yucatan Peninsula, Pan African–Brasiliano (~546 Ma) igneous rocks constitute the basement of the ~65 Ma Chicxulub meteorite impact site (Krogh et al., 1993; Keppie et al., 2011). Because no Pan African–Brasiliano crystalline rocks are known from other parts of the Maya block, we distinguish the NW Yucatan Peninsula from what we will refer to here as the southern Maya block, which

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