

UC San Diego

UC San Diego Previously Published Works

Title

Downstream changes in quartz OSL sensitivity in modern river sand reflects sediment source variability: Case studies from Rocky Mountain and Andean rivers

Permalink

<https://escholarship.org/uc/item/9qq5z69m>

Journal

Quaternary Geochronology, 71

ISSN

1871-1014

Authors

Capaldi, Tomas N

Rittenour, Tammy M

Nelson, Michelle S

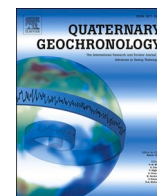
Publication Date

2022-08-01

DOI

10.1016/j.quageo.2022.101317

Peer reviewed



Downstream changes in quartz OSL sensitivity in modern river sand reflects sediment source variability: Case studies from Rocky Mountain and Andean rivers

Tomas N. Capaldi^{a,*}, Tammy M. Rittenour^b, Michelle S. Nelson^b

^a Department of Geoscience, University of Nevada, Las Vegas, Las Vegas, Nevada, 89154-4010, USA

^b Department of Geosciences, Utah State University, 4505 Old Main Hill, Logan, UT, 84322-4505, USA

ARTICLE INFO

Keywords:

Quartz
OSL sensitivity
Modern river sand
Provenance

ABSTRACT

OSL (optically stimulated luminescence) sensitivity of quartz has been shown to either (1) record downstream sediment transport related to increased number and duration of light exposure cycles or (2) be a function of source geology, presenting a potential tool to track sediment provenance. To test these competing models this study leverages a suite of modern river samples from an extensional basin system in the Rocky Mountains of western USA (Bear River) and a retroarc foreland basin system in the southern Central Andes of Argentina (Río San Juan) to understand the relationships among quartz luminescence sensitivity, sediment transport distance, and catchment lithologies. We compare our results with petrographic analysis of the river sand composition, and characterization of the lithology and morphometrics of the river catchments. Samples taken along the Bear River and its major tributaries in the Rocky Mountains show a progressive downstream decrease in quartz OSL sensitivity that records variation in sediment provenance and steady contribution of lower OSL sensitivity quartz recycled from Palaeozoic passive margin stratigraphy. Andean river sand samples from the Río San Juan network exhibit pervasive low sensitivity quartz derived from Andean arc volcanic rocks and recycled Neogene foreland basin strata. These modern river sand data do not show increased sensitivity with transport distance and instead indicates that in these landscapes, quartz OSL sensitivity is an intrinsic property of the source rock. Our study shows that river sands primarily composed of older, recycled low-strained quartz derived from quartzite lithologies exhibit the highest quartz sensitivity values. Moderate quartz OSL sensitivity values are observed in rivers with young igneous quartz derived directly from the volcanic and intrusive rocks. Conversely, microcrystalline quartz in chert lithic grains or polycrystalline quartz found in composite metamorphic lithic grains record the lowest quartz OSL sensitivity values. Determining the controlling factors of quartz sensitivity in river sand provides a current baseline for resolving paleogeographic and paleodrainage histories in the sedimentary record and provides further understanding of how sediments are eroded, transported, and deposited in fluvial systems with diverse tectonic settings and geologic source rocks.

1. Introduction

Optically stimulated luminescence (OSL) sensitivity in quartz is the luminescence signal response to an applied radiation dose. What drives observed OSL sensitivity variability across quartz samples is debated between two contrasting mechanisms; sensitivity changes are induced by Earth surface processes, or sensitivity is an intrinsic quartz property of the source rock. Quartz sensitivity has been shown to increase by repeated bleaching and dosing cycles during sediment transport and lab experiments (Moska and Murray, 2006; Pietsch et al., 2008;

Fitzsimmons et al., 2010; Sawakuchi et al., 2011; Lü et al., 2014). An increase in OSL intensity during sedimentary reworking is mainly related to the sensitization of fast-decay OSL components with increasing number of cycles of irradiation and bleaching (Moska and Murray, 2006) that drives the proportional capture of charge from non-luminescent photon producing centers to greater quantity of luminescence centers (Pietsch et al., 2008). These cycles may lead to the activation of luminescence mechanisms within initially non-luminescent grains (Sawakuchi et al., 2011). Thereby, low sensitivity quartz may be the byproduct of minimal transport or young sedimentary history

* Corresponding author.

E-mail address: tomas.capaldi@unlv.edu (T.N. Capaldi).

<https://doi.org/10.1016/j.quageo.2022.101317>

Received 14 December 2021; Received in revised form 3 April 2022; Accepted 19 April 2022

Available online 29 April 2022

1871-1014/© 2022 Elsevier B.V. All rights reserved.

(Rhodes and Pownall, 1994; Preusser et al., 2006; Lukas et al., 2007). By contrast, the OSL signal in quartz within bedrock can have low sensitivity due to differences in the concentration and types of impurities and defects in the mineral structure to form luminescence traps and centers, as suggested by Preusser et al. (2006). This sensitivity may be linked to formation temperature and pressure conditions during metamorphism or magmatic crystallization (Lukas et al., 2007; Jeong and Choi, 2012; Zular et al., 2015; Guralnik et al., 2015). Thus, changes in quartz OSL sensitivity within a fluvial system may reflect changes in sediment provenance (McGuire and Rhodes, 2015; do Nascimento et al., 2015; Sawakuchi et al., 2018; Gray et al., 2019).

This study examines the downstream trends in quartz OSL sensitivity in modern river sand from two contrasting geologic systems to determine if sensitivity changes are induced by sediment transport or reflect variable source rocks. Because the distribution of sediment sources in drainage networks are explicitly known in active systems, studies of modern rivers provide unparalleled opportunities to identify sediment-source changes by isolating OSL sensitivity within mountainous drainage catchments. Quartz OSL sensitivity was determined for a suite of samples collected along each of the main trunk rivers to test the hypothesis that longer downstream sediment transport would induce an increase in OSL sensitivity. In turn, samples from smaller tributary catchments were analyzed to determine if different bedrock sources yield variable quartz sensitivities. Also, the results of the petrographic analysis for these sand samples were compared to their quartz OSL sensitivity to determine if the quartz varieties and their optical properties show any control on the OSL signal. Understanding the controls on quartz OSL sensitivity will help resolve the competing models, and refine the way we use the quartz OSL sensitivity method as a provenance tool or proxy for sediment transport.

2. Geologic settings

The two river systems sampled in this study are in contrasting tectonic settings with diverse lithologies composing the catchment area bedrock sources. The Rocky Mountains study area in Utah (UT), Idaho (ID), and Wyoming (WY) includes the Bear River which is the largest-discharge internally drained river in North America and flows along low relief north-south trending extensional basins related to regional Miocene Basin and Range extension (Fig. 1; Long et al., 2006; Pederson et al., 2016). The second study catchment, the Río San Juan, is located in the southern Central Andes, Argentina and is fed by an integrative trellis drainage network spanning a continental arc that is related to the Miocene Andean magmatism and actively deforming retroarc fold and thrust belts (Fig. 2; Cristallini and Ramos, 2000; Garzanti et al., 2021).

The Bear River flows 680 km and is sourced in high-elevation watersheds dominated by Unita Mountain hinterland, predominantly composed of Proterozoic to Cambrian quartzites and siliciclastic rocks (Fig. 1; Dehler et al., 2010). Downstream along the WY-UT border the Bear River drains relatively low relief topography dominated by Late Cretaceous to Paleocene siliciclastic deposits that mantle paleotopography developed during shortening along the Sevier fold-thrust belt (DeCelles, 1994). Tributary catchments in Idaho include mixed siliciclastic and carbonate rocks recycled from the Mesozoic foreland basin deposits (Gentry et al., 2018). Around Soda Springs, ID the Bear River diverts course from a northward to a general southward flow (Fig. 1). This southern diversion was a young (55 ka) event caused by channel damming from a volcanic center, forcing the Bear River to be captured away from its former course to the north (Pederson et al., 2016). South of this diversion point, the Bear River flows across basins fed by high relief tributary drainages that erode predominantly Paleozoic carbonates and fine-grained siliciclastic sedimentary rocks, before terminating into the Great Salt Lake (Fig. 1).

The Río San Juan and its upstream tributaries span 650 km with headwaters in high-elevation watersheds along the Frontal Cordillera hinterland. Their source rocks are predominantly composed of late

Paleozoic–Triassic granodiorite intrusions and associated andesitic and rhyolitic lavas, ignimbrites, pyroclastic rocks, and Neogene volcanic and volcanoclastic materials derived from the Andean arc (Fig. 2; Cristallini and Ramos, 2000). Downstream, the Río San Juan drains the Precordillera fold-thrust belt that incorporates a Paleozoic marine clastic and carbonate succession (von Gosen, 1992). Neogene foreland basin deposits are preserved in footwall blocks of major thrust faults with preferential erosion forming intermontane valleys between thrust-generated ranges (Capaldi et al., 2017). East of the Precordillera the Río San Juan enters the retroarc foreland basin that is comprised of active fluvial megafan distributive systems, Holocene eolian dune fields, and modern alluvial fans along basin-bounding structures (Capaldi et al., 2019). The foreland is structurally partitioned by basement-cored uplifts (Sierras Pampeanas) that exhumed Precambrian to lower-Paleozoic basement and include the Sierra Pie de Palo uplift (Garzanti et al., 2021, Fig. 2).

3. Sampling and methods

We sampled from active bedforms along the main trunks of each river, avoiding recent disturbances and anthropogenic influx of sediment. We analyzed 15 total modern river sand samples from the study catchments, eight from the Bear River (RBR01, RBR03, RBR04, RBR06, RBR08; Fig. 1) and tributaries of the Bear River (RLGN01, RGNS01, RSMF01), and seven from the main trunk of the Río San Juan (RSJN03, RSJN04, RSJN01, RSJN02; Fig. 2) and tributaries of the Río San Juan (RPDP01, RLC01, RBLA01). Because our interest was in luminescence sensitivity and petrographic analysis, the samples were collected in clear plastic bags under daylight conditions. Sediment was wet-sieved to target the 150–250 μm sand fraction and pretreated with dilute hydrochloric acid. Heavy minerals were removed using a sodium polytungstate solution with a density of 2.7 g/cm^3 , followed by concentrated hydrofluoric acid treatments to remove feldspars and etch quartz grains, and hydrochloric acid to prevent precipitation of fluorites. The remaining material was then washed, dried, and subsequently re-sieved. For all samples, ten aliquots comprising ~500 grains each were attached by silicone spray to the central 5 mm of 1 cm diameter stainless steel sample discs.

To detect OSL signals, we used 7.5 mm UV filters (U-340) on a Risø TL/OSL Model DA-20 reader at 125 °C with blue-green LEDs (470 nm, at 35 mW/cm^2). To bleach (remove) any residual luminescence signal we exposed the samples to 100s of blue-green LEDs at room temperature. Aliquots were then given a ~22 Gy dose using built-in beta sources ($^{90}\text{Sr}/^{90}\text{Y}$; dose rate between 0.112 and 0.107 Gy/s) and preheated to 240 °C in 10s. To check for feldspar contamination, all aliquots were exposed to 50s of infrared (IR, 532 nm) stimulation at room temperature prior to stimulation with blue-green LEDs at 125 °C for 40s. The resultant sensitivity measurements from ten aliquots per sample were calculated by subtracting the average of the last 4s (background signal) and from the first 0.8s of the fast signal decay curve. The OSL signal was normalized by the dose given and the volume of grains in each aliquot. Quartz OSL sensitivity is reported as photon counts/Gy/ mm^3 and rounded to the nearest 5 photon counts/Gy/ mm^3 in the text for discussion.

The results were organized by river catchment based on the spatial relationships among samples from upstream to downstream. Quartz OSL sensitivity values for all aliquots for individual samples are displayed as kernel density estimates (KDE) with set bandwidth of 40 photon counts/Gy/ mm^3 and as a box and whisker plot.

The relative proportions of geologic units exposed upstream of each sample were quantified (following Capaldi et al., 2017 and references therein). We delineated individual catchments using ArcGIS (ArcHydro tool extension) and 30 m resolution ASTER II digital elevation data (courtesy of METI and NASA). Geologic units in the Rocky Mountains were compiled from the 1:500,000 scale state geologic maps of UT (Hintze et al., 2000), ID (Lewis et al., 2012), and WY (Christensen and

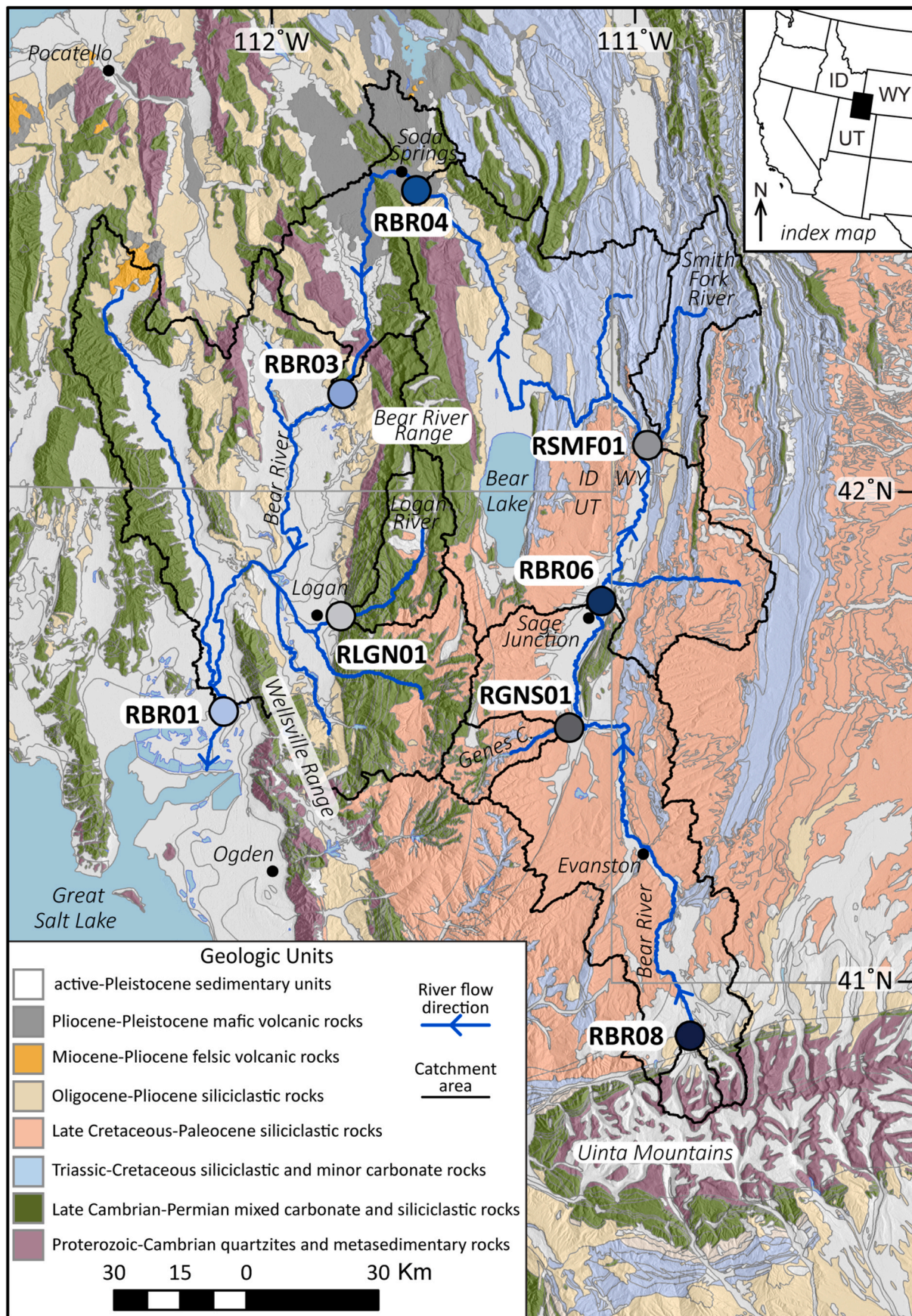


Fig. 1. Geologic Map of the Rocky Mountains in Utah, Idaho, and Wyoming border area (Love and Christiansen, 1985; Hintze et al., 2000; Lewis et al., 2012), with emphasis on the Bear River fluvial networks (blue lines), modern river sample location (circles), watershed catchment area (black outline).

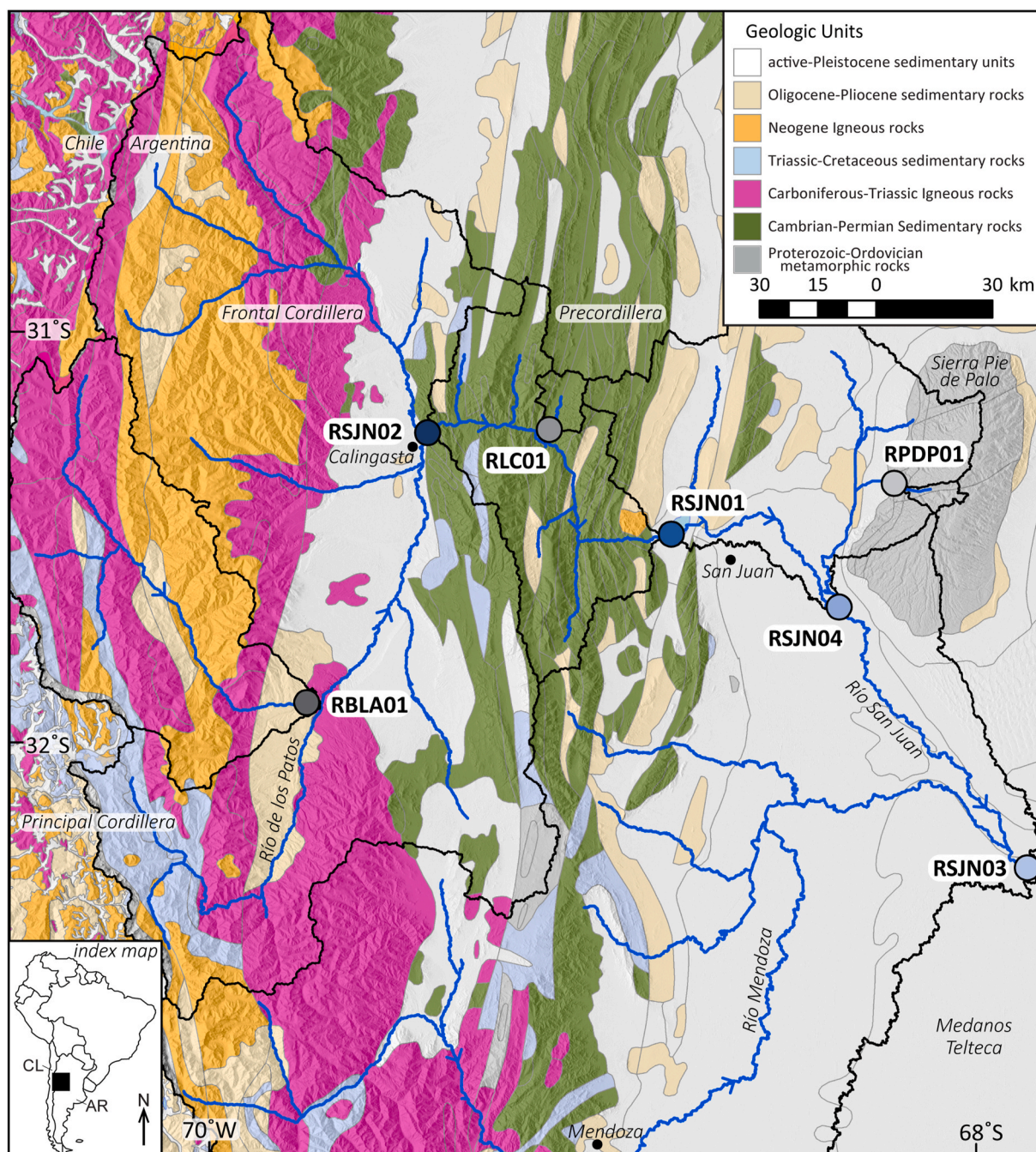


Fig. 2. Geologic Map of the southern Central Andes in Chile and Argentina (SEGEMAR, 1999; Sernageomin, 2003), with emphasis on the Río San Juan fluvial networks (blue lines), modern river sample location (circles), watershed catchment area (black outline).

Love, 1985), allowing for delineation of contributing surface areas for all units within each catchment (Fig. 1). The geologic units in the Andes were compiled from the 1:1,000,000 scale national geologic map of Chile (Sernageomin, 2003) and the 1:2,500,00 scale national geologic map of Argentina (SEGEMAR, 1999, Fig. 2). Water bodies and mafic volcanic rocks were considered negligible sources for quartz and excluded from bedrock area calculations. Also, because Quaternary alluvium is expected to recycle similar quartz sources and were excluded these map units from our bedrock area calculations. Longitudinal river profiles for both systems were generated using the topographic analysis kit (TAK) for TopoToolbox Matlab code (Forte and Whipple, 2019).

4. Results

4.1. Quartz OSL sensitivity from the Rocky Mountains

The quartz OSL sensitivity results from the Bear River and its tributaries are reported from upstream to downstream in Fig. 3. General statistics of each sample can be found in Table S1 in Supplemental Data File S1 and the supporting OSL data are presented in Supplemental Data File S2. Samples span a distance of 650 km of river drainage length and have varying contributing lithologies, allowing the two main hypotheses about the source of quartz luminescence sensitivity to be tested.

The Bear River samples exhibit a general downstream decrease in quartz OSL sensitivity values (Fig. 3). The highest upstream sample from the Bear River (sample RBR08) is sourced from a small headwater

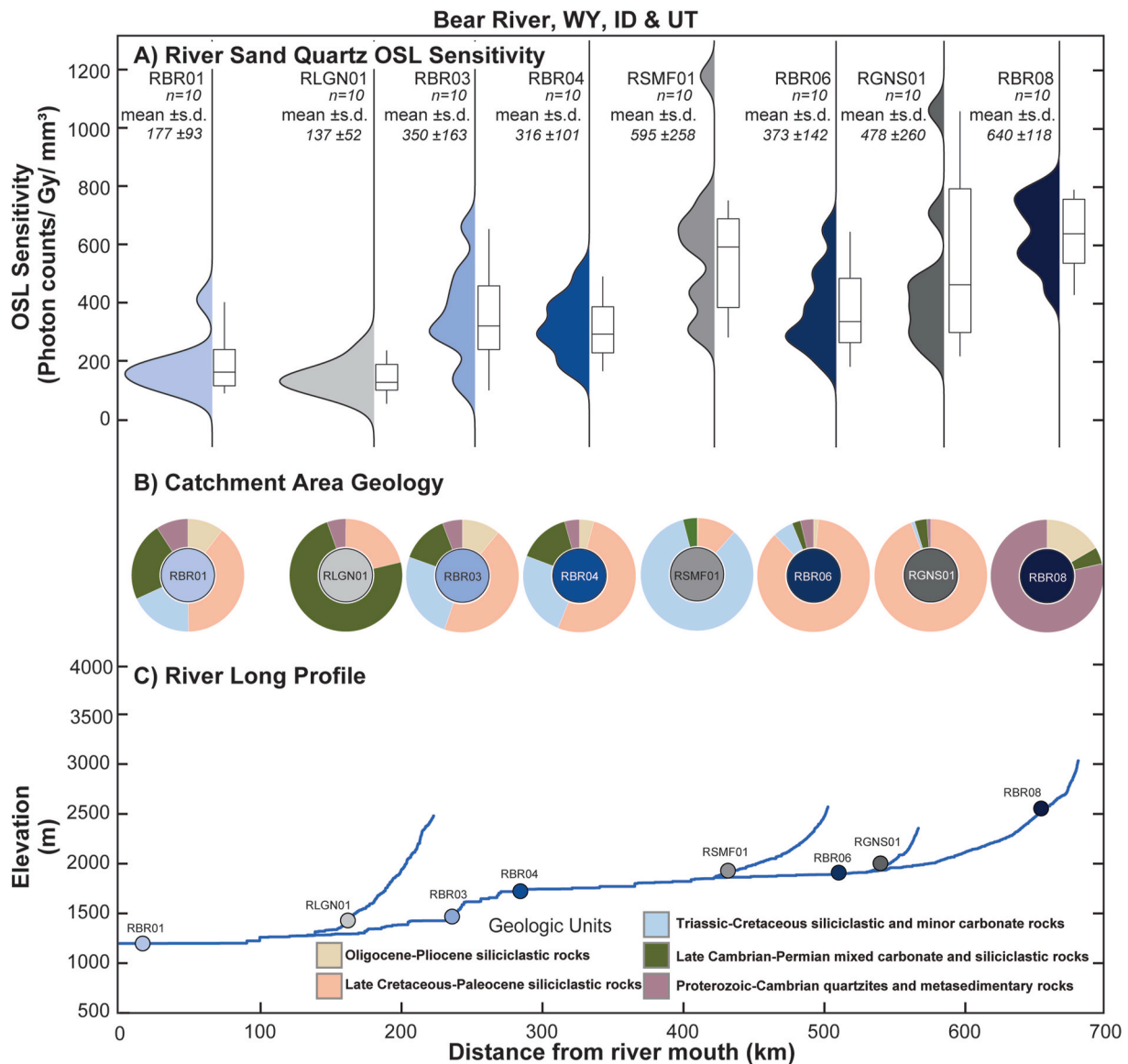


Fig. 3. Comparison diagram of Rocky Mountain modern river sand data relative to sample location. (A) Quartz OSL sensitivity results displayed as box and whisker plots and kernel density estimate for main trunk (blue) and tributary (grey) samples. (B) Ring diagrams showing the relative percentage of catchment area geology for each sample. (C) Elevation vs. distance plot of the Bear River channel and main tributaries (blue lines) with main trunk (blue circles) and tributary sample locations (grey circles).

catchment area in the Unita Mountains of Utah with source rocks predominantly comprised of Proterozoic-Cambrian quartzites and siliciclastic rocks. The resulting quartz sensitivity values from this sample exhibit a mean of 640 ± 118 photon counts/Gy/mm³ with a bimodal distribution at 575 and 775 photon counts/Gy/mm³. The tributary sample RGNS01 comes from Genes Creek, which drains the eastern flank of the Bear River Range with Late Cretaceous to Paleogene siliciclastic rocks (i.e., Wasatch Formation) overlying a minor amount of exposed Paleozoic and Mesozoic units. The mean quartz OSL sensitivity value from this sample is 480 ± 260 photon counts/Gy/mm³ with values that are broadly span a range between 300 and 450 photon counts/Gy/mm³ with notable high sensitivity aliquots at 710, 1060, and outlier 1540 photon counts/Gy/mm³ (Table S1). The Bear River sand sample (RBR06) comes from Sage Junction, UT, which drains a catchment with moderate relief comprised of predominately Late Cretaceous to Paleogene siliciclastic rocks. This sample exhibits quartz OSL sensitivity values that cluster around the mean value of 375 ± 142 photon counts/Gy/mm³ with a broad tail of higher 400 to 650 photon counts/Gy/mm³.

The tributary sand sample from the Smith Fork River, WY, (RSMF01) derives primarily from Triassic to Cretaceous siliciclastic rocks with minor carbonate units. Its resulting quartz sensitivity values are widely dispersed between 300 and 675 photon counts/Gy/mm³ and an outlier at 1180 photon counts/Gy/mm³. The Bear River sample from Soda Springs, ID (RBR04) drains a catchment area with variable bedrock geology that includes, from highest to lowest areal extent, Late Cretaceous to Paleogene siliciclastic rocks, Triassic to Cretaceous siliciclastic rocks, Cambrian to Permian mixed carbonate and siliciclastic rocks, and minor Precambrian and Neogene sedimentary rocks. Its quartz OSL sensitivity values are centered around a mean of 315 ± 101 photon counts/Gy/mm³ ranging between 185 and 495 photon counts/Gy/mm³. The Bear River sample from Oneida narrows, ID (RBR03) drains a catchment area with variable bedrock geology with quartz OSL sensitivity values broadly centered around a mean of 350 ± 163 photon counts/Gy/mm³ with a wide range of aliquots between 110 and 510 photon counts/Gy/mm³. The tributary sand from the Logan River, UT (RLGN01) comes from a high relief catchment area in the western Bear

River Range that is dominated by late Cambrian to Permian mixed carbonate and siliciclastic sedimentary rocks. Its quartz OSL sensitivity results exhibit a unimodal distribution centering around 140 ± 52 photon counts/Gy/mm³ with an outlier at 2690 photon counts/Gy/mm³. The furthest downstream Bear River sample proximal to the Great Salt Lake, UT (RBR01) yields quartz OSL sensitivity values with a unimodal distribution around 180 ± 93 photon counts/Gy/mm³ with an outlier aliquot at 1430 photon counts/Gy/mm³ (Table S1).

4.2. Quartz OSL sensitivity from the andes

The majority of Andean river samples commonly have low OSL sensitivity values around 50 photon counts/Gy/mm³. These samples display an order of magnitude less sensitivity than samples from the Rocky Mountain catchments. The quartz OSL sensitivity results from the Río San Juan and tributary sands are reported from upstream to downstream along 400 km of the river catchment (Fig. 4). The head-water samples from the Río Blanco tributary (RBLA01) and the Río San

Juan (RSJN02) receive sediment from upstream catchment areas that are comprised of high relief exposures of Carboniferous to Triassic plutonic and volcanic rocks and Neogene volcanic rocks within the Andean arc and hinterland region in the Frontal Cordillera. These samples yield similarly low quartz OSL sensitivity values with unimodal distribution around a mean of 55 ± 26 and 60 ± 38 photon counts/Gy/mm³, respectively. The downstream samples across the Precordilleran fold-thrust belt include a tributary (RLC01) and a Río San Juan trunk river (RSJN01) sand with variable bedrock geology that includes Cambrian to Permian sedimentary rocks, and minor Oligocene-Pliocene sedimentary rocks. These fold-thrust belt samples exhibit low sensitivity quartz with mean values around 50 ± 34 and 50 ± 25 photon counts/Gy/mm³, similar to upstream samples from the hinterland. The tributary sand sample (RPDP01) from a catchment that drains the Sierra Pie de Palo metamorphic basement uplift is sourced from amphibolite, gneiss, marble, and metamorphosed mafic rock assemblages, and record very low quartz OSL sensitivity values around 2 ± 1 photon counts/Gy/mm³. The Río San Juan sand sample (RSJN04) downstream of the

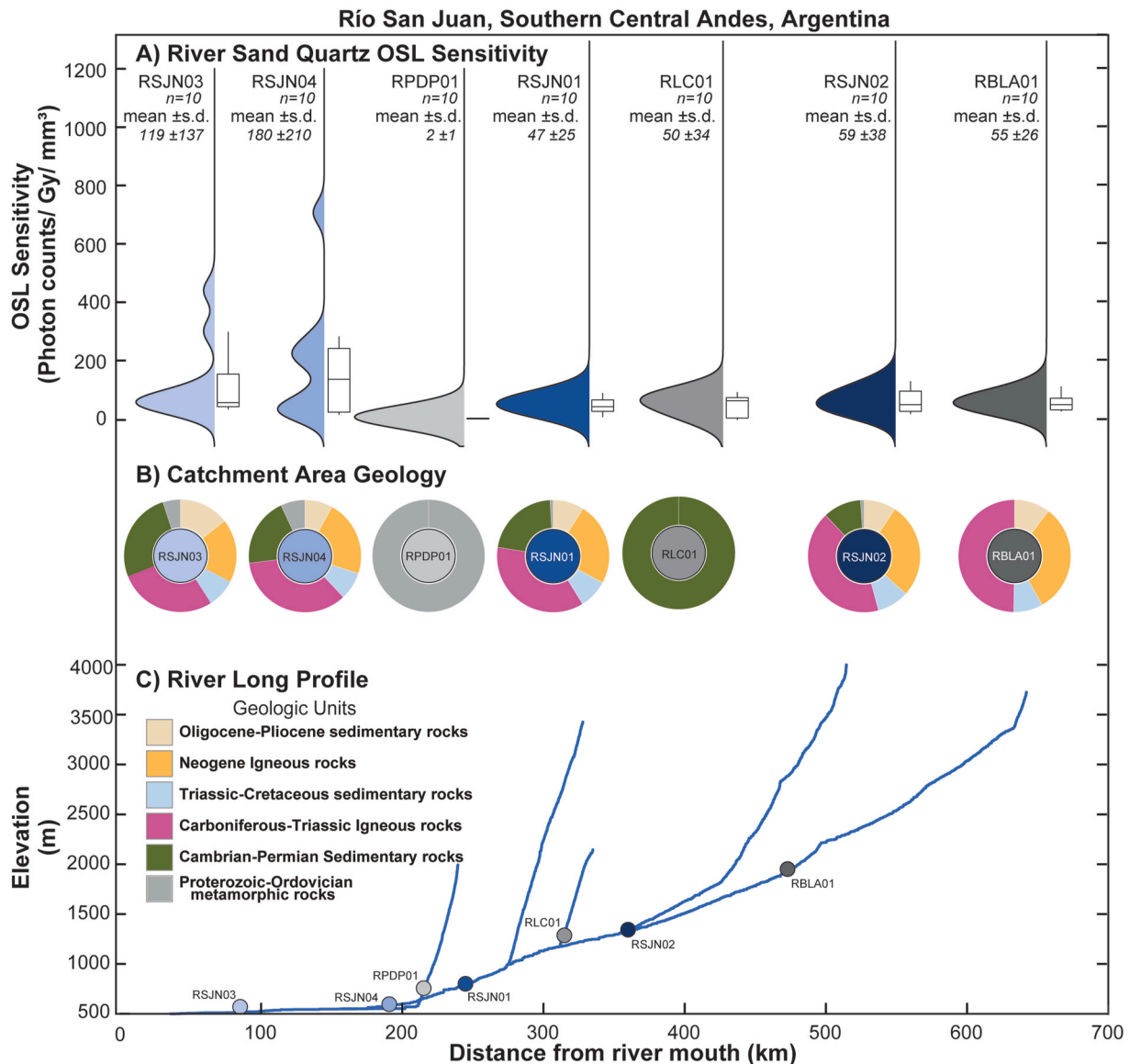


Fig. 4. Comparison diagram of Andean modern river sand data relative to sample location. (A) Quartz OSL sensitivity results displayed as box and whisker plots and kernel density estimate for main trunk (blue) and tributary (grey) samples. (B) Ring diagrams showing the relative percentage of catchment area geology for each sample. (C) Elevation vs. distance plot of the Río San Juan channel and main tributaries (blue lines) with main trunk (blue circles) and tributary sample locations (grey circles).

basement uplift exhibits a mean of 180 ± 210 photon counts/Gy/mm³ with a bimodal distribution centered between 25 and 225 photon counts/Gy/mm³ with an outlier high sensitivity value at 710 photon counts/Gy/mm³. The distal Río San Juan sample (RSJN03) comes from a large catchment area that also include the Río Mendoza to the south. Collectively, the upstream geology is predominately made of igneous arc rocks from the hinterland, mixed Paleozoic carbonate and siliciclastic rocks from the fold-thrust belt, and recycled sediment from the Cenozoic sedimentary basin fill. This distal sand sample has a mean of 120 ± 137 photon counts/Gy/mm³ and exhibits a primarily unimodal distribution at 50 photon counts/Gy/mm³ with a broad tail of higher sensitivity values between 300 and 440 photon counts/Gy/mm³.

4.3. River sand petrography

Sedimentary petrography has remained a fundamental tool to link composition of grains (quartz, feldspar, and rock fragments) in sand and sandstone to their prospective source areas and tectonic setting (e.g., Dickinson, 1985). Preliminary observations of sand petrography from our samples reveals differences in the optical sediment characteristics related to source rocks. Details on the sample processing for petrographic thin-section analysis are summarized in Supplemental Data File S1. The petrography of sand samples is described for high (>500 photon counts/Gy/mm³), moderate (500–200 photon counts/Gy/mm³), low (200–10 photon counts/Gy/mm³), to very low (<10 photon counts/Gy/mm³) OSL sensitivity values (Fig. 5).

Tributary sand sample RBR08 (high sensitivity; Fig. 1) contains monocrystalline quartz or composite quartz grains that exhibit undulatory extinction and commonly show inherited quartz overgrowth cement (Fig. 5A). Tributary sand sample RLGN01 (low sensitivity) has a significant component of microcrystalline quartz derived from the chert-rich units (Fig. 5B). Volcanic lithic rich sand observed in sample RBLA01 (low sensitivity) contains euhedral quartz with straight undulatory extinction and is commonly observed with inclusions (Fig. 5C). Tributary sand sample RPDP01 (very low sensitivity) is predominately

composed of quartz rich metamorphic lithic fragments and polycrystalline quartz with elongated grains that indicate a high metamorphic temperatures and degree of strain (Fig. 5D).

5. Discussion

5.1. The correlation between quartz type and OSL signal

Our results exhibit commonalities among the quartz OSL sensitivity values and the quartz mineral variety observed in the river sand. For example, samples with very low OSL sensitivity values originate in river sands dominated by strained polycrystalline quartz. We found this quartz variety in composite metamorphic lithic grains. Elsewhere, quartz with low OSL sensitivity signals have been recognized in igneous or metamorphic bedrock that have experienced high temperature (>350 °C) and pressure conditions (Lukas et al., 2007; Jeong and Choi, 2012; Zular et al., 2015; Guralnik et al., 2015). The low sensitivity of quartz from high metamorphic or magmatic temperatures may also explain the OSL sensitivity values found in Andean river samples. These samples are dominated by young igneous quartz derived directly from the volcanic and intrusive rocks in the continental arc. The low OSL sensitivity samples from catchment areas with significant amount of carbonate rocks present significant amount of chert lithic fragments that are comprised of microcrystalline quartz. These observations suggests that the diagenetic conditions and processes that led to the reprecipitation silica into chert (Hesse, 1989) forms inherently insensitive quartz (Akridge and Benoit, 2001). Conversely, mature, recycled low-strained quartz derived from Precambrian quartzite units reflects the higher limit in OSL sensitivity values seen here, which suggest that these quartz-rich lithologies produce sensitized grains. Our observations suggest that for the Rocky Mountains and Andean samples analyzed in this study, low sensitivity quartz is an intrinsic property of source rocks. These sources rocks include igneous, metamorphic, and microcrystalline quartz (chert) rich sedimentary rocks.

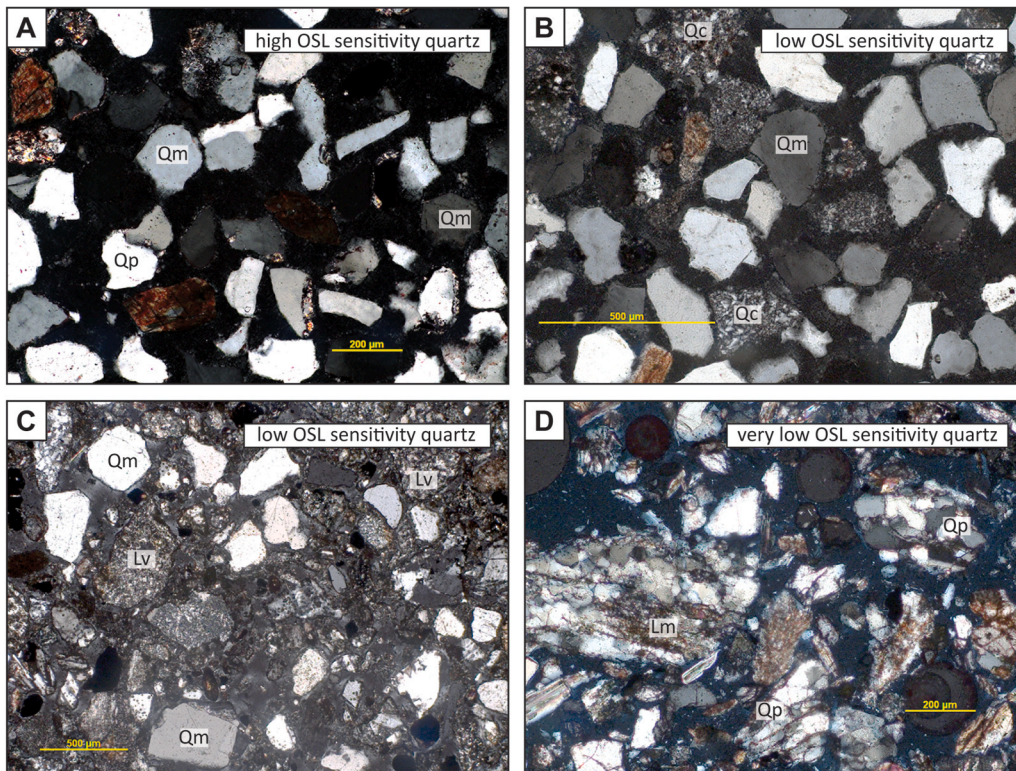


Fig. 5. Photomicrographs of tributary river sand from the Rocky Mountains and Andes. (A) Rocky Mountain tributary sand from the Unita Mountains (sample RBR08). (B) Rocky Mountain tributary sand from the Bear River Range (RLGN01). (C) Andean tributary sand from the Andean arc hinterland (RBLA01). (D) Andean tributary sand from the foreland basement uplift (RPDP01). Identified grains with quartz include monocrystalline quartz (Qm), polycrystalline quartz (Qp), microcrystalline quartz/chert (Qc), volcanic lithic fragment (Lv), and metamorphic lithic fragment (Lm).

5.2. Downstream changes in OSL sensitivity reflect sediment source variability

Previous works have suggested that the Earth-surface processes can enhance quartz OSL properties. Specifically, quartz sensitivity has been shown to increase by repeated bleaching and dosing cycles during continued sediment transport and lab experiments (Moska and Murray, 2006; Pietsch et al., 2008; Fitzsimmons et al., 2010; Lü et al., 2014). Thereby, low quartz OSL sensitivity values may be the byproduct of minimal transport or young sedimentary history (Rhodes and Pownall, 1994; Preusser et al., 2006; Lukas et al., 2007). Likewise, high sensitivity quartz values may reflect sediment that has experienced longer sediment transport, which is demonstrated as a downstream increase in quartz OSL sensitivity (Pietsch et al., 2008). Our results do not record this predicted downstream trend. Instead, the Andean river sands show a stable downstream OSL sensitivity signal, whereas the Rocky Mountain river sands exhibit a substantial downstream decrease in quartz OSL sensitivity values. Conversely, our results suggest that downstream changes in quartz OSL sensitivity may more strongly reflect influx and mixing of new sediment sources (McGuire and Rhodes, 2015; do Nascimento et al., 2015; Sawakuchi et al., 2018; Gray et al., 2019). Next, we will highlight the applicability of quartz OSL sensitivity results to track changes in contributing sediment sources in fluvial systems from both extensional Rocky Mountains and contractional Andean tectonic settings.

Our data from the Bear River catchment suggest the quartz OSL sensitivity signal is diluted in the Rocky Mountains study area by progressive mixing of downstream quartz sources. This dilution pattern appears to be enhanced in high relief regions that contribute greater volumes of sediment. The Bear River flows across a complex series of graben and half-graben extensional basin systems. These basins are flanked by horst-block ranges that increase mean local relief downstream towards the Great Salt Lake, UT (Fig. 1). This downstream increase in relief is also manifest in the Bear River channel profile, which exhibits tectonically induced knickpoints between lower river samples RBRO1 and RBRO4 (Fig. 3C). These knickpoints highlight regions where extension-related deformation has increased the mean local relief, which is concentrated along the Bear River Range and Wellsville Range (Fig. 1). These ranges are predominately composed of Paleozoic mixed siliciclastic and carbonate rocks with quartz type of the river sand dominated by low sensitivity chert grains. Thereby the observed downstream decrease in Bear River OSL signal reflects a disproportional contribution from high-relief regions containing low quartz OSL sensitive sediment sources proximal to the terminal sink of this river.

In the Andes, the retroarc foreland basin river sand has consistently low quartz OSL sensitivity signals. This ubiquitously low quartz sensitivity is not surprising given that hinterland region is comprised of silicate-rich Andean arc rocks that contribute dominantly volcanic-derived quartz. Our results indicate this volcanic and intrusive derived quartz has low OSL sensitivity. Additionally, such arc-derived sediments are preserved in the older Andean foreland deposits that preferentially erode within the retroarc fold and thrust belt region (Capaldi et al., 2017). The hinterland and fold-thrust belt regions are zones of exceedingly high relief and steep river channel profiles (Fig. 4). Because of the high concentration of low-sensitivity quartz in the catchment headwaters, the Andean retroarc river sand is dominated by low sensitivity igneous quartz from source to sink. Several aliquots with slightly higher quartz OSL sensitivities from the distal Río San Juan sand sample (RSJN04) show evidence of downstream mixing and contribution from local foreland sources with higher luminescence sensitivity (Fig. 4). Previous studies that have applied OSL dating to Quaternary fluvial and alluvial fan sediments in the Andes of Argentina reported similar poor quartz characteristics (Spencer and Robinson, 2008; Schmidt et al., 2012). We speculate that such complications may be in part to the presence of low sensitivity quartz recycled from igneous rocks in the Andean arc. Collectively, these modern river sand data do not show

increased sensitivity with transport distance and instead suggest that quartz OSL sensitivity is an intrinsic property of the source rock (Lukas et al., 2007; Jeong and Choi, 2012; Zular et al., 2015; Guralnik et al., 2015). Based on these observations, we posit that quartz sensitivity analysis may provide a baseline for resolving paleogeographic and paleodrainage histories in the sedimentary record.

6. Conclusions

This study provides data to test if quartz luminescence sensitivity is enhanced by sediment transport or is an intrinsic property of the source-rock quartz. To test these two models, we analyzed modern river sands that were sampled from fluvial systems in extensional basins across the Rocky Mountains of Utah, Idaho, and Wyoming, and the retroarc foreland in the southern Central Andes of Argentina. Samples were collected along main trunk rivers to test the hypothesis that increased downstream sediment transport would increase the OSL sensitivity of river sand quartz. To determine if the quartz-mineral type shows any control on OSL signal, we compared the suite of quartz OSL sensitivity results to the bedrock lithologies in their respective catchment areas and to petrographic composition of the sands. Our downstream quartz OSL sensitivity trends were relatively flat in the Andean rivers, and show a stark decrease in sensitivity in the Rocky Mountain catchments. These downstream changes in quartz OSL sensitivity reflect changes in contributing sediment source areas. These changes suggest that river sands primarily composed of older, recycled low-strained quartz derived from quartzite lithologies exhibit the highest quartz sensitivity values in our study. Moderate quartz OSL sensitivity values are observed in rivers draining catchments containing igneous quartz derived directly from the volcanic and intrusive rocks. In turn, microcrystalline quartz in chert lithic grains or polycrystalline quartz found in composite metamorphic lithic grains record the lowest quartz OSL sensitivity values. Quartz OSL sensitivity coupled with sediment petrography has the potential to be a robust sediment provenance tool to track sediment mixing in depositional settings.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Acknowledgements

We thank Carlie Ideker, Harriet Cornachione, Natalie Tanski, Maggie Erlick, and Michael Strange for laboratory assistance. This research benefitted from discussions with Joel Pederson, Clay Barlow, and Margo Odium. We appreciate the constructive reviews from an anonymous reviewer and Guest Editor Naomi Porat that significantly improved the manuscript.

Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.quageo.2022.101317>.

References

- Akridge, D.G., Benoit, P.H., 2001. Luminescence properties of chert and some archaeological applications. *J. Archaeol. Sci.* 28, 143–151. <https://doi.org/10.1006/jasc.2000.0552>.
- Capaldi, T.N., Horton, B.K., McKenzie, N.R., Stockli, D.F., Odium, M.L., 2017. Sediment provenance in contractional orogens: the detrital zircon record from modern rivers in the Andean fold-thrust belt and foreland basin of western Argentina. *Earth Planet. Sci. Lett.* 479, 83–97. <https://doi.org/10.1016/j.epsl.2017.09.001>.
- Capaldi, T.N., George, S.W.M., Hirtz, J.A., Horton, B.K., Stockli, D.F., 2019. Fluvial and eolian sediment mixing during changing climate conditions recorded in Holocene

- Andean foreland deposits from Argentina (31–33°S). *Front. Earth Sci.* 7 <https://doi.org/10.3389/feart.2019.00298>.
- Cristallini, E.O., Ramos, V.A., 2000. Thick-skinned and thin-skinned thrusting in the La Ramada fold and thrust belt: crustal evolution of the High Andes of San Juan, Argentina (32°S). *Tectonophysics* 317, 205–235. [https://doi.org/10.1016/S0040-1951\(99\)00276-0](https://doi.org/10.1016/S0040-1951(99)00276-0).
- Dickinson, W.R., 1985. Interpreting provenance relations from detrital modes of sandstones. In: Zuffa, G.G. (Ed.), *Provenance of Arenites*. Reidel, vol. 148. NATO ASI Series, Dordrecht, pp. 333–361.
- DeCelles, P.G., 1994. Late Cretaceous–Paleocene synorogenic sedimentation and kinematic history of the Sevier thrust belt, northeast Utah and southwest Wyoming. *Geol. Soc. Am. Bull.* 106, 32–56. [https://doi.org/10.1130/0016-7606\(1994\)106<0032:LCPSSA>2.3.CO;2](https://doi.org/10.1130/0016-7606(1994)106<0032:LCPSSA>2.3.CO;2).
- Dehler, C.M., Fanning, C.M., Link, P.K., Kingsbury, E.M., Rycbynski, D., 2010. Maximum depositional age and provenance of the Uinta Mountain group and big cottonwood formation, northern Utah: paleogeography of rifting western Laurentia. *Bull. Geol. Soc. Am.* 122, 1686–1699. <https://doi.org/10.1130/B30094.1>.
- do Nascimento, D.R., Sawakuchi, A.O., Guedes, C.C.F., Giannini, P.C.F., Grohmann, C.H., Ferreira, M.P., 2015. Provenance of sands from the confluence of the Amazon and Madeira rivers based on detrital heavy minerals and luminescence of quartz and feldspar. *Sediment. Geol.* 316, 1–12. <https://doi.org/10.1016/j.sedgeo.2014.11.002>.
- Fitzsimmons, K.E., Rhodes, E.J., Barrows, T.T., 2010. OSL dating of southeast Australian quartz: a preliminary assessment of luminescence characteristics and behaviour. *Quat. Geochronol.* 5, 91–95. <https://doi.org/10.1016/j.quageo.2009.02.009>.
- Forte, A.M., Whipple, K.X., 2019. The topographic analysis kit (TAK) for TopoToolbox. *Earth Surf. Dyn.* 7 (1), 87–95.
- Garzanti, E., Capaldi, T., Vezzoli, G., Limonta, M., Sosa, N., 2021. Transcontinental Retroarc Sediment Routing Controlled by Subduction Geometry and Climate Change (Central and Southern Andes. Basin Research, Argentina), pp. 1–32. <https://doi.org/10.1111/bre.12607>.
- Gentry, A., Yonkee, W.A., Wells, M.L., and Balgord, E.A. Resolving the history of early fault slip and foreland basin evolution along the Wyoming salient of the Sevier fold-and-thrust belt: Integrating detrital zircon geochronology, provenance modeling, and subsidence analysis, in Ingersoll, R.V., Lawton, T.F., and Graham, S.A., eds., *Tectonics, Sedimentary Basins, and Provenance: A Celebration of William R. Dickinson's Career*. Geological Society of America Special Paper 540, p. 509–545, [https://doi.org/10.1130/2018.2540\(23\)](https://doi.org/10.1130/2018.2540(23)).
- Gray, H.J., Jain, M., Sawakuchi, A.O., Mahan, S.A., Tucker, G.E., 2019. Luminescence as a sediment tracer and provenance tool. *Rev. Geophys.* 57, 987–1017. <https://doi.org/10.1029/2019RG000646>.
- Guralnik, B., Ankjægaard, C., Jain, M., Murray, A.S., Müller, A.S., Wälle, M., Lowick, S. E., Preusser, F., Rhodes, E.J., Wu, T.S., Mathew, G., Herman, F., 2015. OSL-thermochronometry using bedrock quartz: a note of caution. *Quat. Geochronol.* 25, 37–48. <https://doi.org/10.1016/j.quageo.2014.09.001>.
- Hesse, R., 1989. Silica diagenesis: origin of inorganic and replacement cherts. *Earth Sci. Rev.* 26, 253–284.
- Hintze, L.F., Willis, G.C., Laes, D.Y.M., Sprinkle, D.A., Brown, K.D., 2000. *Digital Geologic Map of Utah*.
- Jeong, G.Y., Choi, J.H., 2012. Variations in quartz OSL components with lithology, weathering and transportation. *Quat. Geochronol.* 10, 320–326. <https://doi.org/10.1016/j.quageo.2012.02.023>.
- Lewis, R.S., Link, P.K., Stanford, L.R., Long, S.P., 2012. *Idaho State Map*.
- Long, S.P., Link, P.K., Janecke, S.U., Perkins, M.E., Fanning, C.M., 2006. Multiple phases of Tertiary extension and synextensional deposition of the Miocene–Pliocene Salt Lake Formation in an evolving supradetachment basin, Malad Range, southeast Idaho. *U.S.A.: Rocky Mt. Geol.* 41, 1–27.
- Love, J.D., Christiansen, A.C., 1985. *Geologic Map of Wyoming*. US Geological Survey.
- Lü, T., Sun, J., Li, S.H., Gong, Z., Xue, L., 2014. Vertical variations of luminescence sensitivity of quartz grains from loess/paleosol of Luochuan section in the central Chinese Loess Plateau since the last interglacial. *Quat. Geochronol.* 22, 107–115. <https://doi.org/10.1016/j.quageo.2014.04.004>.
- Lukas, S., Spencer, J.Q.G., Robinson, R.A.J., Benn, D.I., 2007. Problems associated with luminescence dating of Late Quaternary glacial sediments in the NW Scottish Highlands. *Quat. Geochronol.* 2, 243–248. <https://doi.org/10.1016/j.quageo.2006.04.007>.
- McGuire, C., Rhodes, E.J., 2015. Downstream MET-IRSL single-grain distributions in the Mojave River, southern California: testing assumptions of a virtual velocity model. *Quat. Geochronol.* 30, 239–244. <https://doi.org/10.1016/j.quageo.2015.02.004>.
- Moska, P., Murray, A.S., 2006. Stability of the quartz fast-component in insensitive samples. *Radiat. Meas.* 41, 878–885. <https://doi.org/10.1016/j.radmeas.2006.06.005>.
- Pederson, J.L., Janecke, S.U., Reheis, M.C., Kaufman, D.S., Oaks, R.Q., 2016. Shroder in lake bonnevillie: a scientific update. In: Oviatt, C.G., J F (Eds.), *The Bear River's History and Diversion: Constraints, Unsolved Problems, and Implications for the Lake Bonneville Record, Developments in Earth Surface Processes*, vol. 20, pp. 28–59. <https://doi.org/10.1016/B978-0-444-63590-7.00002-0>.
- Pietsch, T.J., Olley, J.M., Nanson, G.C., 2008. Fluvial transport as a natural luminescence sensitiser of quartz. *Quat. Geochronol.* 3, 365–376. <https://doi.org/10.1016/j.quageo.2007.12.005>.
- Preusser, F., Ramseier, K., Schlüchter, C., 2006. Characterisation of low OSL intensity quartz from the New Zealand Alps. *Radiat. Meas.* 41, 871–877. <https://doi.org/10.1016/j.radmeas.2006.04.019>.
- Rhodes, E.J., Pownall, L., 1994. Zeroing of the OSL signal in quartz from young glaciofluvial sediments. *Radiat. Meas.* 23, 581–585. [https://doi.org/10.1016/1350-4487\(94\)90103-1](https://doi.org/10.1016/1350-4487(94)90103-1).
- Servicio Geológico Minero (SEGEMAR), 1999. *Geología Argentina: Buenos Aires, Argentina, SEGEMAR, Scale 1:3,000,000, Digital Version (CD-ROM)*.
- Servicio Nacional de Geología y Minería (Sernageomin), 2003. *Mapa Geológico de Chile: version Digital. Sernageomin Publ. Geol. Digit. 4 scale 1:1,000,000*.
- Sawakuchi, A.O., Blair, M.W., DeWitt, R., Faleiros, F.M., Hyppolito, T., Guedes, C.C.F., 2011. Thermal history versus sedimentary history: OSL sensitivity of quartz grains extracted from rocks and sediments. *Quat. Geochronol.* 6, 261–272. <https://doi.org/10.1016/j.quageo.2010.11.002>.
- Sawakuchi, A.O., et al., 2018. Luminescence of quartz and feldspar fingerprints provenance and correlates with the source area denudation in the Amazon River basin. *Earth Planet Sci. Lett.* 492, 152–162. <https://doi.org/10.1016/j.epsl.2018.04.006>.
- Schmidt, S., Tsukamoto, S., Salomon, E., Frechen, M., Hetzel, R., 2012. Optical dating of alluvial deposits at the orogenic front of the Andean Precordillera (Mendoza, Argentina). *Geochronometria* 39, 62–75. <https://doi.org/10.2478/s13386-011-0050-5>.
- Spencer, J.Q.G., Robinson, R.A.J., 2008. Dating intramontane alluvial deposits from NW Argentina using luminescence techniques: problems and potential. *Geomorphology* 93, 144–155. <https://doi.org/10.1016/j.geomorph.2006.12.021>.
- von Gosen, W., 1992. Structural evolution of the Argentine precordillera: the Rio san juan section. *J. Struct. Geol.* 14, 643–667. [https://doi.org/10.1016/0191-8141\(92\)90124-F](https://doi.org/10.1016/0191-8141(92)90124-F).
- Zular, A., Sawakuchi, A.O., Guedes, C.C.F., Giannini, P.C.F., 2015. Attaining provenance proxies from OSL and TL sensitivities: coupling with grain size and heavy minerals data from southern Brazilian coastal sediments. *Radiat. Meas.* 81, 39–45. <https://doi.org/10.1016/j.radmeas.2015.04.010>.