

High-precision provenance determination using detrital-zircon ages and petrography of Quaternary sands on the eastern Snake River Plain, Idaho

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ABSTRACT

The Big Lost trough is an upper Pliocene to Holocene sedimentary basin containing volcanic sills in the northeastern Snake River Plain, Idaho. The basin receives sediment primarily from Basin and Range fluvial systems of the Big Lost River, Little Lost River, and Birch Creek. The Big Lost trough contains a >200-m-thick succession of lacustrine, fluvial, eolian, and playa sediments, recording high-frequency Quaternary climatic fluctuations interbedded with basalt flows. Alternating deposition of clay-rich lacustrine sediments and sandy fluvial and eolian sediments in the central part of the basin was in response to the interaction of fluvial and eolian systems with Pleistocene Lake Terreton. The source areas for modern sands from the fluvial systems can be differentiated by using both petrography and U/Pb age spectra from detrital-zircon populations. Provenance data from subsurface sands indicate that the Big Lost trough was supplied with sand largely deposited by the Big Lost River, with local redeposition by eolian processes, similar to the modern depositional system. Provenance and stratigraphic data suggest that during Pleistocene wet climate cycles, the center of the basin was dominated by lacustrine sedimentation; during dry climate cycles, the base level dropped, the Big Lost River prograded across the basin, and the eolian system became active. At least seven climate oscillations are recorded in strata deposited between ~140 and ~1250 ka.

INTRODUCTION

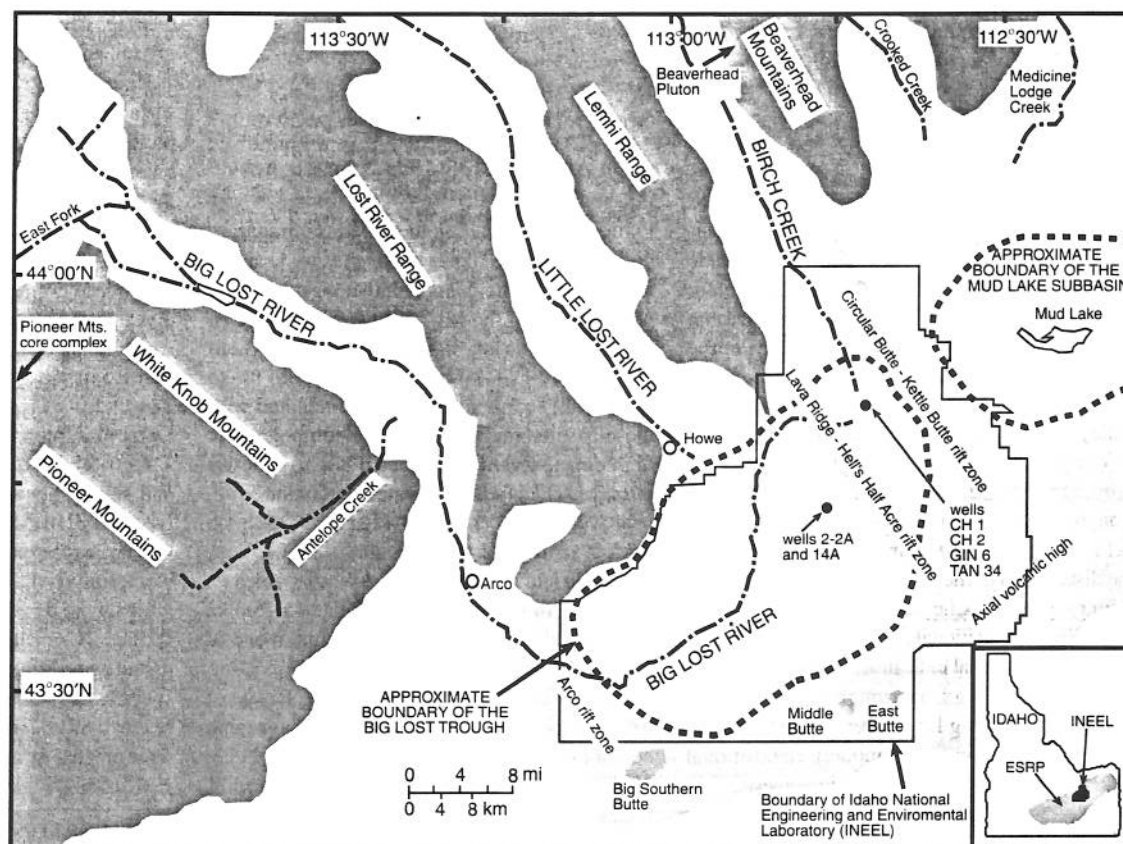
Quaternary sedimentation on the northeastern margin of the eastern Snake River Plain, Idaho (Fig. 1), reflects the interaction of (1) fluvial systems that drain adjacent Basin and Range moun-

tains to the northwest, (2) basaltic volcanism that diverts fluvial systems and forms sills for the basin, (3) a climate-controlled lacustrine system, and (4) an eolian system driven by prevailing southwesterly winds (e.g., Malde, 1991). Perennial lake to ephemeral playa systems, including Pleistocene Lake Terreton, have existed in this area during at least the past 2 m.y. (e.g., Scott, 1982). Big Lost River, Little Lost River, and Birch Creek flow out of the adjacent mountains and terminate in playas and sinks located in a small, closed basin, termed the Big Lost trough (Gianniny et al., 1997; Fig. 1).

A stratigraphic succession, recovered from wells 2-2A and 14A, in the middle of the Big Lost trough (Fig. 2) contains a record of the interaction of the depositional systems operating for the past ~1.5 m.y. There are two hypotheses to explain the alternation of clay- and sand-rich deposits in the center of the basin. (1) The stratigraphic succession records high-frequency fluctuations of Pleistocene Lake Terreton. In this case, subsurface sand units represent dry climate cycles and deposition by the Big Lost River and

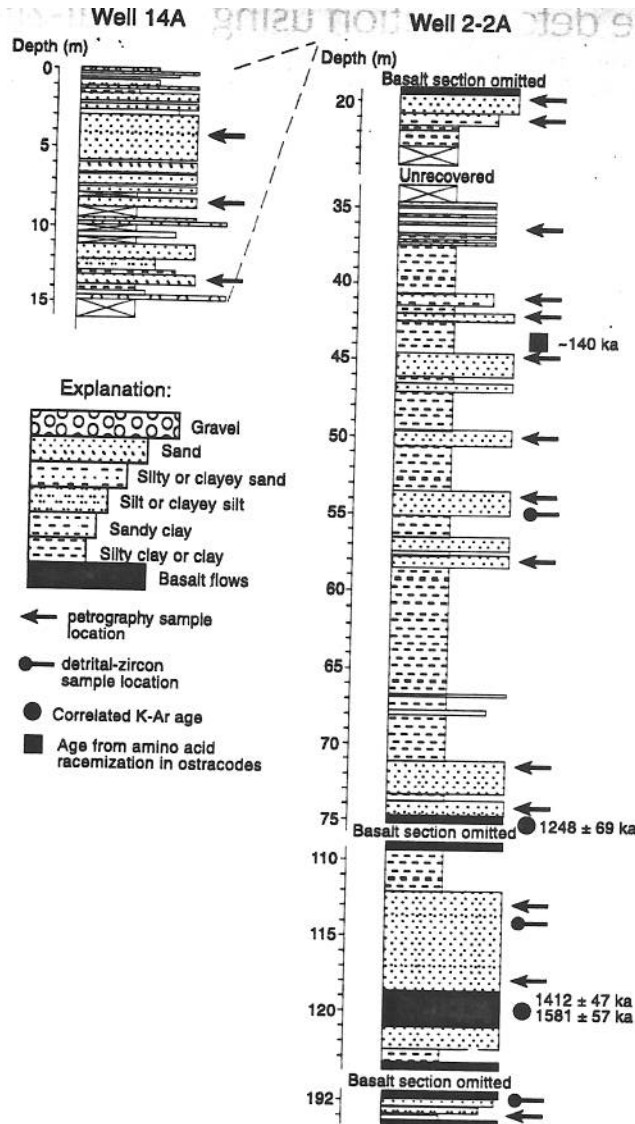
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Figure 1. Map of study area showing location of approximate boundary of Big Lost trough, adjacent mountain ranges, streams that flow into basin, approximate location of volcanic features on Snake River Plain and wells used in this study.



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Figure 2. Stratigraphy in center of the Big Lost Trough as recorded in core samples collected from two adjacent wells. Basalt flow occupies from 1.2 to 19.5 m in well 2-2A, but is absent in well 14A. Samples were not collected below 15.2 m in well 14A. Ages are based on correlation between well 2-2A and wells in vicinity of Test Area North by Anderson and Bowers (1995) and K-Ar dating of basalts in Test Area North area wells by Lanphere et al. (1994).



olian systems, similar to the modern depositional-system configuration. (2) The stratigraphic succession records a long-lived Lake Terretion; sand interbeds represent lacustrine deltas that prograded into central and northern parts of the trough (location of wells 2-2A and 14A, see Fig. 1) from the Little Lost River and Birch Creek valleys during times of greater sediment influx.

The goals of this study were to document the provenance of Quaternary sands in the Big Lost trough, determined by petrographic analysis and detrital-zircon U/Pb geochronology, to determine the distribution of the fluvial systems during basin infilling, and to test the two hypotheses concerning Pleistocene depositional systems. We will present provenance data that indicate that subsurface sands throughout the Big Lost trough were deposited primarily by the Big Lost River, with local eolian reworking, similar to the modern depositional systems, which supports the first hypothesis.

THE BIG LOST TROUGH

Topographic depressions, created between volcanic features on the eastern Snake River

Plain, define small, underfilled sedimentary basins such as the Big Lost trough (Fig. 1) and to the northeast, the Mud Lake subbasin. At the northern end of the Big Lost trough, the age of surficial basaltic lava flows is about 940 ka (Lanphere et al., 1994). On the basis of thin (1- to 3-m-thick) sedimentary units intercalated with these basalts, this area was a paleotopographic high during much of the basin history (Geslin et al., 1997). In the north-central part of the basin, near wells 2-2A and 14A (Figs. 1, 2), a much thicker sedimentary succession is found (e.g., Anderson and Bowers, 1995). A similar volcanic feature, with lava flows as young as 15–200 ka (Kuntz et al., 1994), defines the southern end of the Big Lost trough.

Modern sediments present in the Big Lost trough include lacustrine, fluvial, playa, and eolian facies associations (e.g., Gianniny et al., 1997) and provide analogs to subsurface sediments recovered in wells. An important aspect of the area is that the modern distribution of depositional systems can be used as an analog for ancient dry climate cycles. Modern sand delivery

to the Big Lost trough is dominated by fluvial facies of the Big Lost River, which are commonly reworked by eolian processes.

During wet climate cycles in the Pleistocene, Lake Terretion expanded to cover both the Big Lost trough and Mud Lake subbasin (e.g., Scott, 1982). The fact that the surface of the eastern Snake River Plain in this area generally has extremely little relief (<20 m) suggests that climatically driven changes in lake level would result in rapid fluctuations in the lateral extent of the lake.

SAND PROVENANCE RESULTS

The source areas of surface and subsurface sands were characterized by using modal compositions and U/Pb SHRIMP (sensitive high-resolution ion microprobe) ages of detrital zircons¹. Surficial sands were collected from the Big Lost River, Little Lost River, Birch Creek, and several small drainages north of the Big Lost trough (Fig. 1). Subsurface samples were obtained from wells in the central and northern parts of the basin (Figs. 1, 2).

Petrographic Compositional Analyses

Modern fluvial and eolian sands were compared compositionally by recalculating raw point-count data into detrital modes and plotting on ternary diagrams (Fig. 3). Fields defined by the statistical average and standard deviation for samples from modern source areas successfully differentiate the source areas of the streams (Fig. 3). The average composition of eolian sands overlaps several of the fluvial fields, suggesting mixing and redeposition by eolian processes.

Recalculated modal compositions of subsurface sands were compared to surface sands by plotting subsurface samples as individual points on the ternary diagrams (Fig. 3). The majority of the subsurface sand samples are compositionally similar to surficial sands from the Big Lost River; a few samples are compositionally similar to modern eolian sands. These results suggest that the Big Lost River has been the dominant source of sandy sediments in the basin over the past 1.5 m.y.

Detrital-Zircon U/Pb Geochronology

Detrital zircons separated from six surface and seven subsurface sand samples were analyzed on SHRIMP I at Australian National University. From each sample, ~50 zircon grains were analyzed. The ages of individual zircon grains were derived from the weighted mean of ²⁰⁶Pb/²³⁸U-, ²⁰⁷Pb/²³⁵U-, and ²⁰⁷Pb/²⁰⁶Pb-corrected ages. Figures 4 and 5 show the zircon age spectra for surficial and subsurface samples, respectively. The relative-probability spectra were created by assigning Gaussian distributions

¹GSA Data Repository item 9927, petrographic and zircon geochronology data, is available on request from Documents Secretary, GSA, P.O. Box 9140, Boulder, CO 80301-9140. E-mail: editing@geosociety.org.

to individual ages and errors and then summing them together in 1 m.y. bins.

There are distinctively different detrital-zircon age spectra for the fluvial systems that provide sediment to the Big Lost trough (Fig. 4). Birch Creek and the small northern drainages (Fig. 4 C–F) contain several distinctive detrital-zircon populations: (1) a large group of 1000 to 2000 Ma zircons and a small group of 2500 to 3000 Ma zircons likely recycled from Mesoproterozoic to Ordovician strata exposed in the Beaverhead Mountains and Lemhi Range (Oaks et al., 1977; Skipp and Link, 1992; Winston and Link, 1993); (2) ca. 500 Ma zircons derived from the Ordovician Beaverhead pluton exposed in the Beaverhead Mountains (Fig. 1; Evans and Zartman, 1988); (3) 70 to 100 Ma zircons derived from the Cretaceous Idaho batholith (Worl et al., 1995); and (4) several groups of <20 Ma zircons derived from Snake River Plain volcanic rocks.

The Little Lost River sample (Fig. 4B) also contains a large Paleoproterozoic zircon population (1500–2000 Ma), but is differentiated by the presence of a large ca. 50 Ma zircon population, derived from the Eocene Challis Volcanic Group, and by the lack of 500 Ma and <20 Ma zircon populations.

The Big Lost River sample (Fig. 4A) is easily recognized by an abundance of ca. 50 Ma zircon grains and by a lack of older zircons. It is surprising that the Proterozoic to Archean detrital-zircon signature is faint (4 grains out of 50) despite the fact that the upper reaches of the Big Lost River drain the Pioneer Mountains core complex (Fig. 1) where abundant Paleoproterozoic metamorphic rocks crop out (Worl et al., 1995). The enigmatic zircon signature of the Big Lost River requires further study.

Detrital-zircon age spectra for subsurface sands in the central Big Lost trough (Fig. 5 A–C) display an abundance of zircons with ages of ca. 50 Ma and very few Paleozoic and older zircon grains. There are also small populations of 70 to 100 Ma zircons probably derived from the Cretaceous Idaho batholith. The zircon signatures for these samples are most similar to the zircon signature for the modern Big Lost River (Fig. 4A). This finding suggests, in agreement with modal compositional data, that the Big Lost River drainage was the dominant source of sandy sediment deposited in the basin.

Detrital-zircon age spectra for subsurface samples collected near the northern margin of the basin (Fig. 5 D–G) show changing source areas through time. The detrital-zircon signature of shallow sediments (Fig. 5D) is most similar to the signature of the Big Lost River (Fig. 4A). Deeper samples (Fig. 5 E–G) have detrital-zircon signatures similar to Birch Creek (Fig. 4C) or Crooked Creek (Fig. 4E).

DISCUSSION

The provenance of subsurface sands in the Big Lost trough can be determined with a great

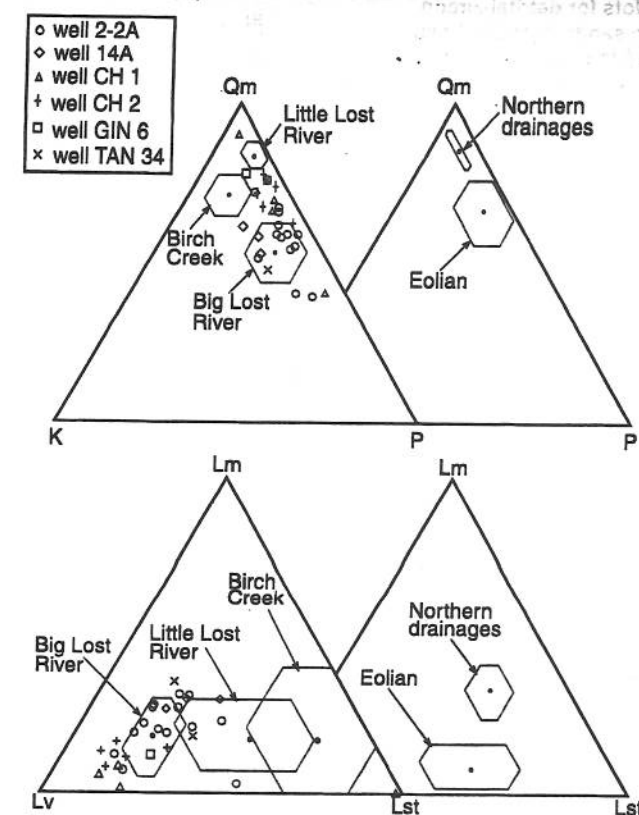


Figure 3. Standard ternary plots of detrital modes from petrographic analysis of sand samples. Qm—monocrystalline quartz, K—potassium feldspar, P—plagioclase feldspar, Lm—metamorphic lithic grains, Lv—volcanic lithic grains, Lst—total sedimentary lithic grains. Polygons represent mean and standard deviation for samples collected from modern drainages (Big Lost River, $n = 6$, Little Lost River, $n = 5$, Birch Creek, $n = 4$, northern drainages, $n = 4$, eolian deposits, $n = 5$). Symbols represent individual samples collected from wells (locations in Fig. 1) in central and northern parts of Big Lost trough ($n = 29$).

deal of accuracy; possible source areas are known and are still providing sediments to the basin, and the provenance signatures of the source areas are unique to the point that they can be differentiated. Both petrographic composi-

tional analyses and detrital-zircon U/Pb geochronology indicate that the source area for subsurface sands in the Big Lost trough is dominantly the Big Lost River drainage.

Big Lost River sands can only be deposited in

Figure 4. Relative probability plots for detrital-zircon ages determined for modern fluvial sands. Big Lost River, Little Lost River, and Birch Creek (A–C) are primary fluvial systems flowing into Big Lost trough; smaller streams (D–F) are north of basin. Upper graphs contain results of all analyses (0 to 3000 Ma zircons); lower graphs are for young (<180 Ma) zircon populations.

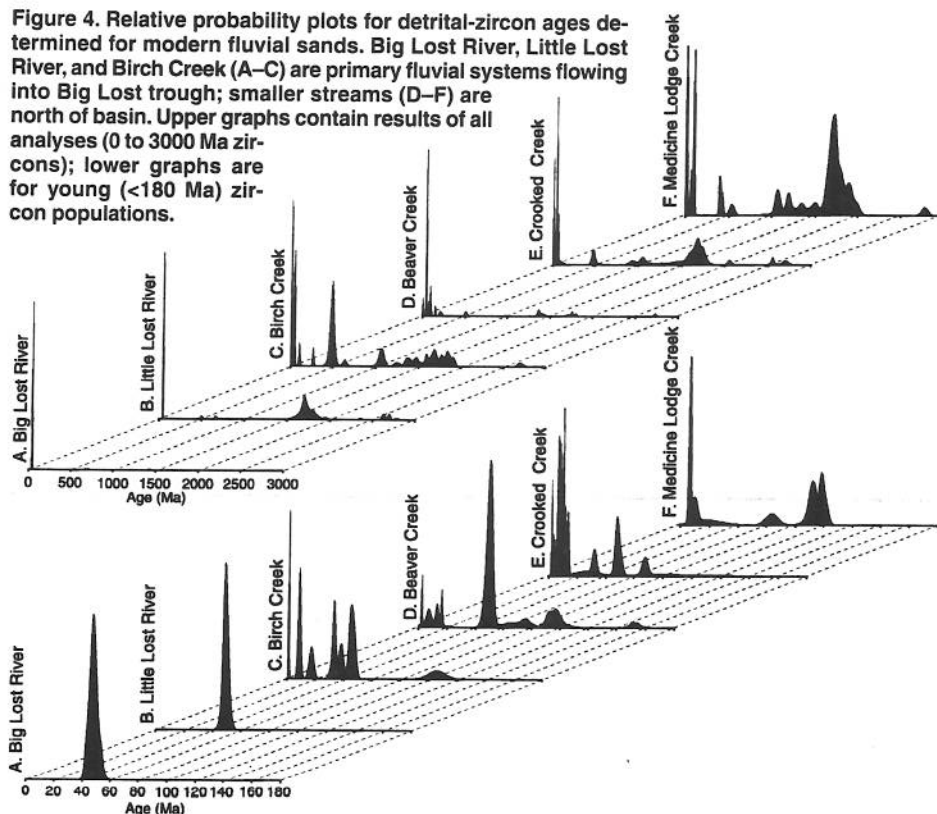
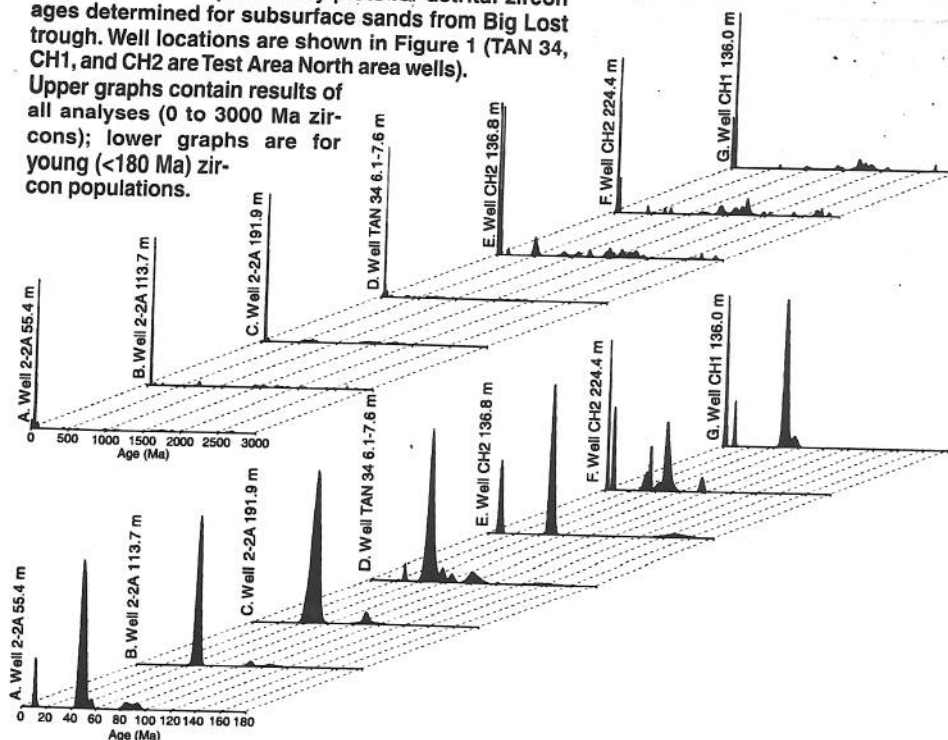


Figure 5. Relative probability plots for detrital-zircon ages determined for subsurface sands from Big Lost trough. Well locations are shown in Figure 1 (TAN 34, CH1, and CH2 are Test Area North area wells). Upper graphs contain results of all analyses (0 to 3000 Ma zircons); lower graphs are for young (<180 Ma) zircon populations.



the central and northern parts of the Big Lost trough during lowstands of Pleistocene Lake Terretion, in a configuration similar to that of present day. If subsurface sand units represent depositional conditions similar to those found today, each sand unit (Fig. 2) represents a dry climate cycle, whereas intervening clay-rich lacustrine deposits represent lake highstands corresponding to wet climate cycles. Therefore, the stratigraphic succession in the middle of the basin records high-frequency fluctuations of Lake Terretion induced by Pleistocene climate change. A continuous succession of strata recovered from well 2-2A, bracketed by ages of ~ 140 and $1,248 \pm 69$ ka (Fig. 2), contains a record of at least seven climatic oscillations, fewer than are present in the time-equivalent deep-sea $\delta^{18}\text{O}$ record (e.g., Berger et al., 1992).

CONCLUSIONS

This study documents the utility of precision provenance analysis using multiple analytical techniques. Analyzing surficial sands from modern drainages to use as analogs facilitated high-precision provenance determinations for Quaternary sands in the Big Lost trough.

Quaternary strata preserved in the Big Lost trough contain alternating clay-rich lacustrine deposits of Pleistocene Lake Terretion and sand-rich deposits with provenance signatures indicating deposition dominantly by the Big Lost River and eolian processes. In our proposed model, clay-rich Lake Terretion deposits represent wet climate cycles, whereas widespread deposits of Big Lost River and eolian sands, based on analogous modern depositional systems, are interpreted to represent Lake Terretion lowstands and dry climate cycles.

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REFERENCES CITED

- Anderson, S. R., and Bowers, B., 1995, Stratigraphy of the unsaturated zone and uppermost part of the Snake River Plain aquifer at Test Area North, Idaho National Engineering Laboratory, Idaho: U.S. Geological Survey Water-Resources Investigations Report 95-4130, 47 p.
- Berger, W. H., Bickert, T., Schmidt, H., and Wefer, T., 1992, Quaternary oxygen isotope record of pelagic foraminifers; Site 806, Ontong Java Plateau: Proceedings of the Ocean Drilling Program, Scientific Results, Volume 130: College Station, Texas, Ocean Drilling Program, p. 381-395.
- Evans, K. V., and Zartman, R. E., 1988, Early Paleozoic alkalic plutonism in east-central Idaho: Geological Society of America Bulletin, v. 100, p. 1981-1987.
- Geslin, J. K., Gianniny, G. L., Link, P. K., and Riesterer, J. W., 1997, Subsurface sedimentary facies and Pleistocene stratigraphy of the northern Idaho National Engineering Laboratory: Controls on hydrogeology, in Sharma, S., and Hardcastle, J. H., eds., Proceedings of the 32nd Annual Symposium on Engineering Geology and Geotechnical Engineering: Moscow, Idaho, University of Idaho, p. 15-28.
- Gianniny, G. L., Geslin, J. K., Riesterer, J. W., Link, P. K., and Thackray, G. D., 1997, Quaternary surficial sediments near Test Area North (TAN), northeastern Snake River Plain: An actualistic guide to aquifer characterization, in Sharma, S., and Hardcastle, J. H., eds., Proceedings of the 32nd Annual Symposium on Engineering Geology and Geotechnical Engineering: Moscow, Idaho, University of Idaho, p. 29-44.
- Kuntz, M. A., Skipp, B., Lanphere, M. A., Scott, W. E., Pierce, K. L., Dalrymple, G. B., Champion, D. E., Embree, G. F., Page, W. R., Morgan, L. A., Smith, R. P., Hackett, W. R., and Rodgers, D. W., 1994, Geological map of the INEL and adjoining areas, eastern Idaho: U.S. Geological Survey Miscellaneous Investigations Series Map I-2330, scale 1:100,000.
- Lanphere, M. A., Kuntz, M. A., and Champion, D. E., 1994, Petrography, age, and paleomagnetism of basaltic lava flows in coreholes at the Test Area North (TAN), Idaho National Engineering Laboratory: U.S. Geological Survey Open-File Report 94-686, 48 p.
- Malde, H. E., 1991, Quaternary geology and structural history of the Snake River Plain, Idaho and Oregon, in Morrison, R. B., ed., Quaternary non-glacial geology, conterminous U.S.: Boulder, Colorado, Geological Society of America, The Geology of North America, v. K-2, p. 251-280.
- Oaks, R. Q., Jr., James, W. C., Francis, G. G., and Schulingkamp, W. J., 1977, Summary of Middle Ordovician stratigraphy and tectonics, northern Utah, southern and central Idaho, in Rocky Mountain thrust belt geology and resources: Casper, Wyoming Geological Association Guidebook, p. 101-118.
- Scott, W. E., 1982, Surficial geologic map of the eastern Snake River Plain and adjacent areas, 111°-115°W, Idaho and Wyoming: U.S. Geological Survey Miscellaneous Investigations Series Map I-1372, scale 1:250,000.
- Skipp, B., and Link, P. K., 1992, Middle and Late Proterozoic rocks and Late Proterozoic tectonics in the southern Beaverhead Mountains, Idaho and Montana, a preliminary report, in Link, P. K., Kuntz, M. A., and Platt, L. B., eds., 1992, Regional geology of eastern Idaho and western Wyoming: Geological Society of America Memoir 179, p. 141-153.
- Winston, D., and Link, P. K., 1993, Middle Proterozoic rocks of Montana, Idaho, and Washington: The Belt Supergroup, in Reed, J., Simms, P., Houston, R., Rankin, D., Link, P., Van Schmus, R., and Bickford, P., eds., Precambrian of the conterminous United States: Boulder, Colorado, Geological Society of America, Geology of North America, v. C-3, p. 487-521.
- Worl, R. G., Link, P. K., Winkler, G. R., and Johnson, K. M., eds., 1995, Geology and mineral resources of the Hailey 1° x 2° quadrangle and the western part of the Idaho Falls 1° x 2° quadrangle, Idaho: U.S. Geological Survey Bulletin 2064, Volume 1, Chapters A-R, separate pagination.

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