U-Pb Age of Continental Red Beds North of Alamo Lake, Arizona*

William J. Elliott[1] and Joseph L. Corones[2]

Search and Discovery Article #51517 (2018)**
Posted September 4, 2018

*Adapted from extended abstract based on poster presentation given at 2018 Pacific Section AAPG Convention, Bakersfield, California, April 22-25, 2018
 DOI:10.1306/51517Elliott2018

[1]Retired Engineering Geologist, P.O. Box 541, Solana Beach, California (redbeds77@gmail.com)
[2]Retired Engineering Geologist

Abstract

Scattered, isolated outcrops of siliciclastic red beds occur throughout southeastern California and southwestern Arizona. Camel, dog, cat, and bird trackways in fine-grained sediments, found near Lincoln Ranch, Arizona, suggest a continental origin. Red and orange staining derives from post-depositional weathering of iron bearing minerals, such as hornblende and biotite, in hot arid or semi-arid climates. North of Alamo Lake, Arizona, an approximately 2 foot thick, cream to light green volcanic ash occurs within the red-orange Chapin Wash Formation. Basal ash was deposited on a dry, mud-cracked lake bed. U-Pb Zircon age of this ash is: 12.53 ± 0.16 Ma (Middle Miocene).

Introduction

The purpose of this article is twofold,

1) To report progress since a red beds poster was presented at the California State University, Fullerton, Desert Symposium at ZZYZX Field Station, California, in 2015, (Elliott, 2015). This poster delineated the approximate areal extent of individual red beds outcrops in southeastern California and southwestern Arizona. Poster topics included preliminary observations of principal outcrop characteristics such as: color, thickness, attitude, composition, post depositional diagenesis, provenance, direction of transport, relative position in basin or basins of deposition, and estimated age, and

2) To report the U-Pb age of Chapin Wash Formation red beds north of Alamo Lake.

The scope of work included is literature research, field work, assembling/archiving data, and dating volcanic ash found within red beds strata.

Methods

Field

An extensive search was made for widely scattered, isolated, seemingly ubiquitous outcrops of continental red beds. For the most part, red beds outcrops tend to be associated with detachment fault terrane (for example, Spencer and Reynolds, 1989). Geologic maps, highway maps, 7½' topographic maps, and Google Earth imagery were used to locate and document red beds outcrops (Figure 1, Appendix A). Red casts seen on Google Earth images are useful, but may be misleading, especially where reddish volcanic rocks are exposed.

Laboratory

A laser-ablation Uranium-Lead age of volcanic ash found sandwiched in between siliciclastic red beds was obtained at the University of Arizona (Tucson) LaserChron Center. Sample preparation was done by JR Morgan at San Diego State University.

Discussion

Red Beds in the Colorado River Corridor

Although of great interest in the late 20th Century as an aid to locating detachment faults, with numerous exceptions, little attention appears to have been paid to making an overarching assessment of the red beds themselves. Over the past several years, a passive effort has been made to locate and document basic data on these seemingly ubiquitous red beds outcrops in southeastern California and southwestern Arizona. Results of this effort, so far, have led to the identification of ~130 scattered and isolated outcrops (Figure 1, Appendix A). For brevity's sake, Figure 1 shows only general locations; Appendix A lists only outcrop number, nearby landmark, latitude, longitude, and elevation.

General Characteristics

Mid-Tertiary sedimentary red beds crop out in several isolated locations in the eastern Mojave Desert and along the Colorado River corridor, between Yuma and Bullhead City, Arizona. The easternmost exposure is at Freeman Road (~ 21 miles east of Gila Bend, Arizona), and the westernmost exposure is at Rainbow Basin (~ 9 miles north of Barstow, California). Exposures vary in size from tens to thousands of square feet. Bedding dips fall in the range of moderate to high (Figure 2). Strike directions vary widely. High angle faulting is common (Figure 3).

Colors vary from tan to magenta, but for the most part are dominated by brick-red to red-orange; cavernous weathering is common (Figure 4). Sediment sizes range from clay, silt, sand and gravel (Figure 5), to boulders as large as 3 to 6 feet in diameter. Clast compositions at each outcrop vary with provenance; for the most part consisting of sub-angular to sub-rounded, dense, durable, volcanic, granitic and metamorphic rocks (Figure 6). Depositional sites vary from proximal to distal.

Red beds are sandwiched in time between Early Miocene-Eocene (?) sediments/older crystalline basement rocks, and only slightly deformed younger Tertiary sediments, for example, ~5 to 6 Ma (Late Miocene/Early Pliocene) Bouse Formation (Karlstrom and others, 2016). These continental deposits contain the codes for unravelling the position and composition of adjacent highlands, position and direction of river and stream systems, as well as outlines of closed intermontane basins into which these sediments were deposited and preserved.

Evidence for Continental Origin

Camel, dog, cat, and bird trackways in fine-grained sediment, found near Lincoln Ranch, Arizona, suggest a continental origin (Gassaway, 1972, p. 1 and 62, and Figs. 14-24), (Figure 7, Figure 8, Figure 9).

Origin of Red Pigment

Warm, red and orange coloration derives from hematite pigment formed after sediment deposition in hot, arid or semi-arid climates. In situ alteration of non-red sediments to hematite-stained red beds results from intrastratal alteration of iron-bearing detrital grains - particularly iron silicates such as hornblende and biotite. (for example, Walker, 1967-a).

Origin of Sedimentary Basins

These continental red beds occur in scattered and isolated outcrops throughout the Colorado River corridor. Presently disconnected from one another, but having similar characteristics (such as brick-red color, siliciclastic fluvial genesis, and being universally tilted and faulted), details of their origin and post depositional history remain to be determined. Are they all a part of one large irregularly shaped basin, do they originate in several smaller interconnected basins, or do they all originate in separate isolated basins?
In order to understand similarities and differences between various red beds outcrops, the following tasks may be pursued to shed light on this enigmatic subject:

1) Detailed sedimentological and stratigraphic measurements,
2) Determination of direction of sediment transport,
3) Structural mapping, and
4) Determination of provenance.

One clue lies in grabens and/or half grabens, for example, Jorgensen and others (1982), Miller and John (1983), Fedo and Miller (1992).

Chapin Wash Formation

Description

Chapin Wash Formation red beds were mapped by Lasky and Webber (1944, 1949), Spencer (1991), Shackelford (1989) and by Spencer and others (2015) in the Rawhide and Artillery mountains region of Mohave County, Arizona (Figure 10). It consists of brick-red to red-orange-brown alluvial fan and playa deposits of highly indurated sandstone, siltstone and mudstone. As an example, Figure 11 shows an approximately 30 feet thick outcrop dipping about 20° southeasterly. An approximately 2 foot thick cream to pale green volcanic ash was found interbedded within these red beds in a small outcrop on the southwest side of Alamo Road (Figure 12) at virtual mile post 56.5. Ash was deposited on a dry, mud-cracked lakebed. Figure 13 shows ash filling mud cracks on the left side, and face of red lakebed clay.

Location

Located less than a half mile northwest of the nominal Alamo Lake static pool, near the southwestern corner of the Artillery Peak 7½' topographic quadrangle map, Township and Range coordinates are: SE¼, Section 27, T11N, R13W, GSRBM (Gila and Salt River Base and Meridian). GPS (Google Earth Global Positioning System) coordinates are: 34º 15' 51.13" N., 113º 35' 34.94" W.; the elevation is 1,150'.

Spencer and others (2015) mapped the Chapin Wash Formation in the Artillery Peak and east half of the Rawhide Wash 7½' topographic quadrangle maps. From these maps, it appears that if mapping had been continued to the south and east, Chapin Wash Formation would have been found beyond their map boundaries.

Wilson (1933) noted Tertiary (?) red beds consisting of more than 1,000 feet of tilted and faulted, reddish-brown to gray conglomerates, arkosic sandstones and shales exposed at Baker Peaks, Antelope Hills and Mohawk Mountains. Similar looking red beds were noted at Osborne Wash (east of Parker, AZ), Gila Mountains (southeast of Yuma, AZ), and northwest of McPhaul bridge (at the Yuma, AZ, shooting range, Adair Park Road). A granitic boulder breccia exposed at Yuma bridge, Yuma Crossing (?), and west of Laguna Dam may be equivalent to the basal red bed series (Wilson, 1933, p. 30, 31). A similar conclusion was reached by Shackelford (1989, p. 25) with respect to the apparent widespread occurrence of the Chapin Wash Formation.

Based on our observations of the many scattered and isolated red beds outcrops between Yuma and Bullhead City, Arizona, it is our opinion that the name Chapin Wash Formation "could" easily apply to most, if not all, of these ubiquitous outcrops. Because of the isolated nature of these red beds outcrops, however, it is our opinion that using the name Chapin Wash Formation to identify all of these outcrops is ***not*** advised. Likely, it is better to qualify naming by using "*Chapin Wash-like red beds*" unless, or until a defensible correlation can be made between outcrops. In the meantime, it is probably better to apply informal provincial geographic names to individual exposures, and where appropriate, simply reference their similarity to the Chapin Wash Formation.

Age

A review of Colorado River corridor red beds literature shows that age estimates vary from Early Cretaceous (Robinson, 1980) to Early Pliocene (Lasky and Webber, 1949).

Wilson (1933, p. 30) identified scattered and isolated red beds in the Colorado River corridor as Tertiary (?). Spencer (1991) bracketed the age of the Chapin Wash Formation red beds between K-Ar 13.3 and 20 Ma - Lower Miocene.

A sample of ash from the Chapin Wash Formation was collected along the southwest side of Alamo Road, at virtual mile post 56.5. The laser ablation Uranium-Lead age of ash found sandwiched in between the siliciclastic Chapin Wash Formation red beds was found to be 12.53 ± 0.16 Ma (this study).

Shackelford (1989, p. 24, 25) noted that a basalt found in the upper portion of the Artillery Formation was dated 15.9 ± 0.3 Ma (whole-rock K-Ar). This provides a lower bound age for Chapin Wash Formation. Furthermore, he noted the Chapin Wash Formation is overlain by a Late Tertiary (?) basalt which he speculated may be equivalent in age to 8-10 Ma basalts on the southwest edge of the Colorado Plateau (~60 miles northeast). Assuming these two dates are correct, or at least reasonably correct, they nicely bracket the age we obtained for the Chapin Wash Formation. Although our orphan date may or may not be representative of other red beds outcrops in the Colorado River corridor, it does provide a starting benchmark for future investigations.

Artillery Formation – A Sidebar Note

The Artillery Formation was named by Lasky and Webber (1949, p. 16) for thousands of feet of catastrophic, fan, and fluvial, closed-basin deposits of Early Eocene (?) age. These continental sediments consist of a variety of mostly red, with some gray and greenish, siliciclastic deposits with inter-beds of limestone and basalt (Lasky and Webber, 1949).

Although, perhaps casually confused with the Chapin Wash Formation (for example, Jemmett, 1966; Nicks, 1982; and Stevens, 1982), Lasky and Webber, 1944, 1949; Shackelford, 1989; Spencer, 1991; and Spencer and others, 2015, make clear age and lithologic distinctions between the older Artillery Formation and the younger Chapin Wash Formation.

Questions to be Answered

Questions to be answered and enigmas to be explained with carful investigation include:

1) Size, shape, and connectedness of basins of sediment accumulation,

2) Direction of transport at individual outcrops,

3) Approximate position and composition of each highland provenance, and

4) Changes in tectonic, volcanic, sedimentary and climate patterns over time.

Conclusions

Red beds have been found as far north as Bullhead City (at Sacramento Spring, near Needles, California), and as far south as Yuma (Telegraph Pass), Arizona. The easternmost exposure is ~21 miles east of Gila Bend (Freeman Road), Arizona, and the westernmost exposure is ~ 9 miles north of Barstow (Rainbow Basin), California.

So far, approximately 130 isolated outcrops have been located and documented in a tabular database (Appendix A).

Siliciclastic red beds sediments are typically brick-red to orange-brown.

Cavernous weathering is common.

Sediment sizes vary from clay to coarse gravel. Boulder sizes range from 12 inches, to occasionally as large as 3 to 6 feet in diameter.

Sediments typically vary from well-indurated to highly-cemented.

Depending upon provenance, clast compositions range from volcanic and plutonic to metamorphic. Clasts vary from angular near source areas (proximal) to well-rounded when far traveled (distal).

Without exception, outcrops are tilted from about 10° to 50°. Direction of strike varies.

Laser-ablation Uranium-Lead age of an ash sandwiched in between red beds of the Chapin Wash Formation, north of Alamo Lake, is 12.53 ± 0.16 Ma.

As noted by several authors (e.g. Jorgensen and others, 1982; Miller and John, 1983; Fedo and Miller, 1992), these sediments appear to be associated with grabens and half-grabens created during Mid-Tertiary extension. Whether or not any or all of these outcrops are connected, remains an enigma.

Carefully coordinated field studies will be required to answer questions raised and yet to be suggested.

Acknowledgements

For their time and personal expense assisting us with processing and dating igneous zircons, we gratefully acknowledge our colleagues, JR and George Morgan. Assistance provided by Kojo Plange, Nicky Giesler, and Mark Pecha at the University of Arizona LaserChron Center, Tucson, Arizona, is very much appreciated; we could not have done this without their help and encouragement. Discussions with Dr. Monte Marshall provided additional insight and suggestions that helped us crystalize our thoughts and improve the manuscript. And, not to be forgotten, our patient wives, Wendy and Felly, who assisted with field work logistics and quiet time for manuscript preparation.

Selected References

Baker, James, 1981, Structural reconnaissance of detachment faulting in the Moon Mountains, Yuma County, Arizona: B.S. Thesis, Department of Geology, San Diego State University, 16 p.

Berg, Lindee, 1982, Mid-Tertiary detachment faulting in the Midway Mountains, Imperial County, California: B.S. thesis. Department of Geology, San Diego State University, 38 p., map scale 3.1 inches = one kilometer.

Berg, Lindee, Gregory Leveille, and Pattie Geis, 1982, Mid-Tertiary detachment faulting and manganese mineralization in the Midway Mountains, Imperial County, California, *in* Eric G. Frost and Donna L. Martin, eds., Mesozoic-Cenozoic Tectonic Evolution of the Colorado River Region, California, Arizona, and Nevada, in conjunction with a symposium and field trip for the Geological Society of America, April, 1982, (Anderson-Hamilton Volume), p. 299-311.

Carr, W.J., and D.D. Dickey, 1980, Geologic map of the Vidal, California, and Parker SW, California-Arizona quadrangles: United States Geological Survey, Map I-1125, map scale 1:24,000, contour interval 40.

Carr, W.J., D.D. Dickey, and W.D. Quinlivan, 1980, Geologic map of the Vidal NW, Vidal Junction and parts of the Savahia Peak quadrangles, San Bernardino County, California: United States Geological Survey, Map I-1126, map scale 1:24,000, contour interval 40.

Dahm, Jerry B., 1983, Geometry and timing of Tertiary deformation of the Dome Rock Mountains, Yuma County, Arizona: M.S. Thesis, Department of Geology, San Diego State University, 82+ p.

Dickey, D.D., W.J. Carr, and W.B. Bull, 1980, Geologic map of the Parker NW, Parker, and parts of the Whipple Mountains SW and Whipple Wash quadrangles, California and Arizona: United States Geological Survey Map I-1124, map scale 1:24,000, contour interval 40.

Eberly, L.D., and T.B. Stanley, Jr., 1978, Cenozoic stratigraphy and geologic history of southwestern Arizona: Geological Society of America Bulletin, v. 89/6, p. 921-941.

Elliott, W.J., 2015, Early Tertiary sedimentary red beds in the eastern Mojave Desert and adjacent Colorado River corridor – a preliminary assessment (abstract and poster), *in* R.E. Reynolds, ed., Mojave Miocene: California State University Desert Studies Center, 2015 Desert Symposium, April 2015, p. 327.

Elliott, W.J., and M. Marshall, 2011, In search of Colorado River “B” Gravel, northeastern Imperial County, California, with notes on early Tertiary red beds, *in* T.A. Wirths, ed., Picacho and the Cargo Muchachos, Gold, Guns, and Geology of Eastern Imperial County, California, San Diego Association of Geologists, Sunbelt Publications, El Cajon, California, second edition, p. 183-195.

Fedo, Christopher M., and Julia M.G. Miller, 1992, Evolution of a Miocene half-graben basin, Colorado River extensional corridor, southeastern California: Geological Society of America Bulletin, v. 104/4, p. 493-493.

Gassaway, Judith S., 1972, Geology of the Lincoln Ranch basin, Buckskin Mountains, Yuma County, Arizona: B.S. Thesis, Department of Geology, San Diego State University, Blakemore E. Thomas, advisor, June, 1972, 64 p., reduced map scale 1.32 inches = one mile.

Gassaway, Judith S., 1977, A reconnaissance study of the Cenozoic geology in west-central Arizona: M.S. Thesis, San Diego State University, 120 p., map scale 1.25" = one mile, contour interval 200'.

Google Earth, 2018, Screen shot images.

Hadley, Jarvis B., 1942, Manganese deposits in the Paymaster Mining District, Imperial County, California: United Stated Geological Survey, Bulletin 931-S, p. 459-473, map scale 1' = 500'.

Hamilton, Warren, 1964, Geologic map of the Big Maria Mountains NE quadrangle, Riverside County, California and Yuma County, Arizona: United States Geological Survey, Geologic Quadrangle Map GQ-350, map scale 1:24,000, contour interval 40'.

Hamilton, Warren, 1984, Generalized geologic map of the Big Maria Mountains region, northeastern Riverside County, southeastern California: United States Geological Survey, Open-File Report 84-407, 7 p., map scale 1:48,000.

Haxel, Gordon B., David B. Smith, Charles Whittington, Andrew Griscom, Denny V. Diveley-White, Robert E. Powell, and Terry J. Kreidler, 1988, Mineral resources of the Orocopia Mountains wilderness study area, Riverside County, California: United States Geological Survey Bulletin, Chapter E, 1710, 22 p.

Jemmett, Joe Paul, 1966, Geology of the northern Plomosa Mountains range, Yuma County, Arizona: Ph.D. Dissertation, University of Arizona, Tucson, Arizona, 128 p., colored map (scale 1: 12,000, contour interval = 20') and structure sections. Artillery Formation discussion, on p. 40-44.

Jorgensen, Michael R., Christopher J. Natenstedt, and Philip N. Trumbly, 1982, Possible relation between Miocene crustal extension/detachment faulting and the deposition of the Tolbard Fanglomerate in the Midway and western Paloverde mountains, Imperial County, California, *in* Eric G. Frost, and Donna L. Martin, eds., Mesozoic-Cenozoic Tectonic Evolution of the Colorado River Region, California, Arizona, and Nevada, in conjunction with a symposium and field trip for the Geological Society of America, April, 1982, (Anderson-Hamilton Volume), p. 313-315.

Karlstrom, K.E., L.C. Crossey, R. Crow, and R. Dorsey, 2016, New directions in research on the Bouse Formation and the origins of the lower Colorado River, *in* Robert E. Reynolds, ed., Going LOCO – Investigations Along the Lower Colorado River, California State University, Fullerton, Desert Studies Center, 2016 Desert Symposium Field Guide and Proceedings, April 2016, p. 91-96.

Lasky, S.G., and B.N. Webber, 1944, Manganese deposits in the Artillery Mountains region, Mohave County, Arizona: United States Geological Survey Bulletin 936-R, p. 417-488.

Lasky, S.G., and B.N. Webber, 1949, Manganese resources of the Artillery Mountains region, Mohave County, Arizona: United States Geological Survey Bulletin 961, 86 p.

Law, Richard D., Kenneth Eriksson, and Cole Davisson, 2001, Formation, evolution, and inversion of the middle Tertiary Diligencia basin, Orocopia Mountains, Southern California: Geological Society of America Bulletin, v. 113/2, p. 196-221.

Leveille, Gregory, 1982, Mid-Tertiary detachment faulting and manganese mineralization in the Midway Mountains, Southeastern California: B.S. Thesis, Department of Geology, San Diego State University, 41 p.

Lombard, James P., 1993, Tertiary stratigraphy of the Laguna Mountains, Yuma County, Arizona, *in* David R. Sherrod, and Jane E. Nielson, eds., Tertiary Stratigraphy of Highly Extended Terranes, California, Arizona, and Nevada, United States Geological Survey, Bulletin 2053, p. 205-212.

Lucchitta, Ivo, 1979, Late Cenozoic uplift of the southwestern Colorado Plateau and adjacent lower Colorado River region: Tectonophysics, v. 61, p. 63-95.

Lucchitta, Ivo and Neil H. Suneson, 1994-a, Geologic map of the Centennial Quadrangle, Mohave and La Paz counties, Arizona: United States Geological Survey, Map GQ 1718, scale 1:24,000, contour interval 40'.

Lucchitta, Ivo and Neil H. Suneson, 1994-b; Geologic map of the, Castanedea Hills SW quadrangle, Mohave and La Paz counties, Arizona: United States Geological Survey, Map GQ 1719, map scale 1:24,000, contour interval 20'.

Mayo, David P., 1993, Tertiary stratigraphy of the Little Chuckwalla Mountains, Southeastern California, *in* David R. Sherrod, and Jane E. Nielson, eds., Tertiary Stratigraphy of Highly Extended Terranes, California, Arizona, and Nevada, United States Geological Survey, Bulletin 2053, p. 185-187.

Miller, David M., Barbara E. John, John C. Antweiler, Robert W. Simpson, Donald B. Hoover, Gary L. Raines, and Terry J. Kreidler, 1983, Mineral resource potential of the Chemehuevi Mountains wilderness study area (CDCA-310), San Bernardino County, California: United States Geological Survey, Map MF-1584-A.

Miller, Julia M.G., and Barbara E. John, 1988, Detached strata in a Tertiary low-angle normal fault terrane, southeastern California - a sedimentary record of un-roofing, breaching, and continued slip: Geology (Geological Society of America), v. 16/7, p. 645-648.

Morton, P.K., 1977, Geology and mineral resources of Imperial County, California: California Division of Mines and Geology, County Report 7, 104 p. Pl. 1 – geologic map, map scale 1: 250,000, contour interval 200'.

Mueller, Karl J., 1982, Mid-Tertiary detachment faulting in the northern Mohawk Mountains, Yuma County, Arizona: B.S. Thesis, Department of Geology, San Diego State University, 38 p. map scale 1:24,000.

Mueller, K.J., E.G. Frost, and G. Haxel, 1982, Tertiary detachment faulting in the Mohawk Mountains of Southwestern Arizona, *in* E.G. Frost, and D.L. Martin, eds., Mesozoic-Cenozoic Tectonic Evolution of the Colorado River Region, California, Arizona, and Nevada, in conjunction with a symposium and field trip for the Geological Society of America, April, 1982, (Anderson-Hamilton Volume), p. 449-457.

Nicks, Wesley T., 1982, Mid-Tertiary detachment faulting in the northern Plomosa Mountains of northern Yuma County (La Paz County as of 1-1-1983), Arizona: B.S. Thesis, Department of Geology, San Diego State University, Eric Frost, Advisor, Spring 1982, 38 p.

Pridmore, Cynthia L., and Christy Craig, 1982, Upper-plate structure and sedimentation of the Baker Peaks area, Yuma County, Arizona, *in* Eric G. Frost, and Donna L. Martin, eds., Mesozoic-Cenozoic Tectonic Evolution of the Colorado River Region, California, Arizona, and Nevada, in conjunction with a symposium and field trip for the Geological Society of America, April, 1982, (Anderson-Hamilton Volume), p. 357-375.

Richard, Stephen M., and David R. Sherrod, 1993, Introduction to Tertiary stratigraphy of the area south of Interstate-10, Arizona and California, *in* David R. Sherrod, and Jane E. Nielson, eds., Tertiary Stratigraphy of Highly Extended Terranes, California, Arizona, and Nevada, United States Geological Survey, Bulletin 2053, p. 171-175.

Robinson, Brad A., 1980, Description and analysis of Mesozoic "red beds," western Arizona and southeastern California, *in* Judith P. Penney, and Claudia Stone, eds., Studies in Western Arizona, Arizona Geological Society Digest volume XII, Tucson, Arizona, May 1980, p. 147-154.

Shackelford, Terry J., 1989, Structural geology of the Rawhide Mountains, Mohave County, Arizona, *in* Jon E. Spencer, and Stephen J. Reynolds, eds., Geology and Mineral Resources of the Buckskin and Rawhide Mountains, West-Central Arizona, Arizona Geological Survey, Bulletin 198 (Shackelford Volume), p. 15-46, Pl. 1, scale 1" = 0.7 mile.

Sherrod, David R., and Richard M. Tosdal, 1991, Geologic setting and Tertiary structural evolution of southwestern Arizona and southeastern California: Journal of Geophysical Research, v. 96, n. B-7, p. 12,407-12,423.

Smith, David, B., Richard M. Tosdal, James A. Pitkin, M. Dean Kleinkopf, and Robert H. Wood, II, 1989, Mineral resources of the Muggins Mountains wilderness study area, Yuma County, Arizona: United States Geological Survey, Bulletin 1702, Chapter D, 16 p.

Spencer, Jon E., 1991, The Artillery manganese district in west-central Arizona: Arizona Geology, v. 21/3, fall 1991, p. 9-12.

Spencer, Jon E., and Stephen J. Reynolds, eds., 1989, Geology and mineral resources of the Buckskin and Rawhide mountains, west-central Arizona: Arizona Geological Survey, Bulletin 198 (Shackelford Volume), 279 p.

Spencer, Jon E., Stephen M. Richard, Bradford J. Johnson, Diane S. Love, Philip A. Pearthree, and Stephen J. Reynolds, 2015, Geologic map of the Artillery Peak and Rawhide Wash 7-1/2' quadrangles, Mohave and La Paz counties, Arizona: Arizona Geological Survey, digital geologic map DGM-100, sheet 1 of 2, version 2.0, map scale 1:24,000, contour interval 40'.

Spittler, Thomas E., and Michael A. Arthur, 1982, The lower Miocene Diligencia Formation of the Orocopia Mountains, Southern California - stratigraphy, petrology, sedimentology and structure, *in* R.V. Ingersoll, and M.O. Woodburne, eds., Cenozoic Nonmarine Deposits of California and Arizona, SEPM Society for Sedimentary Geology, Tulsa, Oklahoma, 122 p. (Starts on p. 83.)

Stevens, Ted, 1982, Structural study of the northeastern portion of the Harcuvar Mountains in west-central Arizona: M.S. Thesis, Department of Geology, San Diego State University, Eric Frost advisor, spring 1982, 31p, map scale 1:24,000.

Terry, Ann Heald, 1969, Geology of a portion of the Precambrian rocks of the Whipple Mountains, California: B.S. Thesis, Department of Geology, San Diego State University, 1969, 65 p., map scale 3 inches = one mile.

Terry, Ann Heald, 1972, The Geology of the Whipple Mountain thrust fault, southeastern California: M.S. Thesis, Department of Geology, San Diego State University, May 1972, 130 p., map scale 1:31,250.

United States Geological Survey, 1990, Artillery Peak, Arizona, 7½' topographic map, map scale 1:24000, contour interval 40'.

United States Geological Survey, 1990, Rawhide Wash, Arizona, 7½' topographic map, map scale 1:24000, contour interval 40'.

Van Houten, F.B, 1948, Origin of red-banded early Cenozoic deposits in Rocky Mountain region: Bulletin of the American Association of Petroleum Geologists, v. 32/11, p. 2083-2126.

Walker, T.R., 1967-a, Formation of red beds in modern and ancient deserts: Geological Society of America Bulletin, v. 78/3, p. 353-368.

Walker, T.R., 1967-b, Color of recent sediments in tropical Mexico - a contribution to the origin of red beds: Geological Society of America, Bulletin, v. 78/7, p. 917-920.

Walker, T.R., 1974, Formation of red beds in moist tropical climates - a hypothesis: Geological Society of America, Bulletin, v. 85/4, p. 633-638.

Walker, T.R., and R.M. Honea, 1969, Iron content of modern deposits in the Sonoran Desert - a contribution to the origin of red beds: Geological Society of America, Bulletin, v. 80/3, p. 535-544.

Walker, T.R., P.H. Ribbe, and R.M. Honea, 1967, Geochemistry of hornblende alteration in Pliocene red beds, Baja California, Mexico: Geological Society of America, Bulletin, v. 78/8, p. 1055-1060.

Wilson, Eldred D., 1933, Geology and mineral deposits of southern Yuma County, Arizona, Part I – general features, Chapter I – Introduction, *in* Geology and mineral deposits of southern Yuma County, Arizona, University of Arizona Bulletin, Arizona Bureau of Mines, v. 4/2, February 15, 1933. Arizona Bureau of Mines, Geological Series No. 7, Bulletin No. 134, 223+ p.

Wilson, Eldred D., Richard T. Moore, F.L. Ransome, C. Longwell, S.G. Lasky, B.N. Webber, M.G. Dings, and P.K. Sims, 1959, Geologic map of Mohave County, Arizona: Arizona Bureau of Mines, University of Arizona, Tucson, Arizona, map scale 1:375,000, contour interval 500'.

Wilson, Eldred D., 1960, Geologic map of Yuma County (including La Paz County), Arizona: Arizona Bureau of Mines, University of Arizona, Tucson, Arizona, map scale 1:375,000, contour interval 500'.

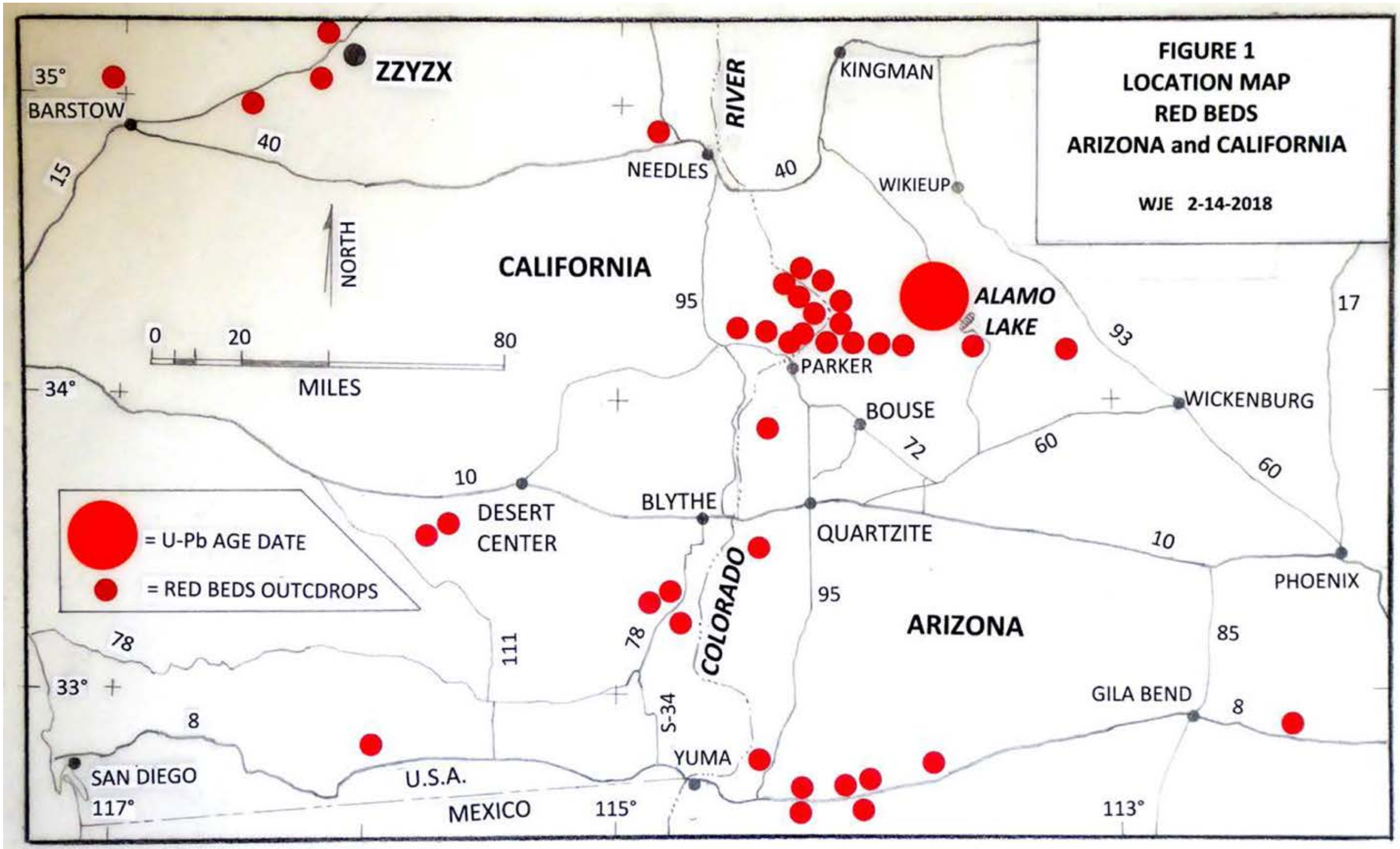

Figure 1. Location map of U-Pb age dated sample and red beds outcrops.

Figure 2. Moderately dipping and faulted red beds at Maggie Wash.

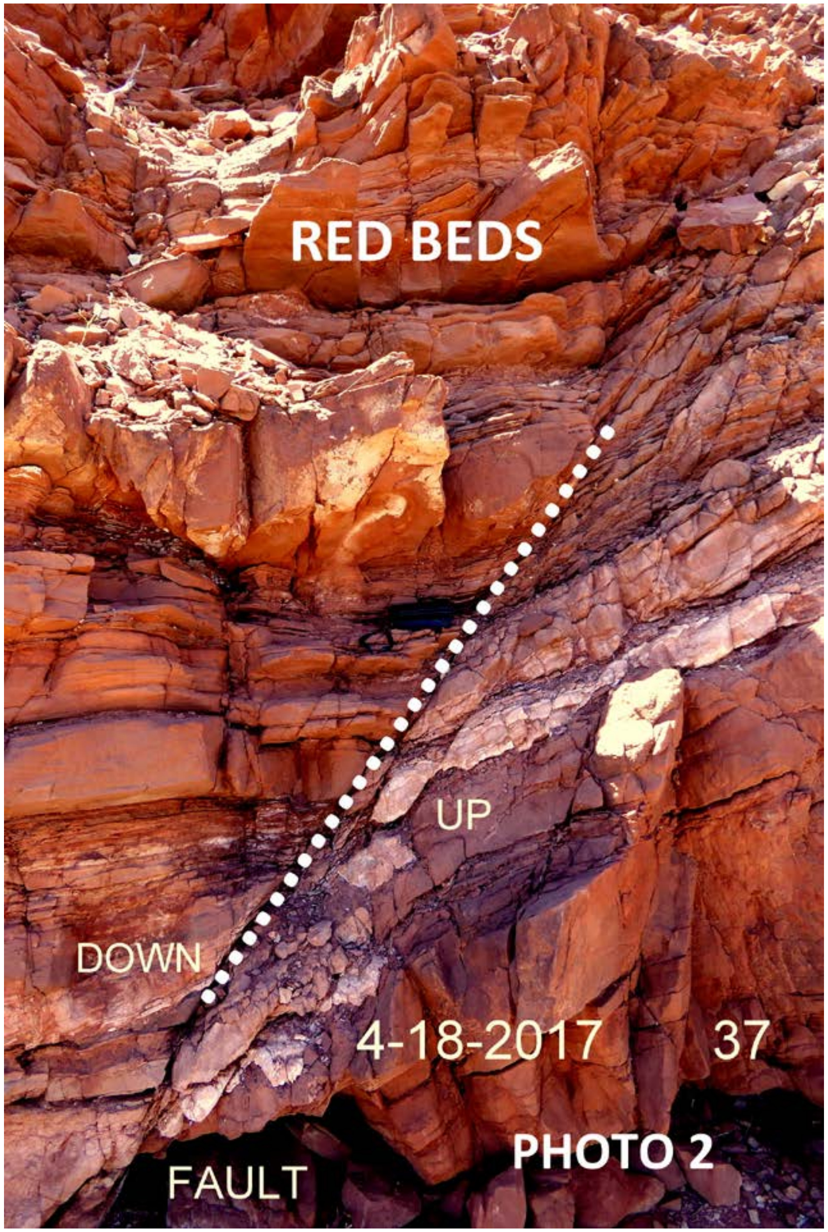

Figure 3. High-angle fault in red beds.

Figure 4. Cavernous weathering is common in the red beds.

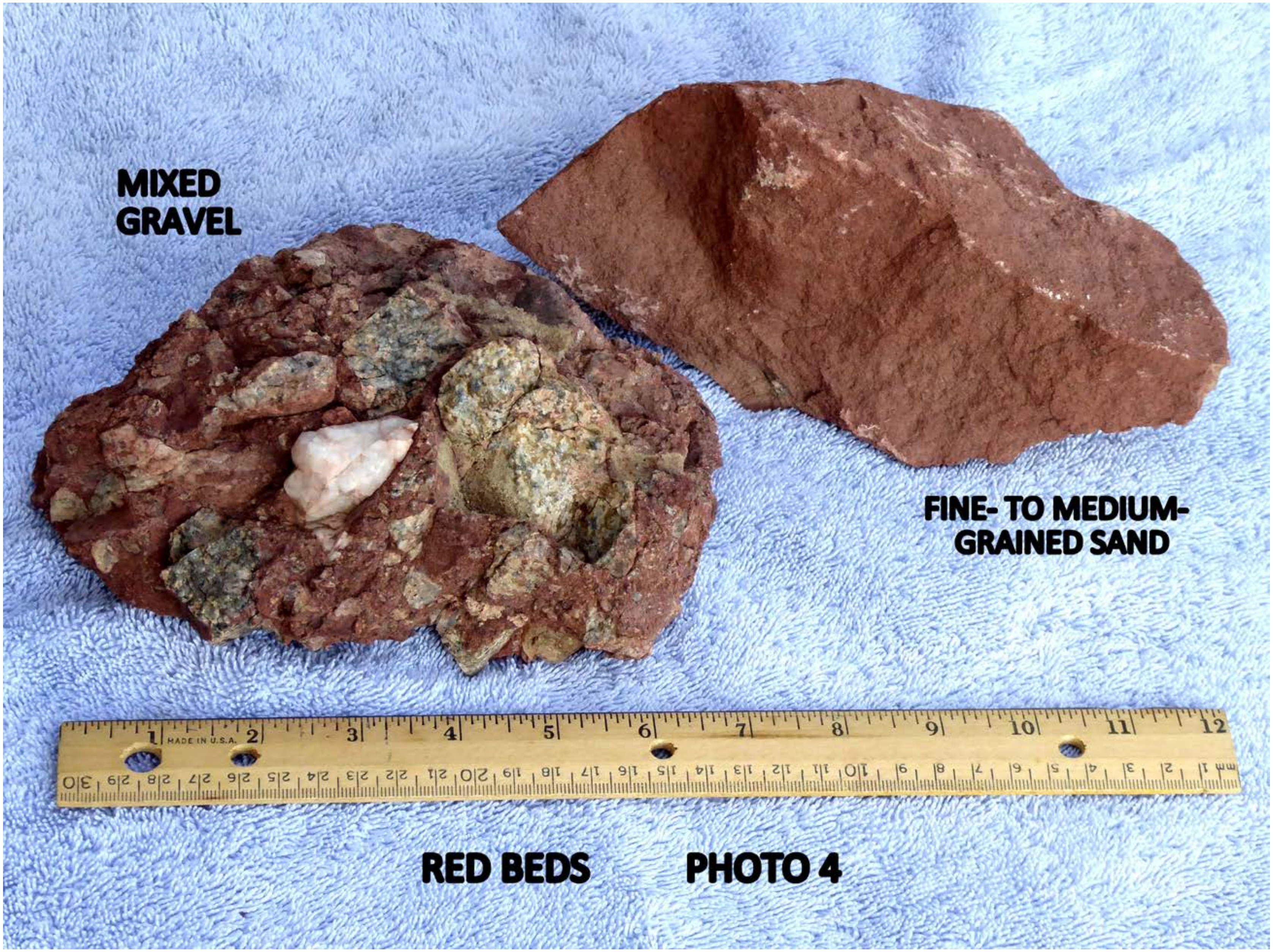

Figure 5. Sediment sizes range from clay, silt, sand and gravel, to boulders as large as 3 to 6 feet in diameter.

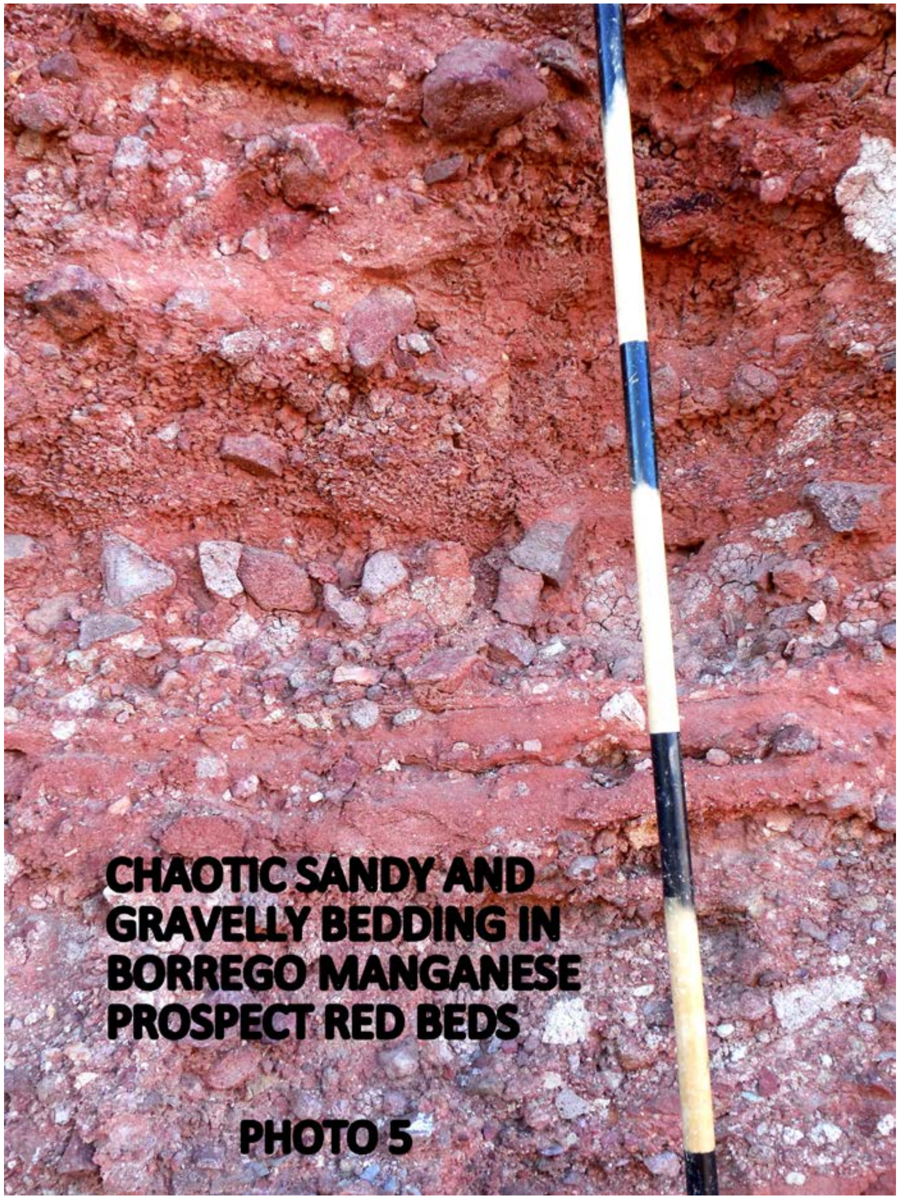

Figure 6. Clast compositions at each outcrop vary with provenance; for the most part consisting of sub-angular to sub-rounded, dense, durable, volcanic, granitic and metamorphic rocks.

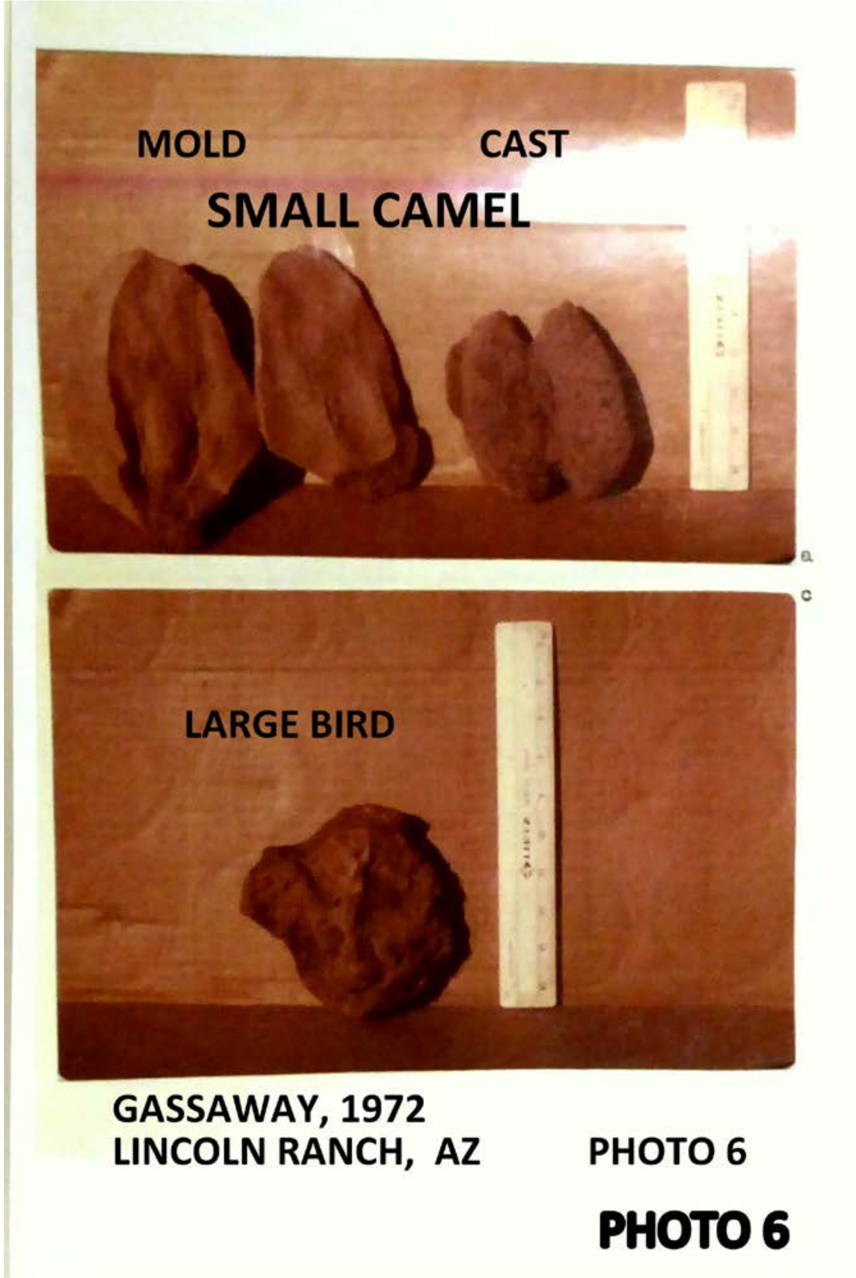

Figure 7. Camel and bird trackways in fine-grained sediment, found near Lincoln Ranch, Arizona, suggest a continental origin.

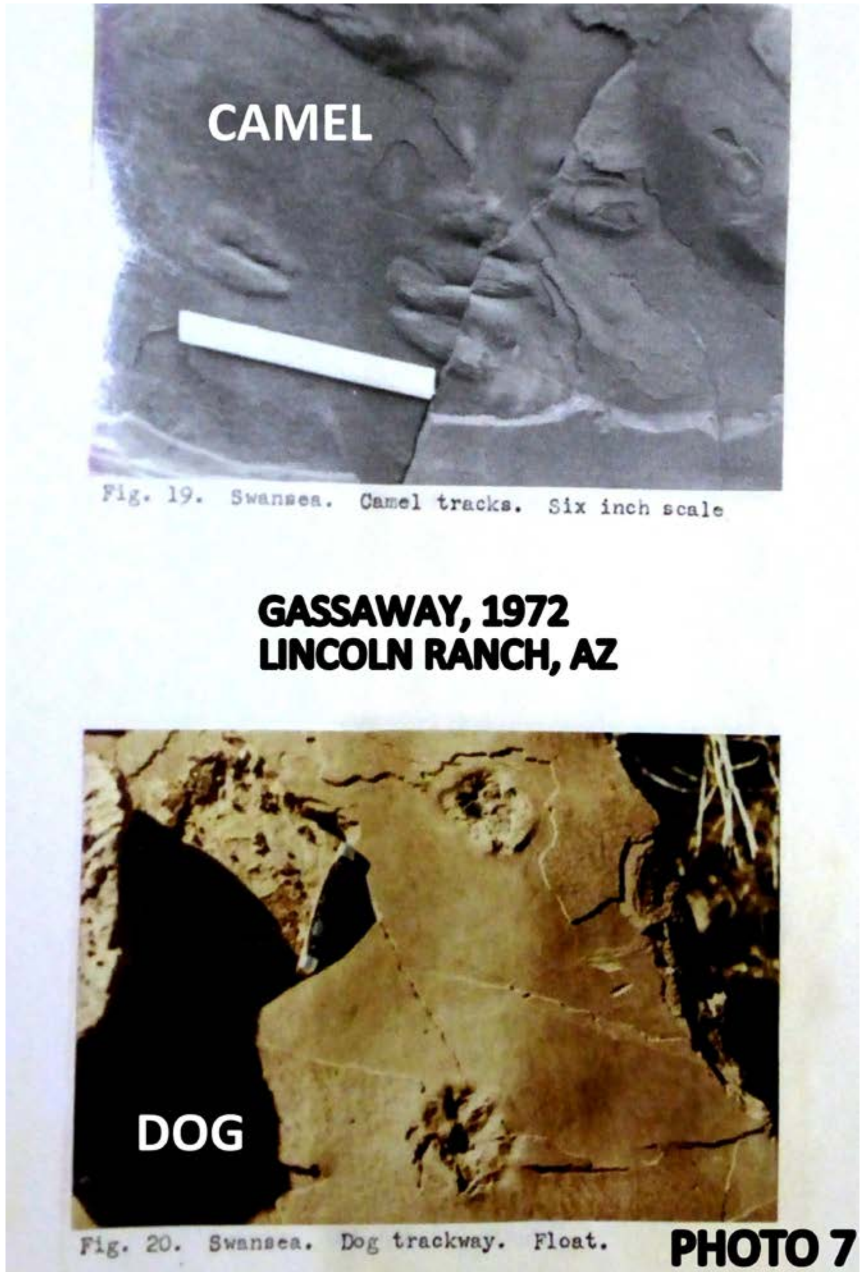

Figure 8. Camel and dog trackways in fine-grained sediment, found near Lincoln Ranch, Arizona, suggest a continental origin.

Figure 9. Bird trackways in fine-grained sediment, found near Lincoln Ranch, Arizona.

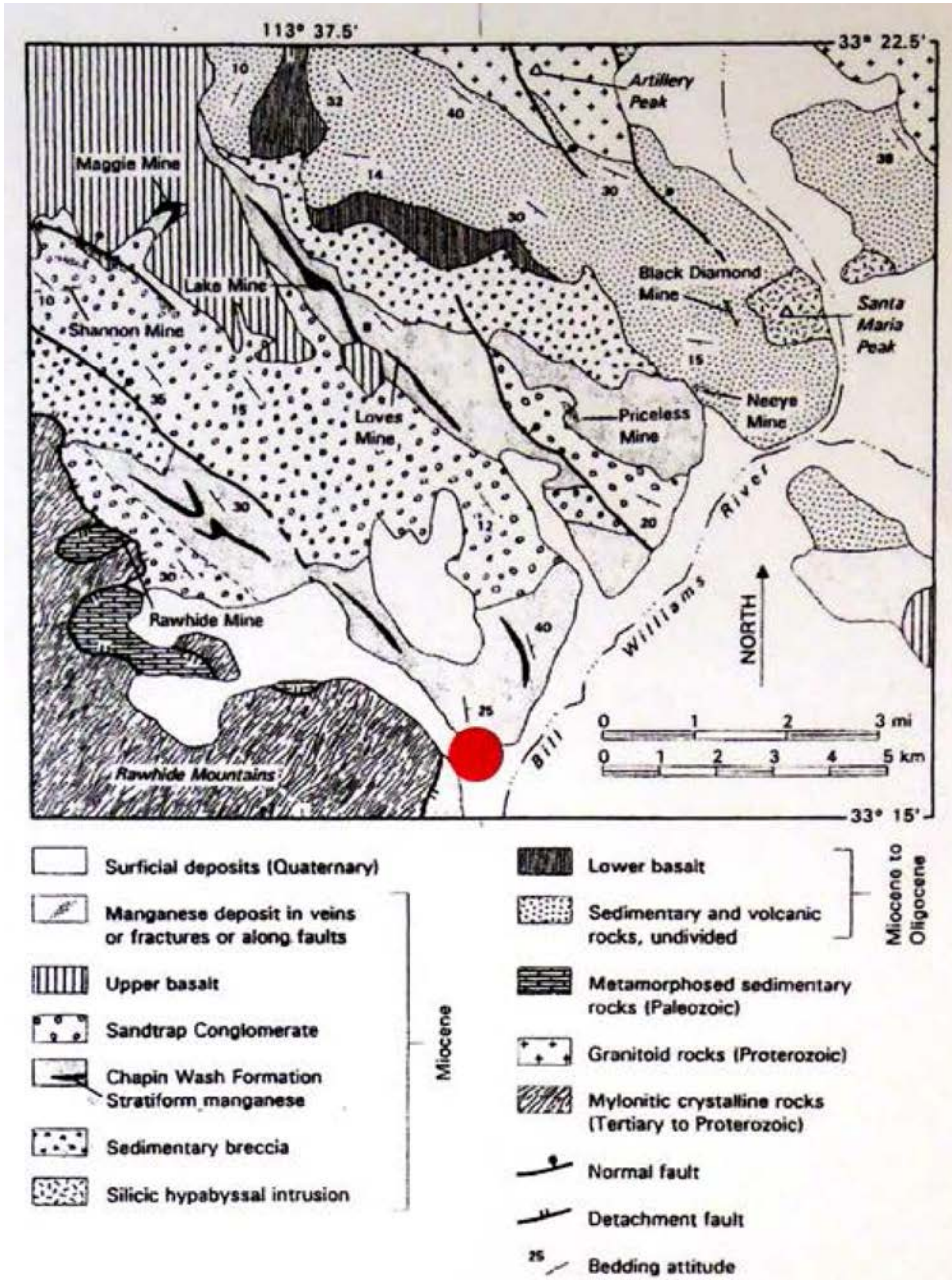

Figure 10. Geologic map showing Chapin Wash Formation and location of ash bed used for U-Pb age dating. Modified after Spencer, 1991.

Figure 11. An approximately 30-foot-thick outcrop of Chapin Wash Formation dipping about 20° southeasterly. An approximately 2-foot-thick cream to pale green volcanic ash was found interbedded within these red beds in a small outcrop on the southwest side of Alamo Road.

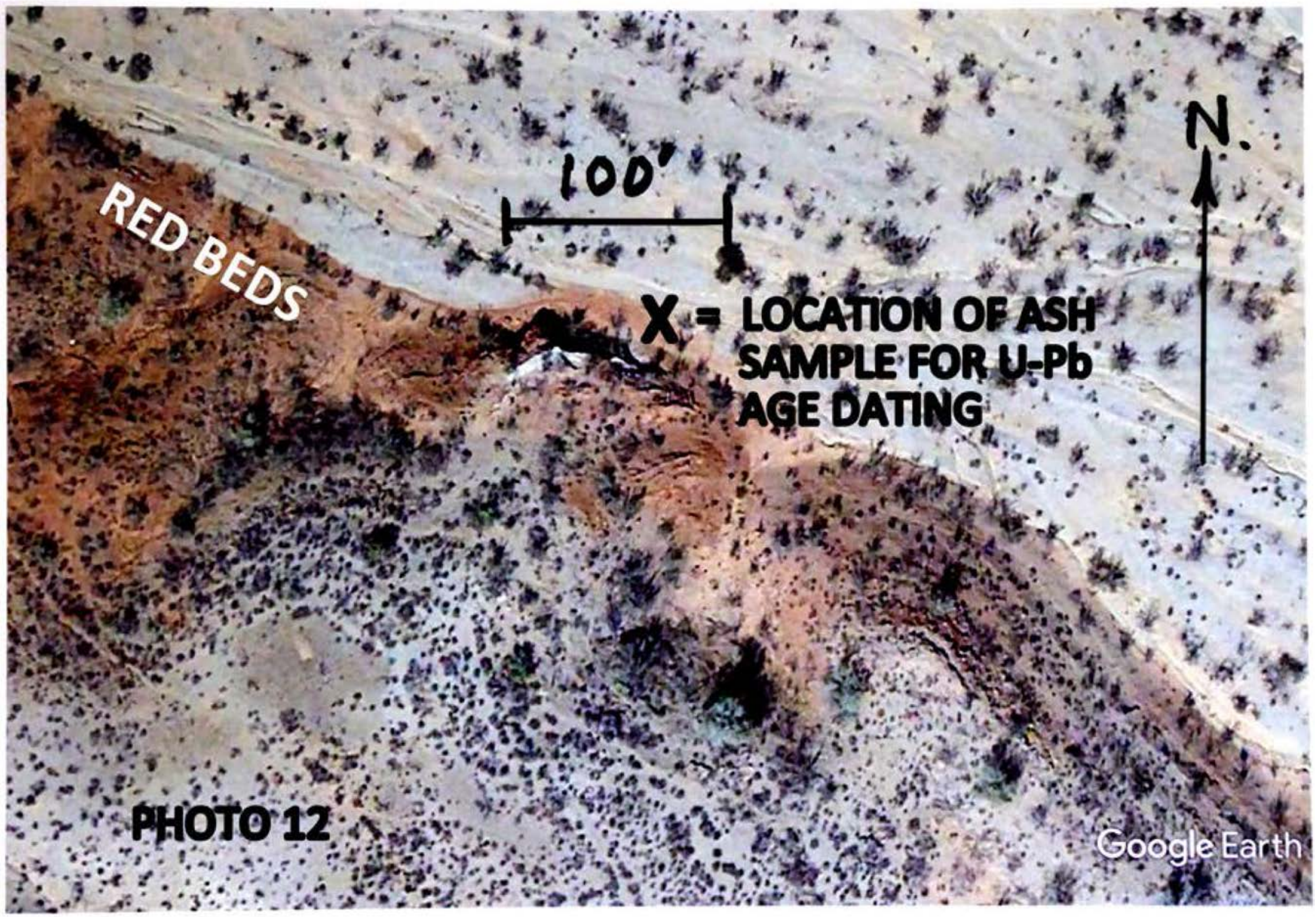

Figure 12. Aerial photo showing location of approximately 2-foot-thick cream to pale green volcanic ash (Figure 11) was found interbedded within these red beds in a small outcrop on the southwest side of Alamo Road at virtual mile post 56.5. Ash was deposited on a dry, mud-cracked lakebed.

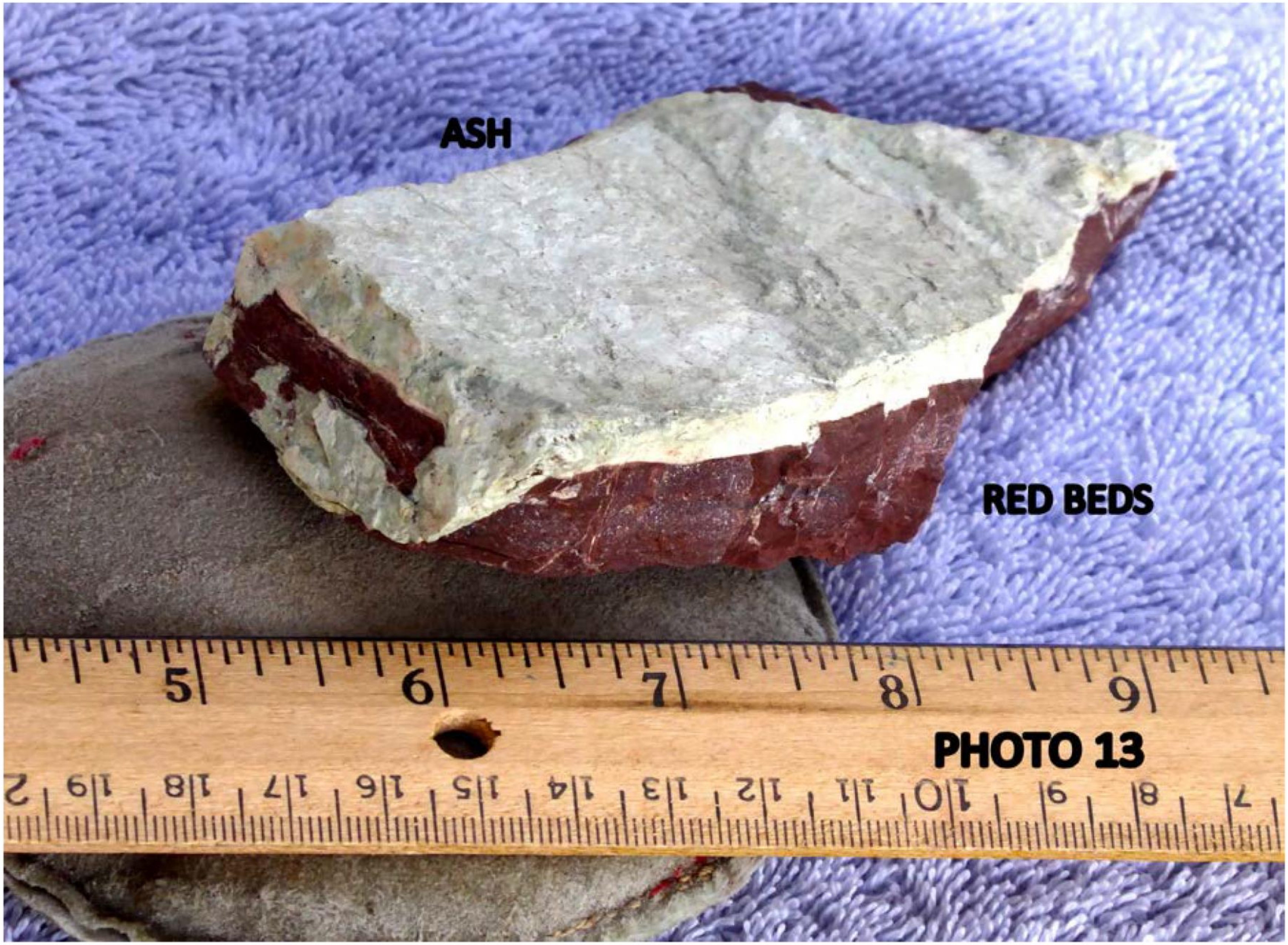

Figure 13. Ash filling mud cracks on the left side, and face of red lake bed clay.

APPENDIX A

RED BEDS LOCATIONS

Sample No.	Nearest Landmark	Latitude	Longitude	Elevation
1	Needles, CA	34° 53.61’ N.	114° 45.79’ W.	1,209’
2	Parker Dam, AZ	34° 16.57’ N.	114° 07.83’ W.	479’
3	Parker Strip, AZ	34° 13.61’ N.	114° 10.98’ W.	455’
4	Lincoln Ranch, AZ	34° 12.14’ N	113° 40.84’ W	911’
5	Mineral Wash, AZ	34° 11.68’ N	114° 01.47’ W	1,083’
6	Mineral Wash, AZ	34° 11.61’ N	114° 01.44’ W	1,085’
7	Osborne Wash, AZ	34° 09.51’ N	114° 03.69’ W	1,117’
8	Shea Road, AZ	34° 08.62’ N	114° 11.37’ W	596’
9	Smoketree Valley, CA	33° 22.89’ N	114° 56.40’ W	870’
10	Tolbard Mn Mine, CA	33° 12’ 11.83” N	114° 47’ 48.87 W	924’
11	Tolbard Mn Mine, CA	33° 12' 15.25” N	114° 47' 47.7” W	980’
12	Mohawk Mts, AZ	32° 46.82’	113° 47.15’	313’
13	Adair Park Rd., Yuma, AZ	32° 46.08’	114° 25.21’	197’
14S	Adair Park Rd., Yuma, AZ	32° 46.02’	114° 25.44’	181’
15	Antelope Hills, AZ	32° 42.60’	114° 00.65’	271’
16	Welton Mesa, AZ	32° 40.85’	114° 03.15’	326’
17	Baker’s Tank, AZ	32° 37.42’	114° 00.55’	534’
18	Basin Road, Baker, CA	35° 06.26’ N.	116° 15.48’ W.	1,128’
19*	ZZYZX Road, Baker, CA	35° 11.72’ N.	116° 08.80’ N.	1,241’
20	Bradshaw Trail, C	33° 32’ 20.29” N	115° 38’ 40.08” W	1143’
21	Wayside Oasis, AZ	34° 16’ 52.64” N	113° 31’ 06.45” W	1336’
22	Palo Verde, CA	33° 22’ 51.28” N	114° 47’ 47.81” W	400’
23	Plomosa Road, , AZ	33° 49’ 35.63” N	114° 03’ 36.36” W	1,336’
24	Plomosa Road, , AZ	33° 49’ 49.30” N	114° 03’ 26.90” W	1,317’
25	Plomosa Road, , AZ	33° 49’ 47.63” N	114° 03’ 17.09” W	1,306’

APPENDIX A

RED BEDS LOCATIONS

26	Plomosa Road, AZ	33° 54’ 40.21” N	114° 03’ 29.83” W	1,135’
27	Plomosa Road, AZ	33° 57’ 22.39” N	114° 03’ 28.04 W	933’
28	Plomosa Road, AZ	33° 57’ 07.82” N	114° 04’ 12.83” W	1,025’
29	Wayside Oasis, AZ	34° 16’ 40.23” N	113° 30’ 20.34”	1358’
30	Plomosa Road, AZ	33° 49’ 49.43” N	114° 03’ 42.73” W	1324’
31	Red Mountain, AZ	34° 14’ 43.05” N	114° 09’ 54.06” W	563’
32	Bullard Pass, Aguila, AZ	34° 04’ 42.52” N	113° 13’ 38.19” W	~2644’
33	Plomosa Rd. AZ	33° 49’ 47.26” N	114° 03’ 31.28” W	1309’
34	Moon Mountain, AZ	33° 49’ 55.00” N	114° 24’ 54.59” W	394'
35	Savahia Peak, CA	34° 15’ 34.47” N	114° 31’ 49.32” W	1423’
36	Savahia Peak, CA	34° 14’ 43.24” N	114° 30’ 34.01” W	1286
37	Alamo Lake, AZ (Ash)	34° 15’ 51.13” N	113° 35’ 34.94” W	1150’
38	Alamo Lake, AZ	34° 15’ 55.32” N	113° 35’ 44.02” W	1173’
39	Alamo Lake, AZ	34° 16’ 29.18 “ N	113° 35’ 56.79” W	1218’
40	Alamo Road, AZ	34° 17’ 08.12” N	113° 37’ 48.44” W	1487’
41	Alamo Road, AZ	34° 17’ 23.90” N	113° 38’ 13.21” W	1541’
42	Alamo Road, AZ	34° 17’ 28.48” N	113° 38’ 23.49” W	1579’
43	Alamo Road, AZ	34° 17’ 42.85” N	113° 38’ 26.59” W	1568’
44	Alamo Road, AZ	34° 17’ 42.85” N	113° 38’ 26.59” W	1568’
45	Alamo Road, AZ	34° 18’ 09.80” N	113° 38’ 23.33” W	1584’
46	Alamo Road, AZ	34° 19’ 02.73” N	113° 39’ 21.48” W	1789’
47	Alamo Road, AZ	34° 19’ 08.25” N	113° 39’ 36.06” W	1851’
48	Alamo Road, AZ	34° 19’ 16.63” N	113° 39’ 43.53” W	1846’
49	Alamo Road, AZ	34° 19’ 20.68” N	113° 39’ 47.90” W	1855’
50	Alamo Road, AZ	34° 19’ 49.72” N	113° 39’ 41.51” W	1796’

APPENDIX A

RED BEDS LOCATIONS

51	Alamo Road	34° 19’ 55.54” N	113° 40’ 29.65” W	1934’
52	Alamo Road	34° 20’ 23.25” N	113° 40’ 41.24” W	1874’
53	Freeman Rd, AZ	32° 50.975' N	112° 19.151' W	1827'
54	Chiriaco Summit, CA	33° 37’ 00” N	115° 39’ 47” W	-
55	Chiriaco Summit, CA	33° 36’ 56” N	115° 39’ 20” W	-
56	Chiriaco Summit, CA	33° 56’ 56” N	115° 38” 24” W	-
57	Chiriaco Summit, CA	33° 35’ 33” N	115° 38’ 13” W	-
58	Chiriaco Summit, CA	33° 35’ 25” N	115° 38’ 00” W	-
59	Chiriaco Summit, CA	33° 35’15” N	115° 38’ 08” W	-
60	Chiriaco Summit, CA	33° 34’ 55” N	115° 37’ 57” W	-
61	Chiriaco Summit, CA	33° 34’ 41” N	115° 37’ 45” W	-
62	Chiriaco Summit, CA	33° 34’ 35” N	115° 37’ 43” W	-
63	Chiriaco Summit, CA	33° 34’ 22” N	115° 37’ 40” W	-
64	Chiriaco Summit, CA	33° 34’ 15” N	115° 37’ 35” W	-
65	Bradshaw Trail, CA	33° 32’ 22” N	115° 39’ 06” N	-
66	Bradshaw Trail, CA	33° 32’10” N	115° 38’ 54” W	-
67*	Ocotillo, CA	32° 47’ 20.81” N	115° 59’ 33.78” W	579’
68	Yuma, AZ	32° 39’ 36” N	114° 19’ 37’ W	767’
69	Yuma, AZ	32° 39’ 43.31” N	114° 19’ 14.68” W	696’
70*	Barstow, CA Rainbow Basin	35° 01’ 59.36” N	117° 02’ 14.12” W	3193’
71	West of Cave Mt., CA	See No.126 and 127, below.		
72	Loves Camp Road, AZ	34° 17’ 06.74” N	113° 37’ 29.30” W	1,435’
73	Loves Camp Road, AZ	34° 17’ 31.81” N	113° 37’ 06.82” W	1,395’
74	Loves Camp Road, AZ	34° 17’ 08” N	113° 36’ 47” W	1,326’
75	Loves Camp Road, AZ (	34° 17’ 04.77” N	113° 36’36.66” W	1,269’

APPENDIX A

RED BEDS LOCATIONS

76	Loves Camp Road, AZ	34° 17’ 15.04” N	113° 35’ 20.46” W	1,283’
77	Loves Camp Road, AZ	34° 17’ 18.33” N	113° 35’ 03.16” W	1,238’
78	Loves Camp Road, AZ	34° 17’ 25.22” N	113° 34’ 47.05” W	1,239’
79	Loves Camp Road, AZ	34° 17’ 27.38” N	113° 34’ 42.15” W	1,215’
80	Loves Camp Road, AZ	34° 17’ 30.58” N	113° 34’ 30.51”W	1,184’
81	Parker Dam, CA	34° 21’ 18.50” N	114° 9’ 20.96” W	665’
82	Parker Dam, CA	34° 20’ 20” N	114° 8’ 31” W	667’
83	Parker Dam, CA	34° 20’ 11” N	114° 8’ 21” W	659’
84	Parker Dam, CA	34° 20’ 2” N	114° 8’ 9” W	671’
85	Parker Dam, CA	34° 19’ 46.14” N	114° 8’ 00.51” W	648’
86	Parker Dam, CA	34° 17’ 22.29” N	114° 6’ 19.87” W	497’
87	Parker Dam, CA	34° 17’ 19.50” N	114° 6’ 27.10” W	520’
88	Havasu Springs, AZ	34° 17’ 46.67 N	114° 7’ 40.74” W	460’
89	Havasu Springs, AZ	34° 17’ 40.81” N	114° 7’ 33.38” W	502’
90*	Havasu Springs, AZ	34° 17’ 47.16” N	114° 7’ 19.01” W	487’
91	Trails End Camp Rd, CA	34° 20’ 58.59” N	114° 14’ 48.72”W	932’
92	Trails End Camp Rd, CA	34° 21’ 06.99” N	114° 15’ 24.64” W	827’
93	Trails End Camp Rd, CA	34° 21’ 11” N	114° 15’ 35” W	803’
94	Trails End Camp Rd, CA	34° 21’ 28.68” N	114° 15’ 53.37” W	751’
95	Trails End Camp Rd, CA	34° 21’ 39.68” N	114° 16’ 2.00” W	712’
96	Trails End Camp Rd, CA	34° 22’ 51.71” N	114° 16’ 21.22” W	520’
97	Trails End Camp Rd, CA	34° 23’ 05.71” N	114° 16’ 38.08” W	495’
98	Trails End Camp Rd, CA	34° 23’ 13.59” N	114° 16’ 37.89” W	478’
99	Trails End Camp Rd, CA	34° 23’ 21.57” N	114° 16’ 38.25” W	467’
100	Trails End Camp Rd, CA	34° 23’ 25.65” N	114° 16’ 38.25” W	469’

APPENDIX A

RED BEDS LOCATIONS

101	Trails End Camp Rd, CA	34° 23' 32.50" N	114° 16' 40.59" W	471'
102*	Havasu Palms, CA	34° 24' 31.42" N	144° 17' 35.36" W	448'
103	Trails End Camp Rd, CA	34° 21' 35.33" N	114° 15' 54.45" W	734'
104	Trails End Camp Rd, CA	34° 21' 17" N	114°15' 47" W	775'
105	Trails End Camp Rd, CA	34° 21' 05" N	114° 15' 10" W	862'
106*	Black Meadow Landing	34° 22' 00.87" N	114° 13' 26.58" W	457'
107*	Black Meadow Landing	34° 21' 54.2O" N	114° 12' 43.67" W	452'
108	Black Meadow Landing	34° 22' 09.61" N	114° 12' 24.72" W	459'
109	Black Meadow Landing	34° 21' 57.75" N	114° 11' 52.51" W	459'
110	Black Meadow Landing	34° 21' 16.79" N	114° 10' 22.79" W	461'
111	Reservoir (MWD Road)	34° 17' 35.44" N	114° 09' 53.06" W	681'
112	Reservoir (MWD Road)	34° 17' 46.14" N	114° 09' 42.79" W	668'
113	Gene Wash Res., CA	34° 17' 50" N	114° 09' 31" W	635'
114	Gene Wash Res., CA	34° 17' 34.97" N	114° 09' 17.59" W	484'
115	City of Parker Dam, CA	34° 17' 30" N	114° 09' 02" W	452'
116	City of Parker Dam, CA	34° 17' 31.12" N	114° 08' 59.27" W	446'
117	City of Parker Dam, CA	34° 17' 19.93" N	114° 08' 49.04" W	407'
118	City of Parker Dam, CA	34° 16' 27.79" N	114° 08' 17.24" W	379'
119	City of Parker Dam, CA	34° 16' 15.61" N	114° 08' 12.15" W	391'
120	City of Parker Dam, CA	34° 16' 10.50" N	114° 08' 11.37" W	396'
121	Sunshine Resort, CA	34° 16' 03.46" N	114° 08' 08.88" W	399'
122	Cross Roads (site), CA	34° 15' 08.94" N	114° 10' 22.01" W	472'
123	Parker, AZ, (Earp, CA)	34° 10' 44.23" N	114° 16' 02.37" W	372'
124	Parker, AZ,(Earp, CA)	34° 10' 36.34" N	114° 16' 15.48" W	374'
125	Parker, AZ,(Earp, CA)	34° 10' 29.36" N	114° 16' 37.21" W	402'

APPENDIX A

RED BEDS LOCATIONS

126	Cave Mtn., CA	35° 03’ 54.49” N	116° 22’ 55.47” W	1941’
127	Cave Mtn., CA	35° 03’ 49.65” N	116° 22’ 58.45” W	1890’
128	Alamo Road, AZ	34° 25’ 08.72” N	113° 44’ 14.57” W	2404’
129	Alamo Road, AZ	34° 25’ 17.60” N	113° 44’ 17.79” W	2480’
130	Alamo Road, AZ	34° 24’ 58.36” N	113° 44’ 27.59” W	2435’
131	Old Blythe-Vidal Road	33° 59’ 08.83” N	114° 35’ 42.77” W	686’

Caveat: The purpose this ongoing reconnaissance is to note and list every possible red beds outcrop observed. Some exposures on this list had to be viewed from a distance and therefore could not be physically verified as sedimentary red beds; a number of these errant exposures are thought to be red volcanics. Other outcrops are listed only to provide completeness and to be sure no stone has been left unturned. The following sample localities may or may not represent sedimentary red beds: 19, 67, 70, 90, 102, 106, 107.