U.S. DEPARTMENT OF THE INTERIOR U.S. GEOLOGICAL SURVEY

REFERENCES CITED

Leonard Wood: U.S. Army Corps of Engineers, Waterways Experiment Station, Technical

Albertson, P.E., Mienert, Dennis, and Butler, Grant, 1995, Geomorphic evaluation of Fort

Report GL-95-19, 241 p. Aley, T.J., and Aley, C., 1987, Groundwater study, Ozark National Scenic Riverways: Protem, Mo., Ozark Underground Laboratory, National Park Service contract CX 6000-4-0083, 222 p. Anderson, K.H., and Wharton, H.M., 1975, Reconnaissance geologic map of the Summersville NE 7.5' quadrangle, Missouri: Missouri Department of Natural Resources, Division of Geology and Land Survey, scale 1:24,000. Ball, S.H., and Smith, A.F., 1903, The geology of Miller County: Missouri Geological Survey [Reports], 2d Series, v. 1, 207 p. Bickford, M.E., Harrower, K.L., Hoppe, W.J., Nelson, B.K., Nusbaum, R.L., and Thomas. J.J., 1981, Rb-Sr and U-Pb geochronology and distribution of rock types in the Precambrian basement of Missouri and Kansas: Geological Society of America Bulletin, v. 92. p. 323–341. Bowles, J.H., and Davidson, L.E., 1921, The copper deposits of Shannon County, Missouri: Rolla, Mo., Missouri School of Mines and Metallurgy, unpublished M.S. thesis. Bretz, J.H., 1965, Geomorphic history of the Ozarks of Missouri: Missouri Geological Survey and Water Resources [Reports], 2d Series, v. 41, 147 p. Bridge, Josiah, 1930, Geology of the Eminence and Cardareva quadrangles: Missouri Geological Survey [Reports], 2d Series, v. 24, 228 p., 3 pls. in pocket, scale 1:62,500. Buehler, H.A., 1907, The lime and cement resources of Missouri: Missouri Geological Survey [Reports], 2d Series, v. 6, 255 p., plate in pocket. Clendenin, C.W., Niewendorp, C.A., and Lowell, G.R., 1989, Reinterpretation of faulting in southeast Missouri: Geology, v. 17, p. 217–220, Cooper, R.A., Nowlan, G.S., and Williams, S.H., 2001, Global stratotype section and point for base of the Ordovician System: Episodes, v. 24, p. 19–31. Cox, R.T., 1995, Intraplate deformation during the Appalachian-Ouachita orogeny as recorded by mesoscale structures on the Ozark Plateau of North America: Columbia, Mo., University of Missouri-Columbia, unpublished Ph.D. dissertation, 229 p. Crane, G.W., 1910, The iron ores of Missouri: Missouri Geological Survey [Reports], 2d Series. v. 10, 434 p. Dake, C.L., 1930, The geology of the Potosi and Edgehill guadrangles: Missouri Geological Survey [Reports], 2d Series, v. 23, 233 p., 2 pls. in pocket, scale 1:62,500. Davis, G.H., 1999, Structural geology of the Colorado Plateau region of southern Utah, with special emphasis on deformation bands: Geological Society of America Special Paper 342, Dreiss, S.J., 1983, Linear unit-response functions as indicators of recharge areas for large karst springs, in Back, William, and LaMoreaux, P.E., eds., V.T. Stringfield Symposium; Processes in Karst Hydrology: Journal of Hydrology, v. 61, no. 1/3, p. 31–44. Ebens, R.J., and Connor, J.J., 1980, Geochemistry of loess and carbonate residuum: U.S. Geological Survey Professional Paper 954–G. 32 p. Fenneman, N.M., 1938, Physiography of the eastern United States: New York, McGraw-Hill, Gott, J.D., 1975, Soil survey of Mark Twain National Forest area, Missouri (parts of Carter, Oregon, Ripley, and Shannon Counties): U.S. Department of Agriculture, Forest Service and Soil Conservation Service, in cooperation with Missouri Agricultural Experiment Station, 56 p., 40 map sheets, scale 1:24,000. Grawe, O.R., 1943, Manganese deposits of Missouri: Missouri Geological Survey and Water Resources, 62d Biennial Report, Appendix 6, 77 p. Harrison, R.W., and McDowell, R.C., 2003, Geologic map of the Wilderness and Handy quadrangles, Oregon, Carter, and Ripley Counties, Missouri: U.S. Geological Survey Geologic Investigations Series Map I–2801, scale 1:24,000 Harrison, R.W., and Schultz, A.P., 2002, Tectonic framework of the southwestern margin of the Illinois basin and its influence on neotectonism and seismicity: Seismological Research Letters, v. 73, issue 75, p. 685–718. Harrison, R.W., Lowell, G.R., and Unruh, D.M., 2000, Geology, geochemistry, and age of Mesoproterozoic igneous rocks in the Eminence-Van Buren area; a major structural outlier of St. Francois terrane, south-central Missouri [abs.]: Geological Society of America Abstracts with Programs, v. 32, no. 3, p A–14. Harrison, R.W., Orndorff, R.C., and Weary, D.J., 2002, Geology of the Stegall Mountain 7.5-minute quadrangle, Shannon and Carter Counties, south-central Missouri: U.S. Geological Survey Geologic Investigations Series Map I–2767, scale 1:24,000. Harrison, R.W., Orndorff, R.C., and Weems, R.E., 1996, Geology of the Fort Leonard Wood Military Reservation and adjacent areas, south-central Missouri, with contributions on Quaternary terraces by Paul E. Albertson, Dennis Mienert, and Grant Butler: U.S.

Geological Survey Open-File Report 96–60, 255 p., 10 pls. in pocket, scales vary. Haynes, C.V., Jr., 1985, Mastodon-bearing springs and late Quaternary geochronology of the lower Pomme de Terre Valley, Missouri: Geological Society of America Special Paper 204, Heller, R.L., 1954, Stratigraphy and paleontology of the Roubidoux Formation of Missouri: Missouri Geological Survey and Water Resources [Reports], 2d Series, v. 35, 118 p., 2 pls. Imes, J.L., and Emmett, L.F., 1994, Geohydrology of the Ozark Plateaus aquifer system in parts of Missouri, Arkansas, Oklahoma, and Kansas: U.S. Geological Survey Professional

Paper 1414–D, 127 p. Kisvarsanyi, E.B., 1975, Data on Precambrian in drill holes of Missouri including rock type and surface configuration: Missouri Geological Survey Report of Investigations 56, 20 p. Kleeschulte, M.J., and Seeger, C.M., 2000, Depositional environment, stratigraphy, and vertical hydraulic conductivity of the St. Francois confining unit in the Fristoe Unit of the Mark Twain National Forest, Missouri: U.S. Geological Survey Water-Resources Investigations Report 00–4037, 65 p. Lowell, G.R., Harrison, R.W., and Unruh, D.M., 2005, Contrasting rift-margin volcanism in the St. Francois terrane of Missouri at 1.47 Ga [abs.], in Abstracts of the 15th Annual V.M. Goldschmidt Conference: Geochimica et Cosmochimica Acta, v. 69, no. 10S, p. A-81. Lowell, G.R., Harrison, R.W., Weary, D.J., Orndorff, R.C., Repetski, J.E., and Pierce, H.A., 2010, Rift-related volcanism and karst geohydrology of the southern Ozark dome, in Evans, K.R., and Aber, J.S., eds., From Precambrian rift volcanoes to the Mississippian shelf

margin; geological field excursions in the Ozark Mountains: Geological Society of America Field Guide 17, p. 99–158. Digital Object Identifier: 10.1130/2010.0017(06) Lyle, J.R., 1977, Petrography and carbonate diagenesis of the Bonneterre Formation in the Viburnum Trend area, southeast Missouri: Economic Geology, v. 72, no. 3, p. 420–434. McDowell, R.C., 1998, Geologic map of the Greer guadrangle, Oregon County, Missouri: U.S. Geological Survey Geologic Investigations Series Map I–2618, scale 1;24,000. McDowell, R.C., and Harrison, R.W., 2000, Geologic map of the Powder Mill Ferry quadrangle, Shannon and Reynolds Counties, Missouri: U.S. Geological Survey Geologic Investigations Series Map I–2722, scale 1:24,000. Missouri Geological Survey, 1979, Geologic map of Missouri: Rolla, Mo., Missouri Division of Geology and Land Survey, scale 1:500,000. Nason, F.L., 1892, A report on the iron ores of Missouri: Missouri Geological Survey

[Report], v. 2, 366 p. Orndorff, R.C., and Harrison, R.W., 2001, Geologic map of the Winona quadrangle, Shannon County, Missouri: U.S. Geological Survey Geologic Investigations Series Map I-2749, scale 1;24,000. Orndorff, R.C., and Weary, D.J., 2009, Geologic map of the Round Spring quadrangle, Shannon County, Missouri: U.S. Geological Survey Scientific Investigations Map 3073, scale 1:24.000 Orndorff, R.C., Harrison, R.W., and Weary, D.J., 1999, Geologic map of the Eminence

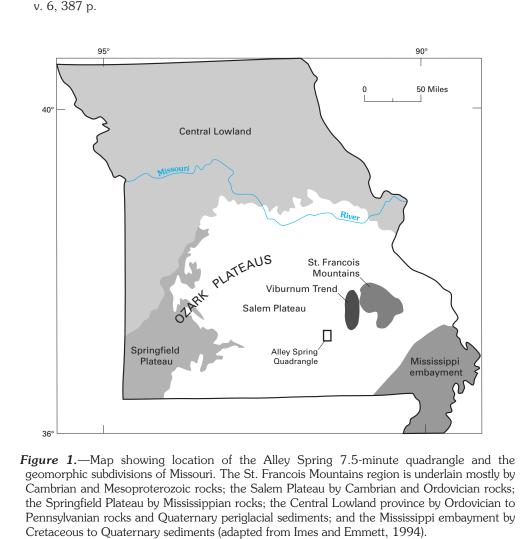
quadrangle, Shannon County, Missouri: U.S. Geological Survey Geologic Investigations Series Map I–2653, scale 1;24,000. Orndorff, R.C., Weary, D.J., and Harrison, R.W., 2006, The role of sandstone in the development of an Ozark karst system, south-central Missouri, in Harmon, R.S., and Wicks, C.M., eds., Perspectives on karst geomorphology, hydrology, and geochemistry; a tribute volume to Derek C. Ford and William B. White: Geological Society of America Special Paper 404. p. 31–38. Pierce, H.A., and Weary, D.J., 2009, Interpretation of the hydrogeology of a large karst

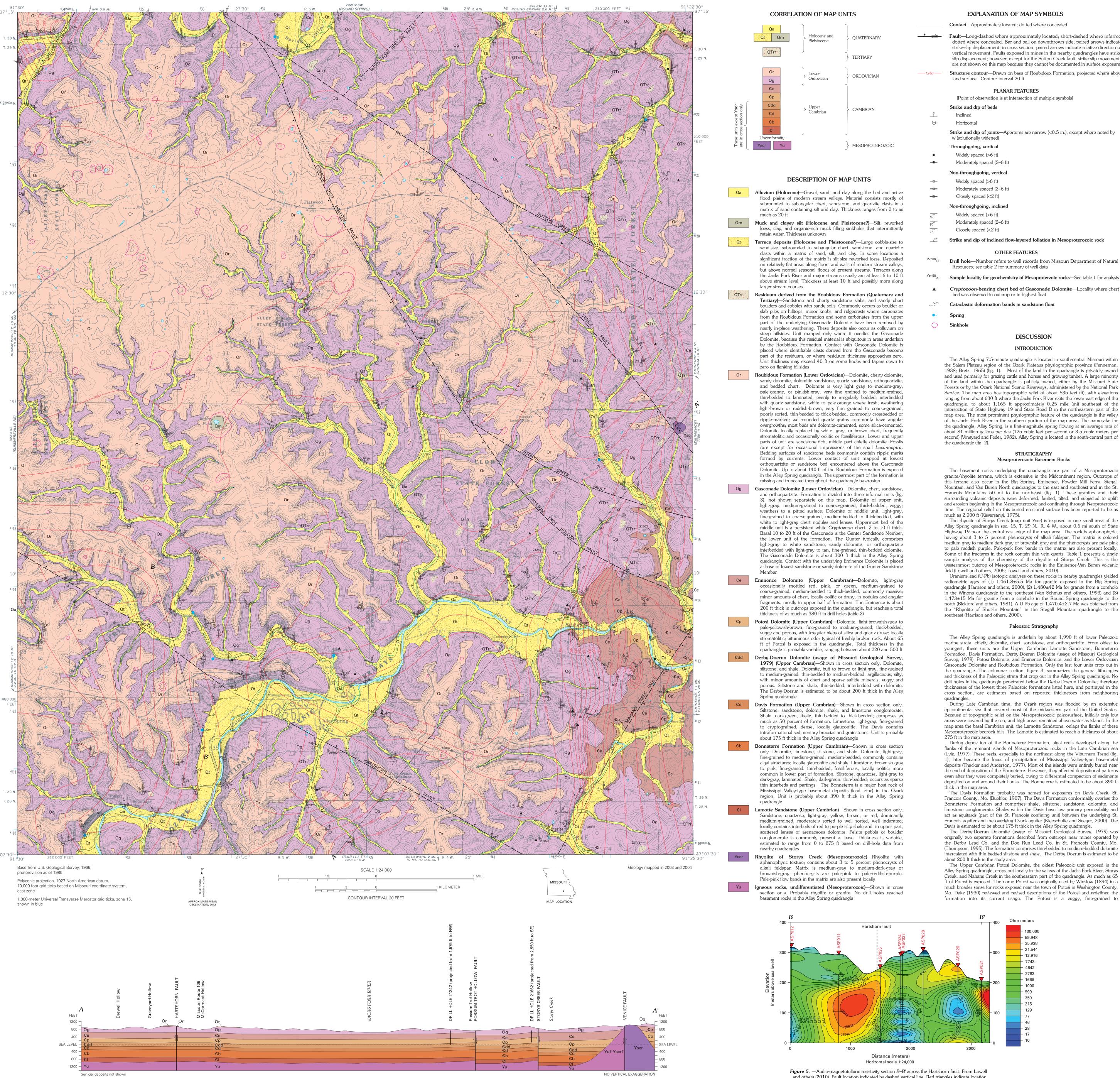
spring in the Ozark National Scenic Riverways, Missouri, from audio-magnetotelluric (AMT) soundings and geologic mapping [abs.]: Geological Society of America Abstracts with Programs, v. 41, no. 7, p. 246 Pratt, W.P., Middendorf, M.A., Satterfield, I.R., and Gerdemann, P.E., 1992, Geologic map of the Rolla 1° x 2° quadrangle, Missouri: U.S. Geological Survey Miscellaneous Investigations Series Map I–1998, scale 1:250,000.

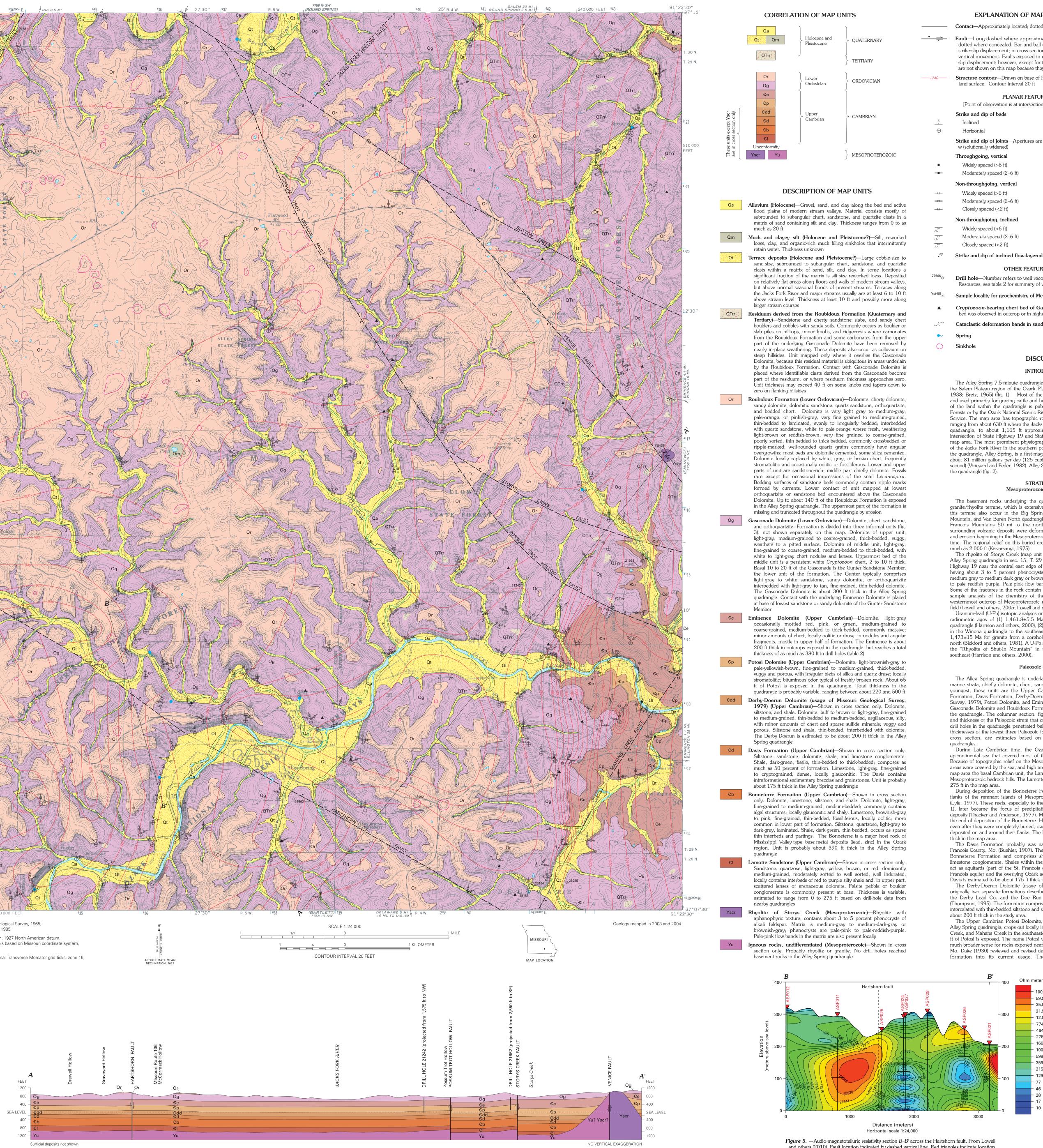
Repetski, J.E., Orndorff, R.C., Weary, D.J., and Ethington, R.L., 2000, Conodont biostratigraphy of the Eminence Dolomite-Gasconade Dolomite contact interval in the Missouri Ozarks [abs.]: Geological Society of America Abstracts with Programs, v. 32, no. 3, p. A-39–A-40. Satterfield, I.R., 1976, Reconnaissance geologic map of the Raymondville 15' quadrangle, Missouri: Missouri Department of Natural Resources, Division of Geology and Land Survey, scale 1:62,500 Thacker, J.L., and Anderson, K.H., 1977, The geologic setting of the southeast Missouri lead district; regional geologic history, structure and stratigraphy: Economic Geology and the Bulletin of the Society of Economic Geologists, v. 72, no. 3, p. 339–348. Thompson, T.L., 1995, The stratigraphic succession in Missouri: Missouri Department of Natural Resources, Division of Geology and Land Survey, v. 40, 2d Series, revised, 190 p. Ulrich, E.O., 1911, Revision of the Paleozoic systems: Geological Society of America Bulletin, v. 22, no. 3, p. 281-680 (especially see p. 630-631)

Van Schmus, W.R., Bickford, M.E., Anderson, J.L., Bender, E.E., Anderson, R.R., Bauer, P.W., Robertson, J.M., Bowring, S.A., Condie, K.C., Denison, R.E., Gilbert, M.C., Grambling, J.A., Mawer, C.K., Shearer, C.K., Hinze, W.J., Karlsstrom, K.E., Kisvarsanyi, E.B., Lidiak, E.G., Reed, J.C., Jr., Sims, P.K., Tweto, Ogden, Silver, L.T., Treves, S.B. Williams, M.L., and Wooden, J.L., 1993, Transcontinental Proterozoic provinces, in Reed, J.C., Jr., Bickford, M.E., Houston, R.S., Link, P.K., Rankin, D.W., Sims, P.K., and Van Schmus, W.R., eds., Precambrian; Conterminous U.S., v. C-2 of The geology of North America: Boulder, Colo., Geological Society of America, p. 171–334. Vineyard, J.D., and Feder, G.L., 1982, Springs of Missouri (rev. ed.): Missouri Department of Natural Resources, Division of Geology and Land Survey, Water Resources Report 29,

Weary, D.J., and Schindler, J.S., 2004, Geologic map of the Van Buren South quadrangle, Carter County, Missouri: U.S. Geological Survey Geologic Investigations Series Map I-2803, scale 1:24,000. Weems, R.E., 2002, Geologic map of the Low Wassie quadrangle, Oregon and Shannon Counties, Missouri: U.S. Geological Survey Geologic Investigations Series Map I-2719, scale 1:24.000 Winslow, Arthur, 1894, Lead and zinc deposits, part 1: Missouri Geological Survey [Report],









GEOLOGIC MAP OF THE ALLEY SPRING QUADRANGLE, SHANNON COUNTY, MISSOURI David J. Weary and Randall C. Orndorff

EXPLANATION OF MAP SYMBOLS

_	Contact—Approximately located; dotted where concealed					
_	Fault —Long-dashed where approximately located; short-dashed where inferred; dotted where concealed. Bar and ball on downthrown side; paired arrows indicate strike-slip displacement; in cross section, paired arrows indicate relative direction of vertical movement. Faults exposed in mines in the nearby quadrangles have strike-slip displacement; however, except for the Sutton Creek fault, strike-slip movements are not shown on this map because they cannot be documented in surface exposures					
_	Structure contour —Drawn on base of Roubidoux Formation; projected where above land surface. Contour interval 20 ft					
	PLANAR FEATURES					
	[Point of observation is at intersection of multiple symbols]					
	Strike and dip of beds					
	Inclined					
	Horizontal					
	Strike and dip of joints —Apertures are narrow (<0.5 in.), except where noted by w (solutionally widened)					
	Throughgoing, vertical					
	Widely spaced (>6 ft)					
	Moderately spaced (2–6 ft)					
	Non-throughgoing, vertical					
	Widely spaced (>6 ft)					
	Moderately spaced (2–6 ft)					
	Closely spaced (<2 ft)					
	Non-throughgoing, inclined					
	Widely spaced (>6 ft)					
	Moderately spaced (2–6 ft)					
	Closely spaced (<2 ft)					
	Strike and dip of inclined flow-layered foliation in Mesoproterozoic rock					
	OTHER FEATURES					
	Drill hole —Number refers to well records from Missouri Department of Natural Resources; see table 2 for summary of well data					
	Sample locality for geochemistry of Mesoproterzoic rocks—See table 1 for analysis					
	<i>Cryptozoon-bearing chert bed of Gasconade Dolomite</i> —Locality where chert bed was observed in outcrop or in highest float					
	Cataclastic deformation bands in sandstone float					

The Alley Spring 7.5-minute quadrangle is located in south-central Missouri within the Salem Plateau region of the Ozark Plateaus physiographic province (Fenneman, 1938; Bretz, 1965) (fig. 1). Most of the land in the quadrangle is privately owned and used primarily for grazing cattle and horses and growing timber. A large minority of the land within the quadrangle is publicly owned, either by the Missouri State Forests or by the Ozark National Scenic Riverways, administered by the National Park Service. The map area has topographic relief of about 535 feet (ft), with elevations ranging from about 630 ft where the Jacks Fork River exits the lower east edge of the quadrangle, to about 1,165 ft approximately 0.25 mile (mi) southeast of the intersection of State Highway 19 and State Road D in the northeastern part of the map area. The most prominent physiographic feature of the quadrangle is the valley of the Jacks Fork River in the southern portion of the map area. The namesake for the quadrangle, Alley Spring, is a first-magnitude spring flowing at an average rate of about 81 million gallons per day (125 cubic feet per second or 3.5 cubic meters per second) (Vineyard and Feder, 1982). Alley Spring is located in the south-central part of

STRATIGRAPHY Mesoproterozoic Basement Rocks

The basement rocks underlying the quadrangle are part of a Mesoproterozoic granite/rhyolite terrane, which is extensive in the Midcontinent region. Outcrops of his terrane also occur in the Big Spring, Eminence, Powder Mill Ferry, Stegall Mountain, and Van Buren North quadrangles to the east and southeast and in the St. Francois Mountains 50 mi to the northeast (fig. 1). These granites and their surrounding volcanic deposits were deformed, faulted, tilted, and subjected to uplift and erosion beginning in the Mesoproterozoic and continuing through Neoproterozoic time. The regional relief on this buried erosional surface has been reported to be as The rhyolite of Storys Creek (map unit Yscr) is exposed in one small area of the Alley Spring quadrangle in sec. 15, T. 29 N., R. 4 W., about 0.5 mi south of State Highway 19 near the central east edge of the map area. The rock is aphanophyric, having about 3 to 5 percent phenocrysts of alkali feldspar. The matrix is colored medium gray to medium dark gray or brownish gray and the phenocrysts are pale pink to pale reddish purple. Pale-pink flow bands in the matrix are also present locally. Some of the fractures in the rock contain thin vein quartz. Table 1 presents a single sample analysis of the chemistry of the rhyolite of Storys Creek. This is the westernmost outcrop of Mesoproterozoic rocks in the Eminence-Van Buren volcanic ield (Lowell and others, 2005; Lowell and others, 2010). Uranium-lead (U-Pb) isotopic analyses on these rocks in nearby quadrangles yielded radiometric ages of (1) 1,461.8±5.5 Ma for granite exposed in the Big Spring quadrangle (Harrison and others, 2000), (2) 1,480±42 Ma for granite from a corehole in the Winona quadrangle to the southeast (Van Schmus and others, 1993) and (3) 1,473±15 Ma for granite from a corehole in the Round Spring quadrangle to the north (Bickford and others, 1981). A U-Pb age of $1,470.4\pm2.7$ Ma was obtained from the "Rhyolite of Shut-In Mountain" in the Stegall Mountain quadrangle to the

Paleozoic Stratigraphy

The Alley Spring quadrangle is underlain by about 1,990 ft of lower Paleozoic marine strata, chiefly dolomite, chert, sandstone, and orthoquartzite. From oldest to youngest, these units are the Upper Cambrian Lamotte Sandstone, Bonneterre ormation, Davis Formation, Derby-Doerun Dolomite (usage of Missouri Geological Survey, 1979), Potosi Dolomite, and Eminence Dolomite; and the Lower Ordovician Gasconade Dolomite and Roubidoux Formation. Only the last four units crop out in the quadrangle. The columnar section, figure 3, summarizes the general lithologies and thickness of the Paleozoic strata that crop out in the Alley Spring guadrangle. No drill holes in the quadrangle penetrated below the Derby-Doerun Dolomite; therefore thicknesses of the lowest three Paleozoic formations listed here, and portrayed in the cross section, are estimates based on reported thicknesses from neighboring During Late Cambrian time, the Ozark region was flooded by an extensive

Because of topographic relief on the Mesoproterozoic paleosurface, initially only low areas were covered by the sea, and high areas remained above water as islands. In the map area the basal Cambrian unit, the Lamotte Sandstone, onlaps the flanks of these Mesoproterozoic bedrock hills. The Lamotte is estimated to reach a thickness of about During deposition of the Bonneterre Formation, algal reefs developed along the

flanks of the remnant islands of Mesoproterozoic rocks in the Late Cambrian sea (Lyle, 1977). These reefs, especially to the northeast along the Viburnum Trend (fig. 1), later became the focus of precipitation of Mississippi Vallev-type base-metal deposits (Thacker and Anderson, 1977). Most of the islands were entirely buried near the end of deposition of the Bonneterre. However, they affected depositional patterns even after they were completely buried, owing to differential compaction of sediments deposited on and around their flanks. The Bonneterre is estimated to be about 390 ft

The Davis Formation probably was named for exposures on Davis Creek, St. Francois County, Mo. (Buehler, 1907). The Davis Formation conformably overlies the Bonneterre Formation and comprises shale, siltstone, sandstone, dolomite, and limestone conglomerate. Shales within the Davis have low primary permeability and act as aguitards (part of the St. Francois confining unit) between the underlying St. Francois aquifer and the overlying Ozark aquifer (Kleeschulte and Seeger, 2000). The Davis is estimated to be about 175 ft thick in the Alley Spring quadrangle. The Derby-Doerun Dolomite (usage of Missouri Geological Survey, 1979) was originally two separate formations described from outcrops near mines operated by

Thompson, 1995). The formation comprises thin-bedded to medium-bedded dolomite intercalated with thin-bedded siltstone and shale. The Derby-Doerun is estimated to be The Upper Cambrian Potosi Dolomite, the oldest Paleozoic unit exposed in the Alley Spring quadrangle, crops out locally in the valleys of the Jacks Fork River, Storys

Creek, and Mahans Creek in the southeastern part of the quadrangle. As much as 65 ft of Potosi is exposed. The name Potosi was originally used by Winslow (1894) in a much broader sense for rocks exposed near the town of Potosi in Washington County, Mo. Dake (1930) reviewed and revised descriptions of the Potosi and redefined th formation into its current usage. The Potosi is a vuggy, fine-grained to

and others (2010). Fault location indicated by dashed vertical line. Red triangles indicate location of sounding stations. Warmer colors (red) indicate higher apparent resistivity. Cooler colors (blue) indicate lower apparent resistivity and may indicate saturation by ionic water along the fault. Vertical exaggeration x5. See geologic map for location of section.

material. In outcrop, the Potosi characteristically is more intensely jointed than the overlying formations. Pronounced cavern development, comprising minor caves and other solution features, exists at or near the contact between the Potosi and the overlying Eminence Dolomite; this suggests a permeability contrast across that boundary. With the exception of algal structures, the Potosi is characteristically unfossiliferous. A single drill hole (21242) penetrated the full thickness of Potosi in the quadrangle and documented a thickness of 260 ft (table 2). The lithologic difference between the Potosi and Eminence is thought to be the result of a secondary alteration of the Potosi that includes dissolution of carbonate, precipitation of silica, and introduction of hydrocarbons. This alteration front causes the contact between these two units to vary up and down stratigraphically The Eminence Dolomite was first described by Ulrich (1911) from exposures in the vicinity of the town of Eminence, Mo. The Eminence comprises mostly massive to thick-bedded, medium-grained to coarse-grained, light-gray to medium-gray dolomite and cherty dolomite; chert occurs as nodules and angular fragments. Many of the beds are stromatolitic, with pits and vugs developed between the laminae, and others are

medium-grained, light-brownish-gray to pale-yellowish-brown dolomite having siliceous

Eminence to be abundantly fossiliferous, especially with trilobites and gastropods in residual cherts. No such fossils were observed during the course of this study. About 200 ft of Eminence Dolomite is exposed in the southeastern part of the map area along the Jacks Fork River, Mahans Creek, and Storys Creek. Lesser exposures of the Eminence also occur locally along the northern edge of the quadrangle in Spring Valley, Jacks Fork Hollow, and the valley of Grassy Creek. Drill holes record a subsurface thickness range of 225 to 380 ft in the guadrangle. The Eminence Dolomite is one of the main cave-bearing formations in the map area. Caves and springs typically are concentrated just below the Gunter Sandstone Member of the overlying Gasconade Dolomite (Orndorff and others, 2006). The conduit of Alley Spring is a water-filled cave in the upper part of the Eminence Dolomite (Ozark Cave Diving Alliance, unpub. data, 2005). Previous maps produced by this U.S. Geological Survey (USGS) project placed the Cambrian-Ordovician boundary in the upper part of the Eminence Dolomite

Orndorff and Harrison, 2001; Harrison and others, 2002; Weems, 2002; Harrison and McDowell, 2003). However, recent international agreement on redefinition of this boundary requires that it be placed at the contact between the Eminence and Gasconade Dolomites (Cooper and others, 2001). Bridge (1930) speculated that an important unconformity exists at the base of the Gasconade (fig. 3). Conodont biostratigraphy suggests that there may be multiple unconformities within the basal Gasconade interval (Repetski and others, 2000). The Gasconade Dolomite was named by Nason (1892) for exposures along the Gasconade River in Laclede, Pulaski, and Phelps Counties, central Missouri. In the map area the basal 10 to 20 ft consists of interbedded sandstone, orthoquartzite, and thin-bedded dolomite and sandy dolomite named the Gunter Sandstone Member by Ball and Smith (1903) for exposures along the Niangua River at Gunter (now Hahatonka Springs), Camden County, in central Missouri. The quartz sandstone

(or) orthoquartzite represent up to about 50 percent of the interval in some places and as little as zero percent in others. In the areas having no quartz sandstone or orthoquartzite, those stratigraphic intervals are occupied by dolomite or sandy dolomite containing floating quartz grains The Gasconade Dolomite is divided into three informal units. The lower unit is the Gunter Sandstone Member. The middle unit includes the former Van Buren Formation of Bridge (1930) (which occupies the lower part of the middle unit), overlain by dolomite up to and including a persistent *Cryptozoon* chert bed. The upper unit is thick-bedded dolomite. Where not buried in residuum from the overlying Roubidoux Formation, the upper unit tends to form dolomite glades on south-facing and west-facing slopes. The total thickness of the Gasconade Formation in the Alley Spring quadrangle is about 300 ft. Bridge (1930) used the name Van Buren Formation for the medium-bedded non-cherty and cherty dolomite above the Gunter Sandstone Member and below a thin

Bridge's Van Buren Formation was defined by its faunal content, but the name is no longer used (Thompson, 1995). Pratt and others (1992) described a lower part and an upper part of the Gasconade Dolomite that are divided by a persistent *Cryptozoon* chert, which is located about 80 to 100 ft below the top of the Gasconade, at the top of the upper part of the middle unit (fig. 3). Outcrops of the chert bed are rare in the Alley Spring quadrangle; however, float of *Cryptozoon* chert boulders, indicating this horizon, was observed in many locations. The *Cryptozoon* chert typically comprises parallel columns, a few inches wide, of convex-upward algal laminae. The chert bed breaks on weathering into distinctive polygonal boulders. Triangular symbols on the map indicate locations where the Cryptozoon chert was observed in outcrop or as Fossils are rare in the Gasconade within the map area, though the presence of

reported at Fort Leonard Wood Military Reservation, about 55 mi to the northwest, and at a locality near the town of Van Buren, about 25 mi to the southeast (Harrison and others, 1996; J.E. Repetski, USGS, oral commun., 2000). The upper unit of the Gasconade Dolomite is one of the main cave-bearing intervals in the Alley Spring quadrangle. Caves and springs typically are concentrated just below the overlying sandstones of the Roubidoux Formation (Orndorff and others, 2006). The Roubidoux Formation was named for exposures in the area of Roubidoux Creek about 50 mi to the northwest in Pulaski County, Mo. (Nason, 1892). The Roubidoux consists of interbedded dolomite, cherty dolomite, sandy dolomite, dolomitic sandstone, quartz sandstone, orthoquartzite, and bedded chert. The contact between the Roubidoux and the underlying Gasconade is probably conformable and is placed at the base of the first significant orthoquartzite or sandstone in the Roubidoux. The lower 20 to 30 ft of the Roubidoux is sandstone-rich and commonly produces a topographic bench that sheds sandstone float onto the slopes below. The middle part of the Roubidoux is chiefly thick-bedded gray dolomite, which resembles the dolomite of the upper part of the Gasconade. The upper part of the Roubidoux is sandstone-rich and forms another topographic bench. Upon weathering the Roubidoux produces a sandy, orange-colored soil that in places is littered with tabular sandstone and orthoguartzite float blocks as well as white chert cobbles and boulders.

(mostly *Lecanospira*) locally are common in cherts and sandstones. Heller (1954) reported the occurrence of brachiopods, cephalopods, and trilobites from this formation elsewhere within the Salem Plateau. Harrison and others (1996) reported the occurrence of conodonts indicative of early Early Ordovician (early to middle Ibexian) age. The top of the Roubidoux Formation is not present in the map area, having been removed by erosion. The Roubidoux is reported to be as much as 250 ft thick in other parts of Missouri (Thompson, 1995). A thickness of about 140 ft of the Roubidoux is exposed in the northwestern part of the guadrangle.

Surficial Geology

Alluvial deposits (Qa) and terrace deposits (Qt) were mapped within the stream valleys and are similar in composition. The terraces comprise Holocene to possibly late Pleistocene alluvial deposits (Haynes, 1985; Albertson and others, 1995) that were derived mostly by washing out and reworking of the clay, silt, and chert fractions from the adjacent upland residual soils and to a lesser extent by reworking of loess. Terraces were mapped as geomorphic features along the sides of the stream valleys at higher elevations than the present-day flood plain. Along the Jacks Fork River and its major tributaries, several levels of surficial terrace deposits occur. Detailed differentiation and mapping of these terraces across the map area were beyond the scope of the present project. Therefore, all terrace deposits were mapped as a single unit (Qt). Pleistocene loess is reported as thin or absent over most of the Salem Plateau

soils having a loess component (Gott, 1975). In most areas, these soils do not constitute a mappable geologic unit, because they are thin and intermingled with underlying clayey residuum due to bioturbation. Small areas having these soils were observed in the Alley Spring quadrangle in saddles between hills and on flat uplands. These areas are not extensive enough to be mapped as a separate unit. Some of the larger sinkholes are filled with deposits of Holocene and Pleistocene(?) muck (Qm) that are large enough to be mapped as a separate unit. Only one area, however, surrounding Indian Pond (sec. 14, T. 29 N., R. 5 W.), was delineated on this map. In upland areas, a pervasive mantle of residuum represents the weathering-in-place of fresh bedrock into soil. Generally, dolomites have been leached away, leaving a residue of angular pebbles, cobbles, and boulders composed of chert, quartzite, and sandstone floating in a matrix of clayey silt to silty clay. On most slopes, the residual soils have undergone downhill creep, producing a thin mantle of colluvium along most valley walls. Because this veneer typically is nearly ubiquitous but thin, it is not mapped as a separate unit. Many of the high ridges and hills in the quadrangle underlain by Gasconade Dolomite bedrock are capped with residual deposits consisting of quartz sandstone slabs and boulders, white chert boulders and cobbles, and sandy soils clearly derived from the in-place weathering of the overlying Roubidoux Formation and ranging from 0 to about 40 ft thick. These deposits also occur as colluvium on steep hillsides. They

Karst features in the Alley Spring quadrangle include caves, springs, sinkholes, disappearing and losing streams, and small-scale solutional features on exposed carbonate bedrock surfaces. Caves can be found anywhere in the stratigraphic section but are concentrated at particular stratigraphic horizons. Many caves are in the upper part of the Eminence Dolomite (just beneath the Gunter Sandstone Member of the overlying Gasconade Dolomite), and in the upper part of the Gasconade Dolomite, near the contact with the Roubidoux Formation (Orndorff and others, 2006; Lowell and others, 2010). Most sinkholes are filled with sediment and residuum, and many were formed by subsidence of the land surface into caves below. Sinkholes can be found in all of the formational units, but they are larger and more numerous in th lower part of the Roubidoux Formation where it collapses into caves in the upper part of the underlying Gasconade Dolomite. Sinkholes observed during the course of field studies in the quadrangle as well as sinkholes implied by closed contours on the

Roubidoux residuum).

1	Table 1.—Major-oxide analysis of					
	Sample locality shown on map. Data percent detection limits provided by A					
	Sample number	Location	UTM			
	Yst-58	sec. 15, T. 29 N., R. 4 W.	643			

crossbedded. At outcrops the thick, non-cherty dolomite beds commonly weather into irregular pinnacles, especially beds lying subjacent to sandstone of the overlying Gunter Sandstone Member of the Gasconade Dolomite. Bridge (1930) reported the

(McDowell, 1998; Orndorff and others, 1999; McDowell and Harrison, 2000; content of the Gunter varies within the Alley Spring quadrangle. Quartz sandstone and

oolite bed in the middle part of the middle unit of the Gasconade Dolomite (fig. 3).

planispiral gastropods and cephalopods from cherts within this unit have been

Fossils generally are rare in the Roubidoux Formation, though impressions of snails

(Ebens and Connor, 1980). Nevertheless, the Alley Spring region includes areas of

have been mapped as a separate unit designated QTrr (Quaternary and Tertiary

topographic map are delineated on the geologic map. Most locations were checked using a global positioning system (GPS) to provide precise coordinates; sinkhole shapes and sizes are approximate and based on visual estimates.

Alley Spring, the largest karst spring in the quadrangle, has an average discharge of 81 million gallons per day (Vineyard and Feder, 1982). There is at least a 25-year history of scuba diving in the spring and in the large water-filled cave that is a conduit supplying groundwater to the spring. Recent (2000 to present) explorations by the Ozark Cave Diving Alliance (OCDA) have extended the mapped portion of the cave. The point of farthest exploration to date is about 2,000 ft west-southwest of the spring, at an elevation approximately 100 ft below the surface of the rise pool. Dye traces indicate that some of the water feeding Alley Spring flows from as far away as 37 mi to the west-northwest (Aley and Aley, 1987). Preliminary analysis of audio-magnetotelluric data collected near Alley Spring has yielded inconclusive results as to the exact location of the conduit(s) to the west and northwest of the known cave (Pierce and Weary, 2009; Lowell and others, 2010). Recent cave diving by the OCDA produced video and photos and supplied rock samples from various parts of the system to allow the USGS to relate the conduit system to the local geology. Cave diving in various Ozark springs has shown in many instances that the rise pool is supplied by a conduit that descends obliquely to depths as great as 300 ft before leveling off and continuing subhorizontally. The angle of descent typically is 25° to 35°. The cave diving survey of Alley Spring shows that the conduit becomes horizontal beneath the Gunter Sandstone Member of the Gasconade Dolomite (about 130 ft below the surface of the rise pool). This demonstrates a stratigraphic control on cave level similar to that observed in dry caves studied throughout the region (Orndorff and others, 2006).

STRUCTURAL GEOLOGY

The regional style of deformation in southeastern Missouri is brittle, with vertical jointing and strike-slip faulting predominant along northeast and northwest trends (Clendenin and others, 1989; Harrison and Schultz, 2002). Strata within the Alley Spring quadrangle are generally subhorizontal to gently dipping. Gentle folding occurs as compressional or transpressional strain near faults and possibly as subsidence into large karstic voids. The steepest dip measured in the quadrangle was 17° to the northwest in rocks exposed along State Highway 106 in sec. 33, T. 29 N., R. 4 W. This high dip is probably associated with deformation of the rocks between the Hartshorn, Mahans Creek, and Possum Trot Hollow faults. It also is possible that there is a buried knob of igneous Mesoproterozoic basement rocks in the southeast corner of sec. 28, T. 29 N., R. 4 W., and the overlying Paleozoic sedimentary rocks are dipping off of it as described in earlier studies in the area (Bridge, 1930; Harrison and others, 2002). Most of the steeper dips measured in the quadrangle are found in this

The rocks of this quadrangle are pervasively jointed. Joints were characterized by their orientation, spacing, persistence, and aperture. Spacing refers to the mean perpendicular distance between parallel joints in a joint set. Joints confined to individual beds are classified as non-throughgoing, and joints extending across bedding planes into overlying and (or) underlying beds are classified as throughgoing. Most joints in the carbonate rocks are open (containing no mineralized infilling) and have narrow apertures. However, some joints have been widened by solution and are as much as 10 inches (in.) wide. Cumulative orientations of all the joint measurements observed in outcrop are shown in figure 4. The two primary joint sets trend north-northwest and east-northeast and are indicative of development under a regional stress field. Cox (1995) interpreted similarly oriented joints throughout the Ozarks as far-field deformation related to the Ouachita and Appalachian orogenies. Cataclastic deformation bands occur locally in sandstones within the quadrangle. All were found in float blocks, diminishing their usefulness for indicating direction of fault movement. The deformation bands are of tectonic origin and are created by millimeter-scale displacements through shearing that involves a combination of pore-space collapse and fracturing of grains (Davis, 1999; Harrison and Schultz, 2002). Because development of deformation bands is a strain-hardening mechanism (Davis, 1999), the bands are usually more resistant to weathering than the surrounding

rock and are commonly found in raised relief on the surfaces of sandstone boulders. Faults in this area are difficult to observe directly, due to vegetation and residuum cover, and have to be inferred on the basis of indirect evidence. This evidence includes (1) vertical offset of strata having insufficient observed dip to explain that offset (vertical stratigraphic offset along faults may reverse in sense as the result of horizontal offset of gentle folds along both sides of the fault, sometimes referred to as scissor faults) and (2) cataclastic deformation bands observed in float blocks of sandstone. Although only indications of vertical offset were observed on faults in the quadrangle, the faults are interpreted to be predominantly strike-slip on the basis of observations of similar faults exposed in subsurface base-metal mines in nearby

The Hartshorn fault traverses the southern part of the quadrangle and trends northwest. This fault has been mapped by the USGS in reconnaissance for tens of miles northwestward from Alley Spring. The mapping of this fault was originally based on small vertical stratigraphic offsets observed in sparse outcrops and well logs and also on interpretation of regional aeromagnetic data (R.W. Harrison, USGS, unpub. data, 2010). Recently acquired electrical resistivity profiles confirm the location of the fault in the vicinity of Alley Spring (fig. 5, cross section B-B') (Pierce and Weary, 2009; Lowell and others, 2010). Total offset on this fault is difficult to determine; the horizontal slip is undetermined and the vertical offset varies locally, ranging from as much as 100 ft to as little as 20 ft, with the southwestern block up in relation to the northeastern block in the Alley Spring quadrangle. The Hartshorn fault continuing to the northwest may be the same structure as the Arthur Creek fault, mapped by Satterfield (1976) near the town of Raymondville, about 20 mi northwest of the Alley Spring quadrangle. The Hartshorn fault trace also approximates the trace of a topographic lineament named the Alley Hollow lineament by Aley and Aley (1987). Another regional strike-slip fault that traverses the Alley Spring quadrangle is the Sutton Creek fault, which crosses the northeastern part of the map area along a northwesterly trend. This fault was mapped in the Eminence quadrangle adjoining to the east (Orndorff and others, 1999) and is mentioned in a report on the copper deposits of Shannon County (Bowles and Davidson, 1921). It extends southeastward into the central part of the Eminence quadrangle and, like the Hartshorn fault, extends for tens of miles to the northwest of the Alley Spring quadrangle. The Sutton Creek fault is probably the same structure as the Oscars fault, mapped in the Raymondville area by Satterfield (1976). In the Alley Spring quadrangle, the block on the southwest side of the fault is down relative to the northeastern block, with vertical offsets ranging from 20 to 40 ft. Geometric relations to adjoining faults indicate left-lateral movement on the Sutton Creek fault.

Two smaller faults in the Alley Spring quadrangle, the Venice and Possum Trot Hollow faults, are interpreted to be splays off the Sutton Creek fault. The Venice fault diverges from the Sutton Creek fault in the northeastern part of the Alley Spring quadrangle and terminates against the McCabe Hollow fault in the western part of the Eminence quadrangle (Orndorff and others, 1999). The Venice fault has an apparent vertical offset ranging from approximately 20 ft to about 140 ft, with the southwestern block down relative to the northeastern block. Vertical offset of the Mesoproterozoic basement rocks may be greater, implying pre-Gasconade movement along this fault. This fault bounds the southwestern margin of the small outcrop area of the Mesoproterozic rhyolite of Storys Creek (map unit Yscr). The Possum Trot Hollow fault diverges from the Sutton Creek fault near the northern edge of the Alley Spring quadrangle and trends toward the southeast, where it continues into the south-central part of the Eminence quadrangle and terminates against the Shawnee Creek fault (Orndorff and others, 1999). Vertical offsets on the Possum Trot Hollow fault range from 20 to 90 ft, down on the southwestern side, along most of its trace. A splay off the Possum Trot Hollow fault extends east-southeastward into the

Eminence quadrangle, where we interpret it to join the Venice fault. This fault, herein named the Storys Creek fault, has a vertical offset of as much as 60 ft. The southern block is down relative to the northern block east of Storys Creek, while the reverse is true west of Storys Creek. The Venice, Possum Trot Hollow, and Storys Creek faults were unrecognized at the time of mapping of the Eminence quadrangle (Orndorff and others, 1999).

A relatively short, northeast-trending fault is mapped in the southeastern part of the Alley Spring quadrangle and is herein named the Mahans Creek fault. This fault trace runs between the Possum Trot Hollow fault to the north and the Hartshorn fault to the south. The Mahans Creek fault separates blocks that are up to the northwest and down to the southeast, with a relative vertical displacement across the fault ranging from about 60 ft to 140 ft. The northeastern part of the northwestern block adjacent to the Mahans Creek fault is warped into an anticline that exposes the Potosi Dolomite in bluffs along the Jacks Fork River.

The Pyrtle Hollow fault crosses the northwest corner of the Alley Spring quadrangle and offsets the northwestern block down as much as 150 ft relative to the southeastern block. This fault extends to the northeast into the Round Spring quadrangle, where it terminates against the southeast-trending Sutton Creek fault (Orndorff and Weary, 2009). The Pyrtle Hollow fault probably extends to the southwest into the Summersville NE 7.5-minute quadrangle, where stratigraphic offset was recognized in earlier mapping and interpreted to be caused by a solutionally let-down synform (Anderson and Wharton, 1975). At the north-central edge of the map area the Jacks Fork Hollow fault, mapped in the Round Spring quadrangle (Orndorff and Weary, 2009), is inferred to extend to the southwest where it terminates against the Sutton Creek fault. Vertical offset is believed to be as much as 120 ft, with the northwestern block up in relation to the

ECONOMIC GEOLOGY

Generally low-quality and low-volume deposits of iron (Crane, 1910) and manganese (Grawe, 1943) have been reported in the Alley Spring region. Gravel, derived from alluvial stream bottoms, and fill earth, derived from residuum, are widely available and are used locally for road-base and dam construction. Dolomite bedrock in the quadrangle, especially the Gasconade Dolomite, could be quarried for road metal or dimension stone.

HYDROLOGY

With the exception of the Jacks Fork River and its major tributaries, most water flow in the Alley Spring quadrangle is subterranean, with surface flow occurring only at times of abundant rainfall. Many small streams have short reaches where water flows from springs or seeps and then is lost to subterranean drainage downslope. Locations of springs that were encountered during fieldwork for this map are indicated by spring symbols. No formal estimate of spring flow was made. As noted in the section, Alley Spring is a very large perennial spring and, with the exception of the Jacks Fork River, is the most significant hydrologic feature in the quadrangle. Within the map area, the Gasconade, Eminence, and Potosi Dolomites are the major stratigraphic units that produce groundwater (Dreiss, 1983). Collectively, these units are part of the regional Ozark aquifer that underlies the Salem Plateau (Imes and

Table 2.—Summary of drill-hole data in the Alley Spring quadrangle, Missouri. [Or, Roubidoux Formation; Og, Gasconade Dolomite; €e, Eminence Dolomite; €p, Potosi Dolomite; €dd, Derby-Doerun Dolomite. Datum is mean sea level]

Drill-hole number	Location	Collar elevation, in feet	Contact elevation, in feet	Bottom elevation, in feet		
Drill-hole data on file with Missouri Department of Natural Resources, Geological Survey and Resource Assessment Division						
18092	SE1/4 NE1/4 sec. 31 T. 29 N., R. 4 W.	1038	898 Or–Og	635		
21242	SE1/4 NE1/4 sec. 20 T. 29 N., R. 4 W.	770	595 Og-€e 305 €e-€p 45 €p-€dd	-5		
21662	NE1/4 NE1/4 sec. 21 T. 29 N., R. 4 W.	760	675 Og-€ e¹ 295 €e-€p	155		
26662	SW1/4 NE1/4 sec. 36 T. 29 N., R. 5 W.	750	605 Or–Og ²	100		
28085	SE1/4 NW1/4 sec. 4 T. 28 N., R. 4 W.	720	645 Og-€e 420 €e-€p	120		
28153	SE1/4 NE1/4 sec. 5 T. 28 N., R. 4 W.	820	520 Og-€e 270 €e-€p	60		
28154	SE1/4 NE1/4 sec. 5 T. 28 N., R. 4 W.	700	550 Og-€e 270 €e-€p	190		

Dolomite reported in areas to the east of the Alley Spring quadrangle (Bridge, 1930; Weary and Schindler, 2004).

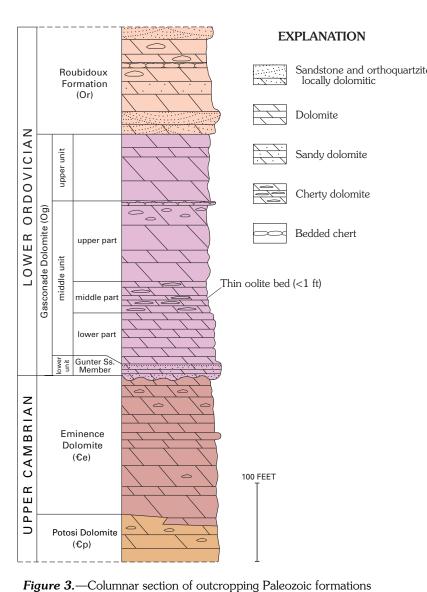
²Field mapping indicates this well starts in the lower part of the Gasconade Dolomite.

This contact may actually be the Og-€e contact.

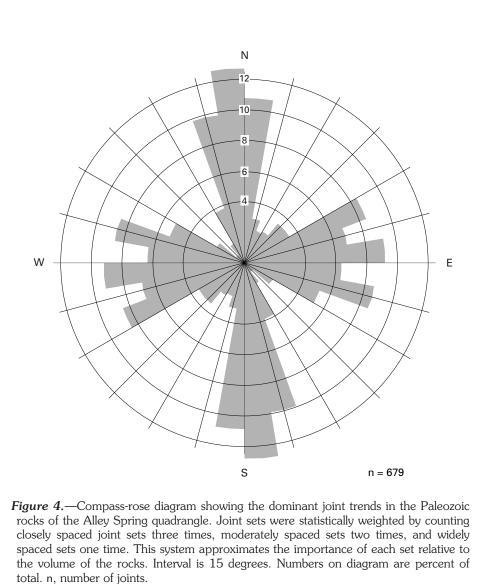




lower part of the Gasconade Dolomite, visible in the background. Alley Spring has an average discharge of 81 million gallons per day (125 cubic feet per second or 3.5 cubic meters per second) (Vineyard and Feder, 1982). Most of the outflow is to the right of this view. The spring is in E 1/2 sec. 25, T. 29 N., R. 5 W.



in the Alley Spring quadrangle showing informal units of the Gasconade Dolomite. Abbreviation used: Ss., sandstone.



ISBN 978-1-4113-3126-

of a representative Mesoproterozoic volcanic rock (map unit Yscr) in the Alley Spring quadrangle, Missouri. ata in weight percent. Whole-rock geochemistry using fusion-inductively coupled plasma emission spectrometry with 0.01Actlabs, Inc., Wheat Ridge, Colo. LOI, Loss on ignition M North UTM East Unit SiO₂ Al₂O₃ Fe₂O₃ MgO MnO CaO TiO₂ Na₂O K₂O P₂O₅ LOI Total

Emmett. 1994).

southeastern block.

643985 4117056 Yscr 76.38 12.32 2.71 0.10 0.05 0.48 0.23 6.71 2.17 0.03 0.35 101.53

Any use of trade, product, or firm names in this publication is for descriptive purposes only and does not imply endorsement by the U.S. Governmen For sale by U.S. Geological Survey, Information Services, Box 25286, Feder Center, Denver, CO 80225; telephone 1-888-ASK-USGS Printed on recycled pa