U.S. Department of the Interior
National Park Service
Natural Resource Stewardship and Science Directorate
Geologic Resources Division

Hot Springs National Park

GRI Ancillary Map Information Document

Produced to accompany the Geologic Resources Inventory (GRI) Digital Geologic Data for Hot Springs National Park

hosp_geology.pdf

Version: 6/6/2013

Geologic Resources Inventory Map Document for Hot Springs National Park

Table of Contents

Geologic Resources Inventory Map Document **1**
About the NPS Geologic Resources Inventory Program **2**
GRI Digital Map and Source Map Citation **4**
Map Unit List **5**
Map Unit Descriptions **6**
Qtufa - Tufa (Holocene and Pleistocene) 6
Qal - Alluvium (Holocene and Pleistocene) 6
Qt - Terrace deposit (Holocene and Pleistocene) 6
Kms - Metasedimentary rocks, undivided (Early to Late Cretaceous) 6
Ki - Igneous rocks, undivided (Early to Late Cretaceous) 6
Ms - Stanley Shale (Early Mississippian) 6
Mshs - Stanley Shale, Hot Springs Sandstone Member (Early Mississippian) 7
MDa - Arkansas Novaculite (Late Devonian to Early Mississippian) 7
Sm - Missouri Mountain Shale (Late Silurian) 8
SOu - Missouri Mountain Shale-Polk Creek Shale (Ordovician to Silurian) 8
Sb - Blaylock Sandstone (Early to Late Silurian) 8
Opc - Polk Creek Shale (Late Ordovician) 8
Obf - Bigfork Chert (Middle to Late Ordovician) 9
Ow - Womble Shale (Middle Ordovician) 9
Ob - Blakely Sandstone (Middle Ordovician) 9
Om - Mazarn Shale (Early Ordovician) 9
GRI Source Map Citation **10**
Arkansas Geological Survey DGM-HSR-003 10
Geologic Cross Section A - A' 10
Report 10
Correlation Chart 12
Stratigraphic Column 13
Joint Frequency 14
Location Map 15
Quadrangle Index Map 15
Legend 16
References 16
Acknowledgements and Disclaimer 17
GRI Digital Data Credits **18**

Geologic Resources Inventory Map Document

Hot Springs National Park, Arkansas

Document to Accompany Digital Geologic-GIS Data

hosp_geology.pdf

Version: 6/6/2013

This document has been developed to accompany the digital geologic-GIS data developed by the Geologic Resources Inventory (GRI) program for Hot Springs National Park, Arkansas (HOSP).

Attempts have been made to reproduce all aspects of the original source products, including the geologic units and their descriptions, geologic cross sections, the geologic report, references and all other pertinent images and information contained in the original publication.

National Park Service (NPS) Geologic Resources Inventory (GRI) Program staff have assembled the digital geologic-GIS data that accompanies this document.

For information about the status of GRI digital geologic-GIS data for a park contact:

Tim Connors
Geologist/GRI Mapping Contact
National Park Service Geologic Resources Division
P.O. Box 25287
Denver, CO 80225-0287
phone: (303) 969-2093
fax: (303) 987-6792
email: Tim_Connors@nps.gov

For information about using GRI digital geologic-GIS data contact:

Stephanie O'Meara
Geologist/GIS Specialist/Data Manager
Colorado State University Research Associate, Cooperator to the National Park Service
1201 Oak Ridge Drive, Suite 200
Fort Collins, CO 80525
phone: (970) 491-6655
fax: (970) 225-3597
e-mail: stephanie.omeara@colostate.edu

About the NPS Geologic Resources Inventory Program

Background

Recognizing the interrelationships between the physical (geology, air, and water) and biological (plants and animals) components of the Earth is vital to understanding, managing, and protecting natural resources. The Geologic Resources Inventory (GRI) helps make this connection by providing information on the role of geology and geologic resource management in parks.

Geologic resources for management consideration include both the processes that act upon the Earth and the features formed as a result of these processes. Geologic processes include: erosion and sedimentation; seismic, volcanic, and geothermal activity; glaciation, rockfalls, landslides, and shoreline change. Geologic features include mountains, canyons, natural arches and bridges, minerals, rocks, fossils, cave and karst systems, beaches, dunes, glaciers, volcanoes, and faults.

The Geologic Resources Inventory aims to raise awareness of geology and the role it plays in the environment, and to provide natural resource managers and staff, park planners, interpreters, researchers, and other NPS personnel with information that can help them make informed management decisions.

The GRI team, working closely with the Colorado State University (CSU) Department of Geosciences and a variety of other partners, provides more than 270 parks with a geologic scoping meeting, digital geologic-GIS map data, and a park-specific geologic report.

Products

Scoping Meetings: These park-specific meetings bring together local geologic experts and park staff to inventory and review available geologic data and discuss geologic resource management issues. A summary document is prepared for each meeting that identifies a plan to provide digital map data for the park.

Digital Geologic Maps: Digital geologic maps reproduce all aspects of traditional paper maps, including notes, legend, and cross sections. Bedrock, surficial, and special purpose maps such as coastal or geologic hazard maps may be used by the GRI to create digital Geographic Information Systems (GIS) data and meet park needs. These digital GIS data allow geologic information to be easily viewed and analyzed in conjunction with a wide range of other resource management information data.

For detailed information regarding GIS parameters such as data attribute field definitions, attribute field codes, value definitions, and rules that govern relationships found in the data, refer to the NPS Geology-GIS Data Model document available at: http://science.nature.nps.gov/im/inventory/geology/GeologyGISDataModel.cfm

Geologic Reports: Park-specific geologic reports identify geologic resource management issues as well as features and processes that are important to park ecosystems. In addition, these reports present a brief geologic history of the park and address specific properties of geologic units present in the park.

For a complete listing of Geologic Resource Inventory products and direct links to the download site visit the GRI publications webpage http://www.nature.nps.gov/geology/inventory/gre_publications.cfm

GRI geologic-GIS data is also available online at the NPS Data Store Search Application: http://irma.nps.gov/App/Reference/Search. To find GRI data for a specific park or parks select the appropriate park (s), enter “GRI” as a Search Text term, and then select the Search Button.

For more information about the Geologic Resources Inventory Program visit the GRI webpage: http://www.nature.nps.gov/geology/inventory, or contact:

Bruce Heise
Inventory Coordinator
National Park Service Geologic Resources Division
P.O. Box 25287
Denver, CO 80225-0287
phone: (303) 969-2017
fax: (303) 987-6792
email: Bruce_Heise@nps.gov

The Geologic Resources Inventory (GRI) program is funded by the National Park Service (NPS) Inventory and Monitoring (I&M) Division.

GRI Digital Map and Source Map Citation

The GRI digital geologic-GIS map for Hot Springs National Park, Arkansas (HOSP):

GRI Digital Geologic Map of Hot Springs National Park and Vicinity, Arkansas (*GRI MapCode HOSP*)

Johnson, Ty C., and William D. Hanson, 2011, Geologic Map of the Hot Springs North, Hot Springs South, Fountain Lake and Lake Catherine 7.5' Quadrangles, Garland, Hot Spring and Saline Counties, Arkansas, Arkansas Geological Survey, Digital Geologic Quadrangle Map DGM-HSR-003 (unpublished data), 1:24000 scale. (Arkansas Geological Survey DGM-HSR-003). (*GRI Source Map ID 75565).*

Additional information pertaining to each source map is also presented in the GRI Source Map Information (HOSPMAP) table included with the GRI geology-GIS data.

Map Unit List

The geologic units present in the digital geologic-GIS data produced for Hot Springs National Park, Arkansas (HOSP) are listed below. Units are listed with their assigned unit symbol and unit name (e.g., Qal - Alluvium). Units are listed from youngest to oldest. No description for water is provided. Information about each geologic unit is also presented in the Geologic Unit Information (HOSPUNIT) table included with the GRI geology-GIS data.

Cenozoic Era

Quaternary
Qtufa - Tufa
Qal - Alluvium
Qt - Terrace deposit

Mesozoic Era

Cretaceous
Kms - Metasedimentary rocks, undivided
Ki - Igneous rocks, undivided
Kia - Igneous rocks, alkalic dike
Ki - Igneous rocks
  Kil - Igneous rocks, lamprophyric dike
  Kid - Igneous rocks, undifferentiated dike
  Kis - Igneous rocks, undifferentiated sill

Paleozoic Era

Mississippian
Ms - Stanley Shale
Mshs - Stanley Shale, Hot Springs Sandstone Member

Mississippian and Devonian
MDa - Arkansas Novaculite

Silurian
Sm - Missouri Mountain Shale

Silurian and Ordovician
SOu - Missouri Mountain Shale-Polk Creek Shale

Silurian
Sb - Blaylock Sandstone

Ordovician
Opc - Polk Creek Shale
Obf - Bigfork Chert
Ow - Womble Shale
Ob - Blakely Sandstone
Om - Mazarn Shale

Map Unit Descriptions

Descriptions of all geologic map units, generally listed from youngest to oldest, are presented below.

Qtufa - Tufa (Holocene and Pleistocene)

Tufa is a rock formed by precipitation of the hot springs water flowing over the ground surface. The water is supersaturated with respect to calcium carbonate which degasses CO2 when it reaches the surface and precipitates tufa. The rock has distinctly banded dark gray and white layers of calcite, and has a fibrous, porous texture. Colluvial material is incorporated in the tufa, as well as layers of conglomerate. Tufa deposits are six to eight feet thick (Purdue and Miser, 1923). *GRI Source Map ID 75565* (Arkansas Geological Survey DGM-HSR-003)

Qal - Alluvium (Holocene and Pleistocene)

Unconsolidated gravel, sand, silt, and clay comprise the unit. This unit occurs in the flood plains of streams and rivers. *GRI Source Map ID 75565* (Arkansas Geological Survey DGM-HSR-003)

Qt - Terrace deposit (Holocene and Pleistocene)

Unconsolidated sediment generally grades upward from basal gravel to silt and clay. Terraces are topographic features which are former flood plains of streams and/or rivers. *GRI Source Map ID 75565* (Arkansas Geological Survey DGM-HSR-003)

Kms - Metasedimentary rocks, undivided (Early to Late Cretaceous)

Contact metamorphism has altered the rocks surrounding the igneous intrusions for a distance of about 2500 feet (762 m) at Magnet Cove and at Potash Sulphur Springs about 2200 feet (671 m). The rocks are primarily metaquartzite where the Arkansas Novaculite is altered and hornfels where the Stanley Shale is altered. The grade of metamorphism decreases with distance from intrusions and the zone is uneven due to faults and changing rock types. *GRI Source Map ID 75565* (Arkansas Geological Survey DGM-HSR-003)

Ki - Igneous rocks, undivided (Early to Late Cretaceous)

Igneous rocks were emplaced during the mid-Cretaceous in the form of plutons, dikes and sills. Plutons consist of nepheline syenite and related rock types while the dikes and sills are alkalic to lamprophyric or undifferentiated. Igneous plutons are located at Magnet Cove and Potash Sulphur Springs.
Includes the following dikes/sills:

Alkalic dikes (Kia)
Lamprophyric dikes (Kil)
Undifferentiated dikes (Kid)
Undifferentiated sill (Kis)

GRI Source Map ID 75565 (Arkansas Geological Survey DGM-HSR-003)

Ms - Stanley Shale (Early Mississippian)

The Stanley is composed predominantly of grayish-black to brownish-gray shale, with lesser amounts of thin- to massive-bedded, fine-grained, gray to brownish-gray, micaceous, feldspathic sandstone, dark-

green to black tuff and black chert. Weathered shale is olive-gray, and weathered sandstone is generally brown and more porous. The formation was deposited by turbidity currents. This unit is 1500 feet (457 m) thick in the mapping area and has a total thickness of over 10,000 feet (3048 m) (McFarland, 2004). The contact is conformable with the Hot Springs Sandstone member. Near the contact, clean sandstones are interbedded with shale and sandstone in the Stanley. Sandstone on sandstone contact can also occur making the determination of the actual contact difficult to pick. Locally a conglomerate marks the contact. *GRI Source Map ID 75565* (Arkansas Geological Survey DGM-HSR-003)

Mshs - Stanley Shale, Hot Springs Sandstone Member (Early Mississippian)

The base of the Stanley, and consists of medium- to fine-grained, sub-angular to sub-rounded quartz arenite. Bedding is massive- to thin- bedded. In places, the unit is quartzitic. Siltstone and shale is present at the top of this member locally. On weathered surfaces this sandstone is very light-gray to light-tan. On fresh surfaces the sandstone is light-gray to white and rarely dark-gray. Intraformational conglomerates also occur and range in thickness from one inch to five feet (2.5cm-1.5m). Thin, less than one inch, quartz veins are common in the sandstone. Thickness of this member is highly variable, locally reflecting its morphology as a channel deposit. Thicknesses range from 0 – 450 (0-137 m) feet pinching out to the south. The thickest parts of the formation occur in the noses of anticlines. The unit is deposited by turbidity currents. This member is restricted to the Zigzag Mountains where it forms hogback ridge lines with the Arkansas Novaculite. The contact with the Arkansas Novaculite is unconformable. A conglomerate is commonly at its base. The matrix is sand or novaculite with novaculite clasts that range in size from very coarse sand to boulders. In places, the conglomerate is up to 60 feet (18 m) thick. *GRI Source Map ID 75565* (Arkansas Geological Survey DGM-HSR-003)

MDa - Arkansas Novaculite (Late Devonian to Early Mississippian)

Three informal divisions of the Arkansas Novaculite are recognized:

The lower division is white to dark-gray cryptocrystalline quartz. Fine-grained novaculite is translucent on thin edges and is harder and denser than opaque coarser-grained novaculite. Bedding is massive, 4 to 30 feet (1.2-9.1 m) thick, with interbedded gray shales, minor amounts of sandstone and conglomerate near the base. Bedding planes are locally very flat and can be confused with joint planes. A hummocky surface was also common. On Glazypeau Mountain the lower novaculite pinches out, and when present, sandstone is encountered at the base. The lower division is a prominent ridge former, is approximately 275 feet (84 m) thick in Hot Springs and thickens in the Trap Mountains to 450 feet (137 m).

The middle division is typically dark-gray to black siliceous shale interbedded with numerous thin beds of dark novaculite and chert. In the Zigzag Mountains the novaculite and chert beds are generally less than two inches thick, but in the Trap Mountains they range from 2 to 4 inches (5-10 cm) thick. Thin- to thick-bedded quartz arenite sandstone resembling the Hot Springs Sandstone is present in the Trap Mountains in Lake Catherine State Park. This division reaches a maximum thickness of 80 feet (0-24 m) in the Zigzag Mountains and 100 to 300 feet (30-91 m) in the Trap Mountains. The contact with the lower division is sharp. Locally this division is totally or partially replaced by conglomerate.

The upper division is white, thin- bedded novaculite interbedded with soft, white shale and is typically calcareous and tripolitic. Thicker beds of novaculite at the top of this division resemble the lower member with beds are up to 4 feet thick. This unit becomes thin-bedded in the Glazypeau Mountain area and resembles the Bigfork Chert. Thickness of the upper division reaches a maximum of 160 feet (0-49 m) in Hot Springs and 100 feet (0-30 m) in the Trap Mountains. The contact with the Stanley Shale and/or Hot Springs Sandstone is unconformable. Locally, the upper and/or middle divisions are

eroded and replaced by conglomerate.

Grain size of the novaculite averages about 5 microns (Holbrook and Stone, 1978). Conglomerates with novaculite clasts occur at various intervals in the formation and are deposited by granular-grain flows that form beds several inches thick to boulder-clast flows several feet thick. The novaculites are 99 percent silica with the remaining one percent predominantly pyrite and/or FeMn-bearing calcite (J.M. Howard, per. comm., 2010). Many quartz veins occur within the novaculite, but are too small to observe in outcrop. This unit and the Hot Springs Sandstone compose the backbone of the Zigzag Mountains in the Hot Springs area. The estimated total thickness of the Arkansas Novaculite in the Hot Springs area is 400 feet (122 m) and reaches 600 feet (183 m) in the Trap Mountains. Flow indicators include ripples marks, distributary channel features and thickening to the south. The contact with the middle division of the Arkansas Novaculite is unconformable and often marked by a conglomerate or breccia. *GRI Source Map ID 75565* (Arkansas Geological Survey DGM-HSR-003)

Sm - Missouri Mountain Shale (Late Silurian)

The Missouri Mountain consists predominantly of shale with minor amounts of conglomerate, novaculite and sandstone or quartzite. Weathered shale is dull green to maroon in color. One to four thin quartzite beds occur near the top of this unit. These beds are commonly one to two inches but beds up to 8 inches (20 cm) thick are locally present. This formation is 75 to 125 feet (23-38 m) thick in the Trap Mountains and is mapped with the Polk Creek in the Zigzag Mountains. Few identifiable fossils have been recovered from this unit. The unit was deposited in a deep marine environment and has a conformable contact with the Blaylock. Shale clasts are locally incorporated in the basal sandstone beds. *GRI Source Map ID 75565* (Arkansas Geological Survey DGM-HSR-003)

SOu - Missouri Mountain Shale-Polk Creek Shale (Ordovician to Silurian)

Missouri Mountain Shale is dark gray on a fresh surface and weathers green to maroon. Locally there are a few thin beds of quartzite near the top of the formation. The Polk Creek is black, sooty, fissile, shale that weathers light-gray to buff. Thickness ranges from 200 to 250 feet (61-76 m). The Polk Creek and the Missouri Mountain are unconformable. In the Zigzag Mountains these two units are mapped together when the Blaylock Sandstone is not present. *GRI Source Map ID 75565* (Arkansas Geological Survey DGM-HSR-003)

Sb - Blaylock Sandstone (Early to Late Silurian)

The Blaylock consists of tan to gray, fine- to medium-grained sandstone, siltstone interbedded with black fissile shale. Graptolites and trace fossils are rare. This formation is 300 to 600 feet (91-183 m) thick in the Trap Mountains, and is not present in the Zigzag Mountains. The contact with the Polk Creek Shale is unconformable. *GRI Source Map ID 75565* (Arkansas Geological Survey DGM-HSR-003)

Opc - Polk Creek Shale (Late Ordovician)

The Polk Creek consists of black, sooty, fissile shale with minor black chert and traces of gray quartzite. Weathered shales are light-gray to white and are very soft. Thickness ranges from 50 to 100 feet (15-30 m). Graptolites are common throughout the formation. The unit is conformable with the Bigfork Chert. This contact grades rapidly from chert beds to shale. *GRI Source Map ID 75565* (Arkansas Geological Survey DGM-HSR-003)

Obf - Bigfork Chert (Middle to Late Ordovician)

The Bigfork consists of thin-bedded, dark- to light-gray cryptocrystalline chert interbedded primarily with black siliceous shale and subordinate amounts of calcareous siltstone and dense blue-gray limestone. Some intervals are tripolitic. Shale weathers to a soft texture and buff color. Sandstone beds and chert with floating sand grains are locally present near the top of the unit. Fossils are rare but fragments of brachiopods, crinoids, sponges, conodonts, and graptolites have been reported (McFarland, 2004). Debris flows deposited in this unit contain igneous pebbles and cobbles and limestone fragments. This unit is identifiable by its thin-interbedded nature and disharmonic folding. Dendritic drainage patterns are common to this unit. Thickness ranges up to 750 feet (229 m) (McFarland, 2004). The unit is conformable with the Womble Shale. *GRI Source Map ID 75565* (Arkansas Geological Survey DGM-HSR-003)

Ow - Womble Shale (Middle Ordovician)

The Womble consists of dark gray to black shale and dark gray limy siltstone, with a few beds of dark gray silty limestone. Shale can be siliceous and hard at the top of the formation. Graptolites and conodonts are present. Milky quartz veins are common. The unit is conformable with the underlying Blakely Sandstone. Thickness ranges from 500 to 1200 feet (152-366 m) (McFarland, 2004). *GRI Source Map ID 75565* (Arkansas Geological Survey DGM-HSR-003)

Ob - Blakely Sandstone (Middle Ordovician)

The Blakely Sandstone consists of black and green shale in alternating layers with hard gray sandstone and lesser amounts of blue-gray limestone. Although shale makes up locally 50% - 75% of the sequence, it is thick sandstone sequences that outcrop prominently. The sandstone is light-gray to blue, medium-grained, well-cemented and thin- to thick- bedded. The shale of the Blakely is sometimes ribboned much like the Mazarn Shale. Graptolites and conodonts have been reported from the formation. The unit is conformable with underlying Mazarn Shale, and the thickness ranges from 500 to 750 feet (152-229 m). *GRI Source Map ID 75565* (Arkansas Geological Survey DGM-HSR-003)

Om - Mazarn Shale (Early Ordovician)

The Mazarn is predominantly shale with lesser amounts of siltstone, silty to conglomeratic sandstone, limestone and glossy black chert. The shale is mostly gray-black but thin layers of olive-gray silty shale or siltstone are interbedded with the darker shale in some sequences. When the dark-gray and greenish shale is cleaved at an angle to bedding it yields a ribboned surface. In many places quartzose siltstone and/or very fine-grained sandstone is present. Dense, blue-gray, thin-bedded limestones can occur throughout the interval. The occurrence of chert is usually in the upper part of the formation. Milky quartz veins are common in some areas. Graptolite fossils were observed but sparse. Thickness ranges from 1000 to over 2500 feet (305-762 m) (McFarland, 2004). The unit is conformable with the underlying formation. *GRI Source Map ID 75565* (Arkansas Geological Survey DGM-HSR-003)

GRI Source Map Citation

The GRI digital geologic-GIS map for Hot Springs National Park, Arkansas (HOSP) was compiled from the following source (currently in interim form):

Johnson, Ty C., and William D. Hanson, 2011, Geologic Map of the Hot Springs North, Hot Springs South, Fountain Lake and Lake Catherine 7.5' Quadrangles, Garland, Hot Spring and Saline Counties, Arkansas, Arkansas Geological Survey, Digital Geologic Quadrangle Map DGM-HSR-003 (unpublished data), 1:24,000 scale. (Arkansas Geological Survey DGM-HSR-003). (*GRI Source Map ID 75565).*

The PDF version of the source map will be made available after ongoing edits to the map have been completed, but can also be requested from the GRI team.

Additional information pertaining to this source map is also presented in the Source Map Information (MAP) table included with the GRI geology-GIS data.

Arkansas Geological Survey DGM-HSR-003

Geologic Cross Section A - A'

The geologic cross section present in the GRI digital geologic-GIS data produced for Hot Springs National Park, Arkansas (HOSP) may be accessed through this link: Cross-Section A - A'.

Report

From 2009 through 2011 the Arkansas Geological Survey (AGS) undertook the geological mapping of four United States Geological Survey 7.5 minute quadrangles surrounding Hot Springs National Park in Arkansas. This was done in cooperation with the National Park Service (NPS) which is currently interested in compiling more detailed geologic map data of selected park lands and areas adjacent. This project area includes: Hot Springs North, Hot Springs South, Fountain Lake and Lake Catherine quadrangles. This area lies within the Ouachita Mountains Physiographic Province and overlaps parts of the Mazarn and Saline Basins which are separated by the Zigzag Mountains. The Trap Mountains are located on the southern edge of the Mazarn Basin. Rocks in this area are predominantly sedimentary and deposited in a deep marine environment. They primarily consist of shale, sandstone, siltstone, novaculite, chert and conglomerate. Formations range in age from Ordovician to Mississippian and generally thicken to the south. Sparse plutonic igneous rocks were emplaced during the Cretaceous. All terraces were deposited along major streams during the Quaternary. Tufa has precipitated recently where the hot springs flow over the surface.

All Paleozoic units in this area have been subjected to low grade metamorphism, temperatures less than that of the zeolite facies, during the Ouachita Orogeny (Jackson, 1977). A thermal event occurred from the late Pennsylvanian into the early Permian resulting in quartz vein formation that may have been related to metamorphism (Arbenz, 2008). Degree of metamorphism increases toward the core of the mountain range with a maximum of 15 micrometer grain size in the core area to the north and 9-6 micrometers for the Zigzag Mountains (Stone, per. comm., 2011). Local stresses also control metamorphic effects.

The Cretaceous igneous rocks (Ki) consist of nepheline syenite and related rock types. They are located at Magnet Cove, Potash Sulphur Springs and the V-Intrusive near Lake Catherine. There are numerous dikes and sills throughout the project area that are primarily composed of either alkalic or lamprophyric rock types. Lamprophyric dikes were intruded initially, around the beginning of the

Cretaceous and have a wide geographic extent. The alkalic igneous plutons and related dikes were intruded later. The igneous rocks at Potash Sulphur Springs were emplaced 101 mybp and those at Magnet Cove between 100-89 mybp. All intrusions ended approximately 80 mybp (Howard, per. comm. 2011). Contact metamorphism associated with the plutonic rocks at Magnet Cove and Potash Sulphur Springs has altered the surrounding sedimentary rocks primarily to hornfels and metaquartzite. This metamorphism extends to a distance of 2500 feet (762 m) and 2200 feet (670.5 m) respectively.

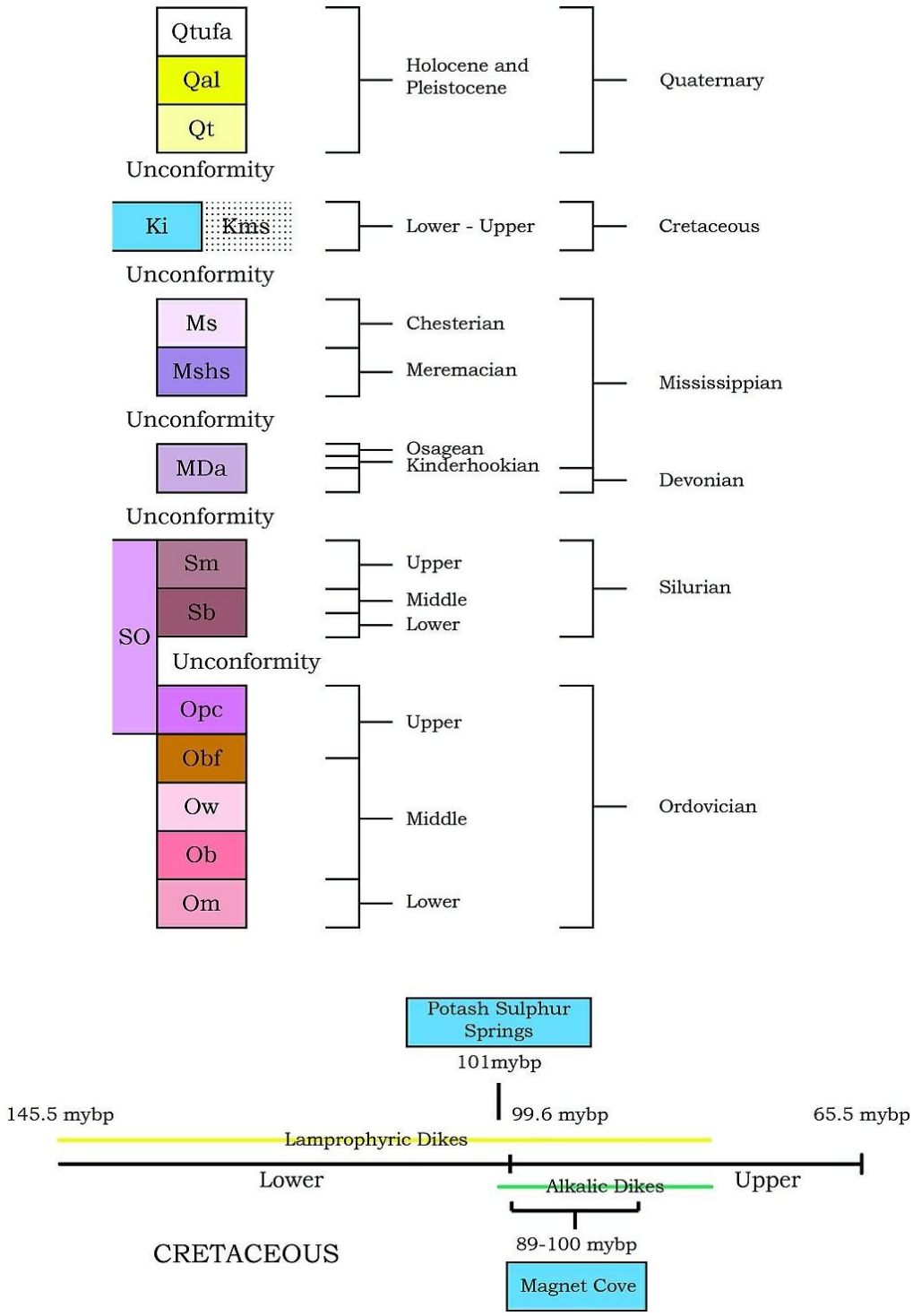
The Ouachita Orogeny occurred from the Mississippian to Early Permian. Thickening of the orogenic units occurred due to accelerated subsidence, as evidenced by flysh deposits in the Stanley Shale. Folding of the sedimentary units progressed until shortening resulted in over-thrusting. The Saline Basin, Zigzag Mountains and Crystal Mountains are part of the Central Uplifts. As uplifting occurred in the Central Uplifts during the last major tectonic event, the ductile middle Paleozoic rocks underwent simple shear as overlying younger and more competent strata resisted further northward movement. South vergent overturned folds and faults and some back thrusting from the north resulted in the Zigzag Mountains, the southern limb of the Central Uplifts. In contrast to this structure, the Trap Mountains and the Mazarn Basin folds and faults maintained their original north vergence (Arbenz, 2008). The narrow transition zone of overturning from the north to the south between the Zigzag Mountains and the Mazarn Basin suggest that the south vergence was produced during the uplift of the Central Uplifts (Arbenz, 2008). Thrust faults are disharmonic and exhibit varying amounts of displacement (Misch/Oles, 1956). They are commonly present along fold axes and are generally thrust from the south. Inclination of bedding and the number of joint sets increase near faults. A major sole thrust between older Ordovician sandstone and shale and younger Ordovician to Devonian chert and shale crops out in the northern part of the mapping area exposing a lower thrust sheet of more intensely deformed core-type strata. Folding in the Zigzag Mountains consists of northeast-southwest trending asymmetrical, overturned and cylindrical folds plunging to the southwest. The Trap Mountain folds are very tight, east-west trending and north vergent, and plunge east or west. Folding in the pre-orogenic strata is polyharmonic (Viele, 1995). Competent novaculite and sandstone form the framework of large folds and are more harmonic. Less competent shale and thin-bedded chert form tightly folded, disharmonic folds especially near faults and in the axes of larger folds. Faulting also responds to the rigidity of the rock units. Stresses were more focused in areas of thick, competent rock, resulting in more faults and tighter folds.

The Zigzag Mountains are accentuated by the erosionally resistant nature of the Arkansas Novaculite and the Hot Springs Sandstone while the Trap Mountains are accentuated by the Arkansas Novaculite. Erosion of the relatively thick sequences of shale between these harder rocks resulted in sharp, hogback ridge lines. Forty to fifty thousand feet (12,192-15,240 m) of rock has eroded from the Ouachita Mountains. Thick sequences of shale allowed extensive erosion. Erosion during orogenic rise through the present time is displayed by relatively young formations in structural lows. Calculated cooling and erosion rates of Cretaceous igneous intrusions suggest 1+/-0.5 km of material has been eroded since the time of emplacement (Howard, 1974).

The recharge area for the hot springs is likely north and northeast of their present location. In that area the Bigfork Chert, Arkansas Novaculite and the Hot Springs Sandstone Member of the Stanley Formation are present at the surface. Intense fracturing of these units has provided necessary secondary porosity, and Indian Mountain and other areas to the north have sufficient elevation to provide the hydraulic head needed to drive the hydrothermal system. The flow paths of the water coalesce on faults, fractures and bedding planes along southwestward plunging structures to a depth at which it becomes heated by the geothermal gradient. The heated water is less dense and rises to the surface.

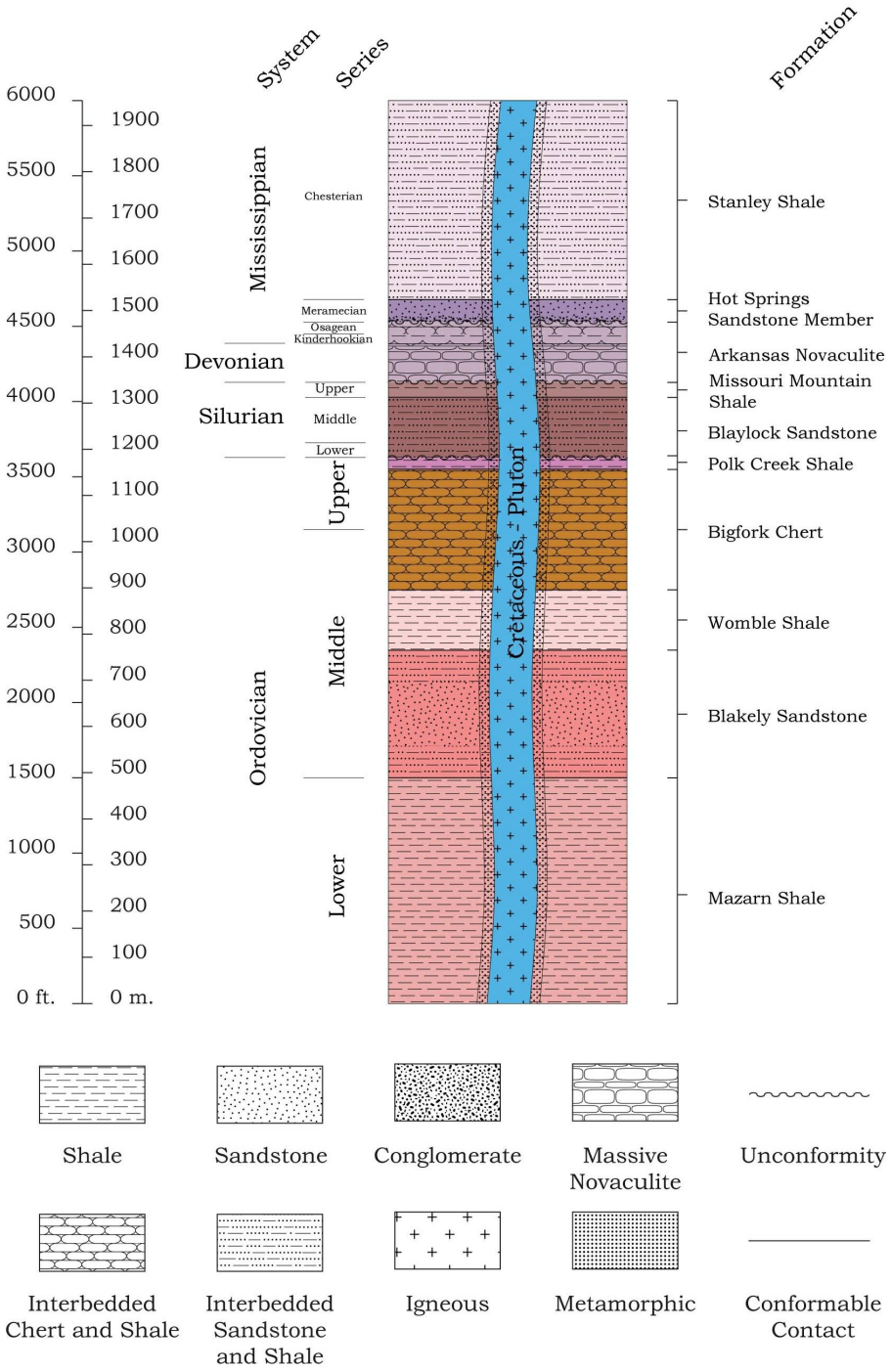
Extracted from: (Arkansas Geological Survey DGM-HSR-003)

Correlation Chart



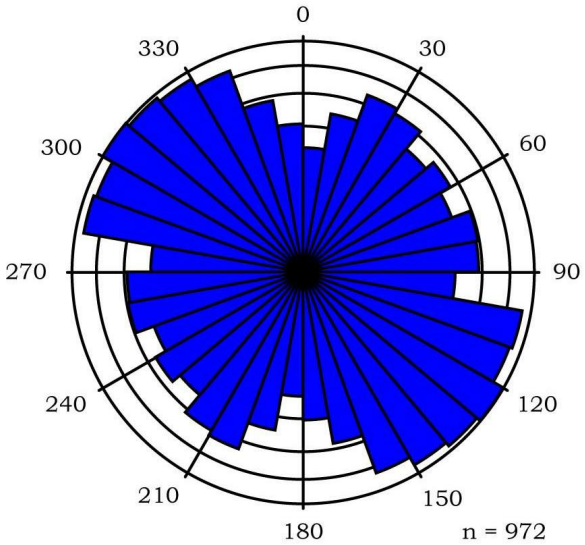
Extracted from: (Arkansas Geological Survey DGM-HSR-003)

Stratigraphic Column

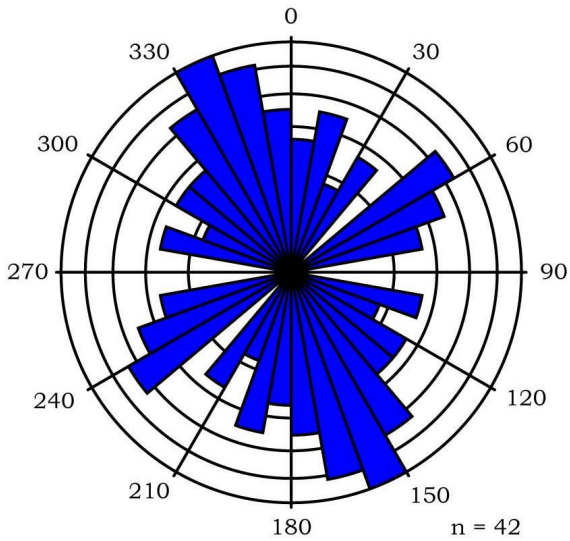


Extracted from: (Arkansas Geological Survey DGM-HSR-003)

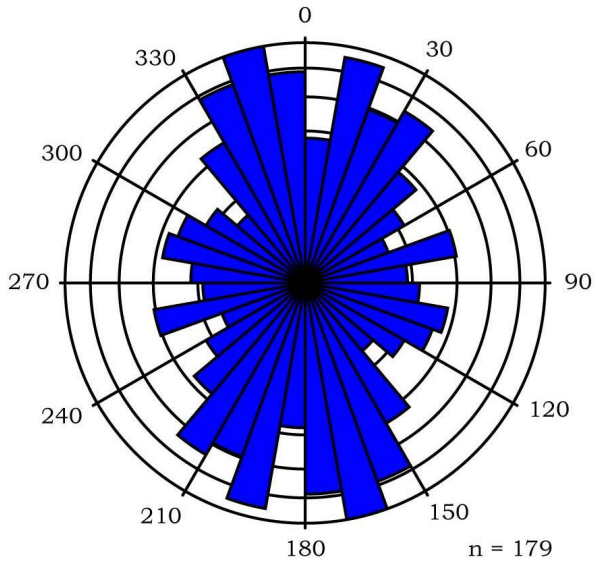
Joint Frequency



Rose diagram of strike frequency of joints recorded within the Hot Springs Area, Zigzag Mountains.



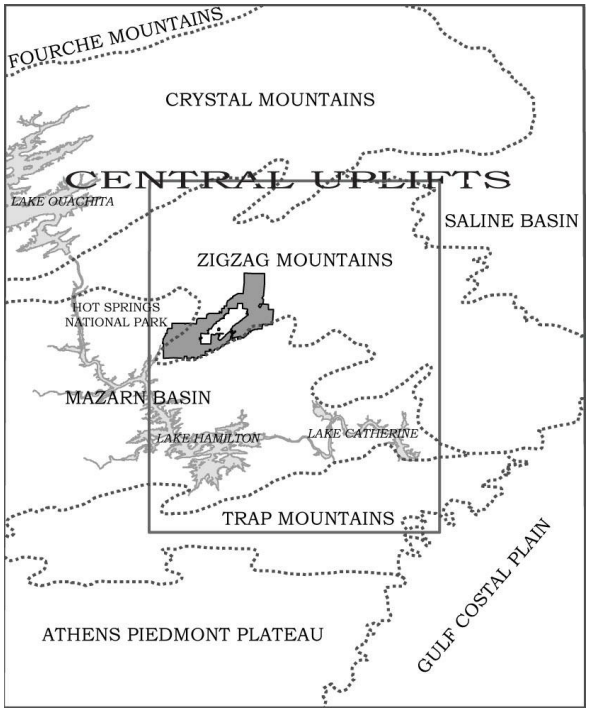
Rose diagram of strike frequency of joints recorded within the Hot Springs Area, Mazarn Basin.



Rose diagram of strike frequency of joints recorded within the Hot Springs Area, Trap Mountains.

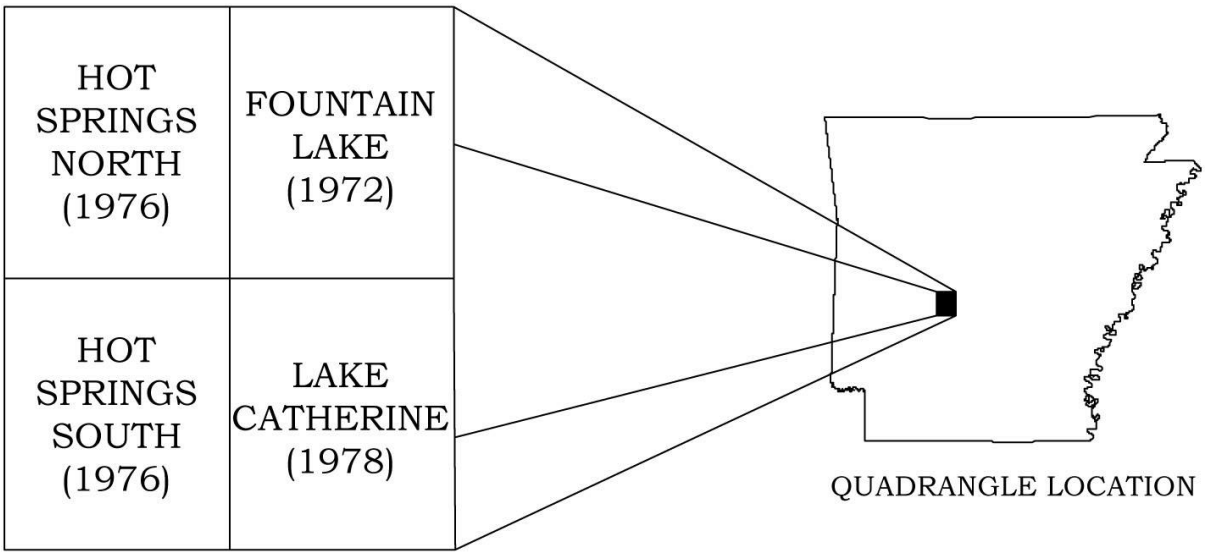
Extracted from: (Arkansas Geological Survey DGM-HSR-003)

Location Map



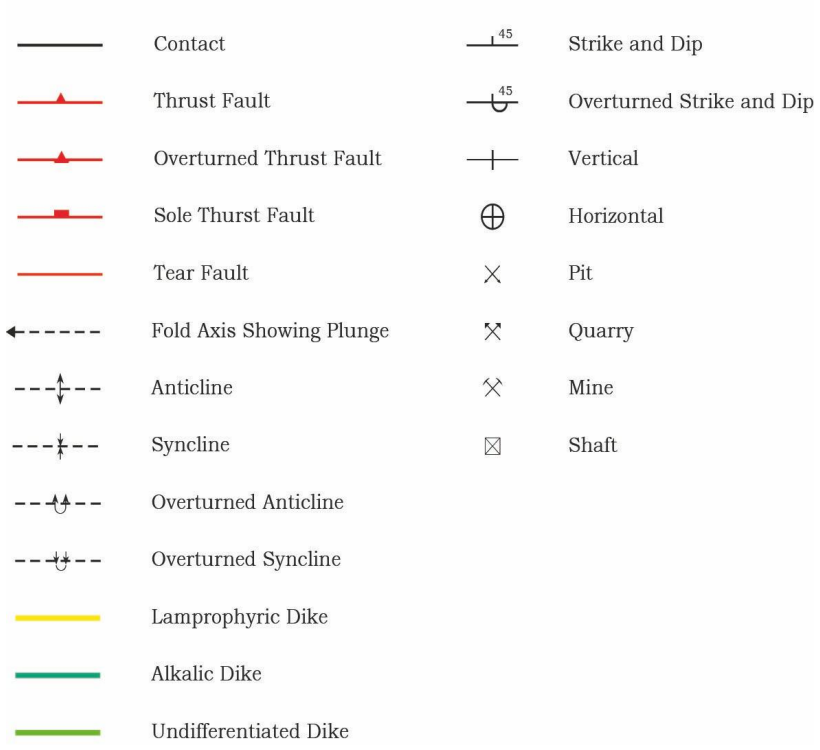
Extracted from: (Arkansas Geological Survey DGM-HSR-003)

Quadrangle Index Map



Extracted from: (Arkansas Geological Survey DGM-HSR-003)

Legend



Extracted from: (Arkansas Geological Survey DGM-HSR-003)

References

Arndt, R.H., and Stroud, R.B., 1953, Thrust faulting near the Hot Springs, Hot Springs National Park, Arkansas – A Special Report,Institute of Science and Technology, University of Arkansas, Fayetteville, Arkansas, 29p., 4 plates.

Arbenz, J.K., 2008, Structural Framework of the Ouachita Mountains, in Stratigraphic and structural evolution of the Ouachita Mountains and Arkoma Basin, southeastern Oklahoma and west-central Arkansas: Application to petroleum exploration: 2004 Field Symposium, Suneson, N.H., editor, Oklahoma Geological Survey Circular 112 A, p.4-40, 9 plates, CD-Rom.

Danilchik, W., and Haley, B.R., 1964, Geology of the Paleozoic area in the Malvern Quadrangle, Garland and Hot Springs Counties Arkansas, U.S. Geological Survey Miscellaneous Geologic Investigations, Map I-405, scale 1:48,000.

Erickson, R.L., and Blade, L.V., 1963, Geochemistry and Petrology of the alkalic igneous complex at Magnet Cove, Arkansas: US Geological Survey Professional Paper 425, 99p.

Godo, T.J., 1982, Unpublished Drilling Report; Shell Oil Company, Cross Section Trap Mountain Anticlinorium; control well: International Paper No. 1; seismic lines: 82-506-2307 and 84-506-2342.

Holbrook, D.F., and Stone, C.G., 1978, Arkansas Novaculite - A silica resource, Thirteenth Annual Forum on the Geology of Industrial Minerals, Oklahoma Geological Survey Circular 79, 8p.

Howard, J.M., 1974, Transition element geochemistry and petrography of the Potash Sulfur[sic] Springs intrusive complex, Garland County, Arkansas, University of Arkansas, Fayetteville, Arkansas, unpublished Masters of Science Thesis, 118p., 1 plate.

Jackson, K.C., 1977, Analcite as a Temperature indicator of Arkansas Ouachita Deformation in Symposium on the Geology of the Ouachita Mountains - vol. II, Economic geology, Mineralogy, and Miscellaneous, C.G. Stone, ed., Arkansas Geological Commission, Little Rock, pp. 63-64.

Misch, P., and Oles, K.F., 1956, Stratigraphic and structural studies in the Ouachita Mountains, Oklahoma and Arkansas, in Stratigraphic and structural evolution of the Ouachita Mountains and Arkoma Basin, southeastern Oklahoma and west-central Arkansas: Application to petroleum exploration: 2004 Field Symposium, Suneson, N.H., editor, Oklahoma Geological Survey Circular 112 A, p.4-40, 9 plates, CD-Rom.

McFarland, J.D. III, 2004, 2004, Stratigraphic Summary of Arkansas: Arkansas Geological Survey, Little Rock, Arkansas, 38 p.

Owens, D.R., Bedrock geology of the “V” intrusive, Garland County, Arkansas, University of Arkansas, Fayetteville, Arkansas, unpublished Masters of Science Thesis, 96p., 2 plates.

Purdue, A.H., and Miser, H.D., 1923, Geologic Atlas of the United States Hot Springs Folio Arkansas, U.S. Geological Survey Hot Springs Folio 215, 12p.,5pl., U.S. Geological Survey, Washington D.C.

Stone C.G., and Haley, B.R., 1972, Geologic map of the Hot Springs North, Hot Springs South, Fountain Lake, Lake Catherine quadrangles, Arkansas Geological Survey, unpublished geologic worksheet, scale 1:24000.

Viele, G.W., 1995, Origin of Disharmonic Folding, Central Ouachita Mountains Oklahoma, in Structural Styles of the Southern Midcontinent: 1992 Symposium, Johnson, K.S., editor, Oklahoma Geological Survey Circular 97, p. 16-25.

Extracted from: (Arkansas Geological Survey DGM-HSR-003)

Acknowledgements and Disclaimer

Acknowledgments: This project is part of a contract between the National Park Service (Contract No. C2360086145) and the Arkansas Geological Survey (AGS). We would like to thank AGS Director and State Geologist Bekki White, the AGS staff, the National Park Service, Hot Springs National Park personnel and the many individuals and businesses who granted us access to their property. Special thanks to C. G. Stone, who previously mapped the area with the late Boyd R. Haley, for his insight and support.

Disclaimer: This map was prepared in a digital format using ArcGIS ArcView 9.10 software on computers at the AGS. The AGS does not guarantee the accuracy of this map especially when used on any other system or with any other software. As mapping continues and is refined, the data presented on this map may be updated. For the latest edition of the and other AGS maps and publications please call Publication Sales at 501-296-1877. Map and cross section digitized by Ty C. Johnson

Extracted from: (Arkansas Geological Survey DGM-HSR-003)

GRI Digital Data Credits

This document was developed and completed by Jack Garner (National Park Service) with assistance from Heather Stanton (Colorado State University) and quality control by Jim Chappell (Colorado State University) for the NPS Geologic Resources Division (GRD) Geologic Resources Inventory(GRI) Program.

The information contained here was compiled to accompany the digital geologic-GIS map(s) and other digital data for Hot Springs National Park, Arkansas (HOSP) developed by Jack Garner (National Park Service). Format migration and Google Earth product by Stephanie O'Meara (Colorado State University)

GRI finalization by Heather Stanton and Stephanie O'Meara (Colorado State University).

GRI program coordination and scoping provided by Bruce Heise and Tim Connors (NPS GRD, Lakewood, Colorado).