Geologic Resource Evaluation Scoping Summary
Canyon de Chelly National Monument, Arizona

Geologic Resources Division
National Park Service
US Department of the Interior

Prepared by Katie KellerLynn
June 2007

Administered by the NPS Geologic Resources Division (GRD), the Geologic Resource Evaluation (GRE) Program provides each of 270 identified natural-area units in the National Park System with a geologic scoping meeting, a digital geologic map, and a geologic resource evaluation report. The purpose of scoping is to identify geologic mapping coverage and needs, distinctive geologic processes and features, resource management issues, and potential monitoring and research needs. Outcomes of this scoping process are a scoping summary (this report), a digital geologic map, and a geologic resource evaluation report. Participants at geologic scoping meetings evaluate the adequacy of existing geologic maps for resource management, discuss park-specific geologic management issues, and if possible tour the site with park staff and geologists knowledgeable about the park's geologic resources.

The National Park Service held a GRE scoping meeting for Canyon de Chelly National Monument on February 15–16, 2007. Participants at the meeting included NPS staff from the national monument and the Geologic Resources Division, and cooperators from the U.S. Geological Survey, Arizona State University, Colorado State University, and Northern Arizona University (table 1). Participants spent the first day touring portions of the national monument with field-trip leaders from Northern Arizona University. Stops included Spider Rock Overlook, the rim of Bat Canyon, Sliding House Overlook, White House Ruin, the mouth of Canyon del Muerto (near Tsaile Dam), Mummy Cave Overlook, and Antelope House Overlook. During the second day, Tim Connors (GRD) facilitated the evaluation of map coverage, and Lisa Norby (GRD) led the discussion regarding geologic processes and features. Ron Blakey (Northern Arizona University) presented the overall geologic history of the monument, and Steve Semken (Arizona State University) highlighted the Tertiary volcanic features in the area.

This scoping summary highlights the GRE scoping meeting for Canyon de Chelly National Monument, including the geologic setting, the plan for providing a digital geologic map, a list of geologic resource management issues, descriptions of significant geologic features and processes, and a record of meeting participants and other cooperators.

Park and Geologic Setting

Reflecting one of the longest continuously inhabited landscapes in North America, the cultural resources of Canyon de Chelly National Monument are remarkably preserved. A dry climate, sheltering cliffs, and the watchful eyes of local residents have protected the distinctive architecture, artifacts, and rock imagery (Thybony, 1997). In this summary, the term "Anasazi" is used rather than "ancestral Puebloans" for the people who inhabited the canyons before Navajo occupation. This usage reflects a Navajo perspective that was presented during the scoping session. The term "Anasazi" has many meanings such as "foreigner" and "enemy;" here the term is used to mean "my relatives," which is acceptable to many traditional Navajo people (Margaret Hiza, e-mail communication, June 1, 2007). Lands within the monument's boundaries are designated as Navajo Tribal Trust land, and the Navajo Nation controls the land and minerals within the monument. The 1931 enabling legislation of the national monument assigned primary responsibility for the management of cultural resources, other features of scientific and historic interest, park administration, and visitor services to the National Park Service.

Canyon de Chelly National Monument hosts two main canyons: Canyon del Muerto with its tributary Black Rock Canyon, and Canyon de Chelly from which Monument Canyon and Bat Canyon extend. As shown on

the park guide/map, Canyon de Chelly is home to Chinle Wash. Canyon del Muerto joins Canyon de Chelly from the north. At the junction of these two canyons is Junction Ruin, which visitors observe from Junction Overlook. Canyon de Chelly runs for about 26 miles (42 km), and Canyon del Muerto about 18 miles (29 km). These canyons extend eastward into an uplifted area called the Defiance Plateau; the Chuska Mountains mark the western portion of this plateau.

During the field trip, scoping participants had the opportunity to view the three rock formations exposed in Canyon de Chelly National Monument, which from oldest to youngest are sandstones of the Supai Group (referred to as "Supai sandstone" in this summary), De Chelly Sandstone (*Note*: The USGS lexicon at http://ngmdb.usgs.gov/Geolex/NewUnits/unit_7852.html lists "De Chelly Sandstone" as the spelling, which will be used throughout this document.), and the Shinarump Member of the Chinle Formation (referred to as "Shinarump conglomerate" in this summary). Of these, the De Chelly Sandstone is the most prominent and is the material of many geologic features (e.g., rock monoliths, cliffs, and cross-bedding). Fluvial and mass wasting processes are active within the canyons. In February 2007, participants experienced these processes during their 4-wheel-drive excursion to White House Ruin at the bottom of Canyon de Chelly.

At the first field-trip stop, Spider Rock Overlook, participants viewed the oldest rocks in the park, which lie at the base of Spider Rock. The reddish brown, fine-grained sedimentary rocks immediately beneath the massive cliff-forming sandstone of Spider Rock are Supai sandstone. This name is taken from similar rocks in the Grand Canyon. These sloping rocks at the base of Spider Rock were deposited as a sabkha during the Permian Period (~280 million years ago). Sabkhas form under arid or semiarid conditions just above normal high-tide level on coastal plains. They are "wet places" situated among sand dunes. Upon evaporation, evaporite deposits (salts) were left behind.

Spider Rock is the only place in Canyon de Chelly where the entire De Chelly Formation is exposed from top to bottom (825 feet [251 m]) (Baars, 1998). The obvious, large cross-bedding of the De Chelly Sandstone is a result of windblown deposition of sand. During the Permian Period, the De Chelly Sandstone was part of a vast desert. Individual sets of cross-beds represent bedding surfaces on the sheltered, lee slopes of sand dunes and suggest the size of the original sand dunes. As noted during the field trip, water flows along the intersections of these cross-beds, dissolving the calcium-carbonate cement that holds the sand grains together, and creating the alcoves that the Anasazi used (see "Caves" section). In the walls of Canyon de Chelly, cross-bedded sets vary between 10 and 50 feet (3 and 15 m) in height, indicating that these were large, mature sand dunes (Baars, 1998). During the field trip, participants could clearly see the cross-beds in the canyon walls while overlooking Bat Canyon and from the floor of Canyon de Chelly. As described by Stokes (1968), many extensive, smooth parallel surfaces suggest water action in the dunes. Eolian processes removed the sand down to the water table, thus creating the horizontal surfaces, which now separate intervals of cross-bedded sandstone. The height of cross-beds is controlled by the level of the water table. A decrease in sand supply or a change in wind direction stripped the sand to the level of the groundwater table, with eroded sand being deposited downwind. More recent scientific thinking has revised the Stokes model, making connections to sea-level rise (e.g., Blakey, 1996; Kocurek et al., 2001).

Deposited during the Triassic Period, the youngest bedrock exposed in Canyon de Chelly National Monument is the Shinarump Member of the Chinle Formation. The dark brown Shinarump conglomerate rests directly atop the De Chelly Sandstone, forming a hard cap rock. Participants spent a lot of time on the Shinarump conglomerate, as most roads and overlooks in the national monument are built upon it. Shinarump sand and gravel were deposited by streams; the scoured contact between the De Chelly Sandstone and Shinarump conglomerate is an erosional surface, or unconformity (Baars, 1998). At the time of deposition, the Continental Divide was in the Appalachian Mountains, which extended across Texas. Rivers flowed westward from the Continental Divide and deposited the Shinarump sediments.

Four significant geologic events influenced Canyon de Chelly. First, the Defiance Uplift, of which the Defiance Plateau is the modern expression, is related to the Ancestral Rocky Mountains of Colorado and neighboring areas, which dominated the landscape during the Pennsylvanian Period. The Defiance Uplift is an elongated region that extends more than 100 miles (161 km) from the Four Corners area to Interstate 40, just inside the Arizona border. The Ancestral Rocky Mountains resulted from plate collusion associated with the assembly of the supercontinent Pangaea. This uplift reexposed Precambrian rocks (i.e., schist, gneiss, and granite), though not much sediment was shed into the surrounding basins from the uplifted area. At lower elevations, however, the Supai sandstone was deposited as a sabkha between an erg (sand sea) and an inland sea. The Defiance Uplift served as an effective deterrent to marine circulation in adjacent basins: the San Juan Basin to the east and the Black Mesa Basin to the west.

Second, at the end of the Cretaceous Period and into the Cenozoic Era (80–50 million years ago), the Laramide Orogeny caused regional uplift of the Colorado Plateau and Rocky Mountains, and local westward tilting of the Canyon de Chelly area. Compression during the Laramide Orogeny reactivated the Defiance Uplift—the second episode of uplift and tilting.

Third, 35–20 million years ago, the Defiance Uplift and surrounding area was the site of numerous volcanic eruptions. The eruptions were highly explosive, producing dikes, volcanic necks, and flows. For example, nearby Shiprock is a diatreme, and represents the "plumbing" or neck of a volcano. This volcanic neck was deeply buried below the surface at the time of eruption. Clustered in Monument Valley and scattered throughout the area, volcanic features include Black Rock Mesa at the head of Canyon de Chelly.

Fourth, downcutting of the sediments exposed the De Chelly Sandstone and created the canyons of the monument. The timing of incision is uncertain, but it certainly predates the cutting of the Grand Canyon, interpreted as occurring ~5 million years ago. During the field trip, Ron Blakey and Paul Umhoefer surmised that canyon carving could have commenced as much as 10 million years ago. Dating of volcanic deposits may help constrain the timing of canyon cutting (Steve Semken, Arizona State University, scoping presentation, February 16, 2007). In addition to these four "significant" geologic events, geomorphic changes related to wetter conditions during the Pleistocene ice age include the deposition of terraces and arroyo cutting. Also, human activities have exacerbated present geologic processes, in particular incision.

Geologic Mapping Plan for Canyon de Chelly National Monument

During the scoping meeting, Tim Connors (GRD) showed some of the main features of the GRE Program's digital geologic maps, which reproduce all aspects of paper maps, including notes, legend, and cross sections, with the added benefit of being GIS compatible. The NPS GRE Geology–GIS Geodatabase Data Model incorporates the standards of digital map creation set for the GRE Program. Staff members digitize maps or convert digital data to the GRE digital geologic map model using ESRI ArcGIS software. Final digital geologic map products include data in geodatabase, shapefile, and coverage format, layer files, FGDC-compliant metadata, and a Windows HelpFile that captures ancillary map data. Completed digital maps are available from the NPS Data Store at http://science.nature.nps.gov/nrdata/.

Canyon de Chelly National Monument (CACH) is situated on twelve 7.5-minute quadrangles: Tsaile, Red Cornfield Mesa, Lower Wheatfields, Mummy Cave Ruins, Del Muerto, Chinle, White Clay, Spider Rock, Three Turkey Canyon, Little White House Ruins, Sawmill, and White Rock Wash. An additional six quadrangles are of interest to CACH staff because they lie within the same watershed as the monument; park staff would like the geologic information to better manage their resources. The six quadrangles are Lukachukai, Tsaile Butte, Upper Wheatfields, Crystal, Sonsela Buttes, and Buell Park. Bedrock and surficial geologic data have been published for all of these quadrangles at 1:125,000 scale for bedrock and 1:500,000 scale or surficial geology. Participants agreed at the scoping meeting that the Cooley 1:125,000-scale map is sufficient for general geology. However, the Cooley map should not be considered reliable for quadrangle

(1:24,000) scale or a more detailed depiction of geology (Paul Umhoefer and Lisa Skinner, written communication, May 9, 2007). None of the selected maps is known to exist in a digital-GIS format, so GRE staff will digitize the source maps and create a geodatabase from them. GRE staff has assigned each map with a unique "GMAP ID" used for data management purposes. These numbers appear in table 2 and with the map citations listed in this summary.

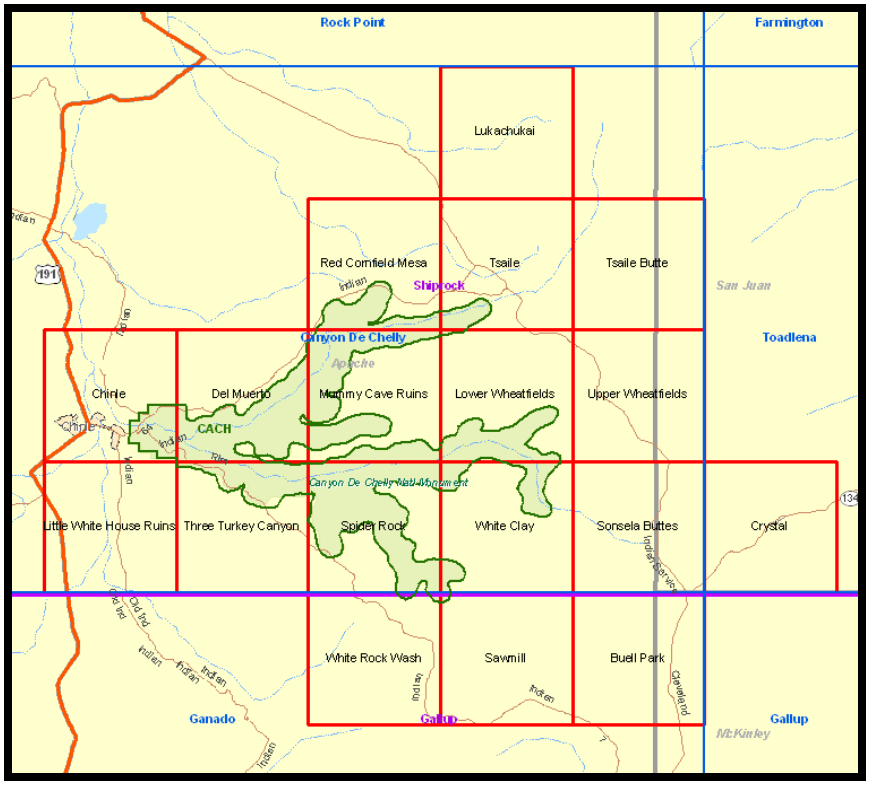

Figure 1. Maps of Interest for Canyon de Chelly National Monument. The figure shows USGS 7.5' quadrangles (red outline, black labels), 30' × 60' sheets (blue outline and labels), and 1° × 2° sheets (purple outline and labels). The green outline represents the boundary of Canyon de Chelly National Monument.

To provide digital geology for the eighteen 7.5' quadrangles (see fig. 1), GRE staff will use the following sources (see figs. 2 and 3):

Bedrock Data

(74602) Cooley, M.E., Harshbarger, J.W., Akers, J.P., Hardt, W.F., and Hicks, O.N., 1969, Geologic map of the Navajo and Hopi Indian reservations, Arizona, New Mexico, and Utah (sheet 5 of plate 1), *in* Regional hydrogeology of the Navajo and Hopi Indian reservations, Arizona, New Mexico, and Utah: U.S. Geological Survey Professional Paper 521-A, 5 plates, scale 1:125,000.

(74603) Cooley, M.E., Harshbarger, J.W., Akers, J.P., Hardt, W.F., and Hicks, O.N., 1969, Geologic map of the Navajo and Hopi Indian reservations, Arizona, New Mexico, and Utah (sheet 6 of plate 1), *in* Regional hydrogeology of the Navajo and Hopi Indian reservations, Arizona, New Mexico, and Utah: U.S. Geological Survey Professional Paper 521-A, 5 plates, scale 1:125,000.

Surficial Data

(74606) Cooley, M.E., Harshbarger, J.W., Akers, J.P., Hardt, W.F., and Hicks, O.N., 1969, Map showing surficial deposits, volcanic provinces, internally drained areas, streamflow data, and occurrence of water in

the alluvium in the Navajo and Hopi Indian reservations, Arizona, New Mexico, and Utah (plate 2), *in* Regional hydrogeology of the Navajo and Hopi Indian reservations, Arizona, New Mexico, and Utah with a section on vegetation: U.S. Geological Survey Professional Paper 521-A, 5 plates, scale 1:500,000.

Dedicated larger-scale coverage will supercede U.S. Geological Survey Professional Paper 521-A for the following 7.5' maps:

(1093) Thaden, R.E., 1990, Geologic map of the Buell Park quadrangle, Apache County, Arizona, and McKinley County, New Mexico: U.S. Geological Survey Geologic Quadrangle GQ-1649, scale 1:24,000.

(1095) Byers, V.P., 1980, Geologic map and sections of the Sonsela Butte 4 SE quadrangle, Apache County, Arizona, and San Juan and McKinley counties, New Mexico: U.S. Geological Survey Open-File Report OF-80-788, scale 1:24,000.

(15897) Byers, V.P., 1979, Geologic map and sections of the Crystal quadrangle, San Juan and McKinley counties, New Mexico: U.S. Geological Survey Open-File Report OF-79-599, scale 1:24,000.

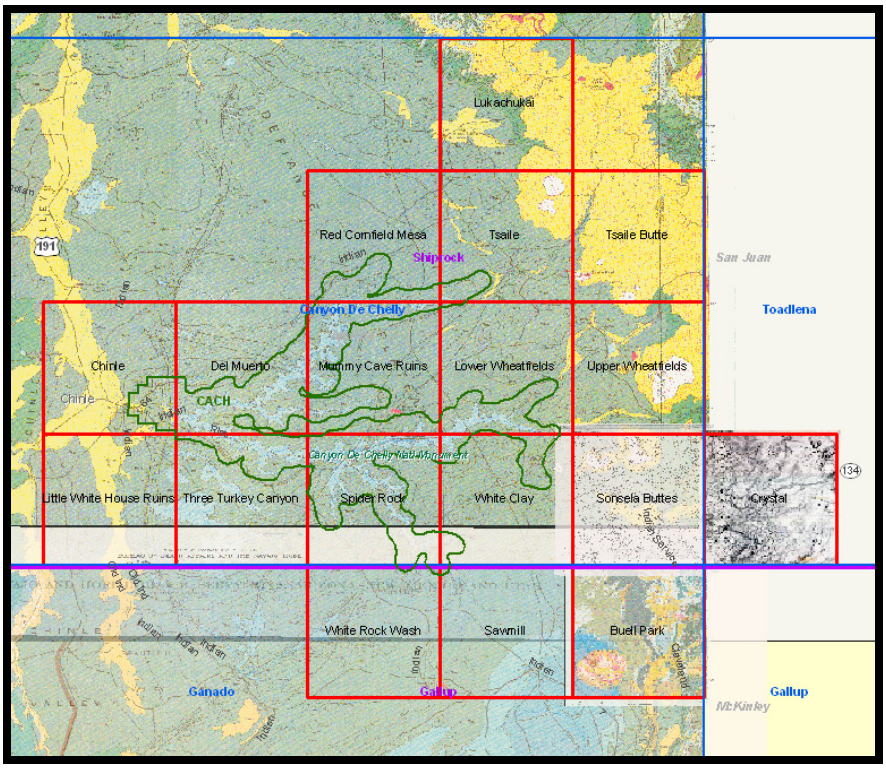

Figure 2. Footprint of Existing Geologic Maps for Canyon de Chelly Area of Interest. The figure shows USGS 7.5' quadrangles (red outline, black labels), 30' × 60' sheets (blue outline and labels), and 1° × 2° sheets (purple outline and labels). The green outline represents the boundary of Canyon de Chelly National Monument.

During scoping, investigators from Northern Arizona University (NAU) discussed creating a geomorphic map of the bottom of the canyon area that would show significant recent geomorphic features. GRE staff has received the NAU proposal (Lisa Norby, GRD, written communication, April 13, 2007). If the mapping project moves forward, Paul Umhoefer would be the principal investigator for the proposal. Units would be mapped at 1:12,000 scale and include fluvial terraces, landslide deposits, talus cones, sand dunes, alluvial fans, and stream deposits in the canyon. The contact between the Triassic Shinarump conglomerate and the Permian De Chelly Sandstone could also be mapped. Participants discussed the possibility of convening a meeting of cooperators interested in creating a new surficial geologic map, including GRE staff, NPS Soils

Program (i.e., Pete Biggam), NAU geologists, NPS Water Resources Division (e.g., Joel Wagner), U.S. Geological Survey (i.e., Kathryn Thomas who is conducting vegetation mapping), and other academics (e.g., Ellen Wohl and David Cooper, Colorado State University). University of Arizona, Office of Arid Lands Studies, in conjunction with Diné College may have conducted some additional vegetation mapping using USDA funding. Stuart Marsh (Director, Professor, and Chair Arid Lands Resource Sciences) is the contact for the project (smarsh@ag.arizona.edu, 520-621-8586) (Margaret Hiza Redsteer, e-mail communication, June 1, 2007).

Participants also discussed that once the existing maps were digitally converted to GIS, these data would be compared to existing recent aerial photographs to ensure that geologic features had been captured appropriately given the publication scale (i.e., 1:125,000). The contact for these photos is Karl Brown (NPS–Fort Collins office). Upon completion of the digital geology, GRE staff will work on this task. Discrepancies, if any, will be noted as well as discussion of the quality of the final product for appropriate resource management.

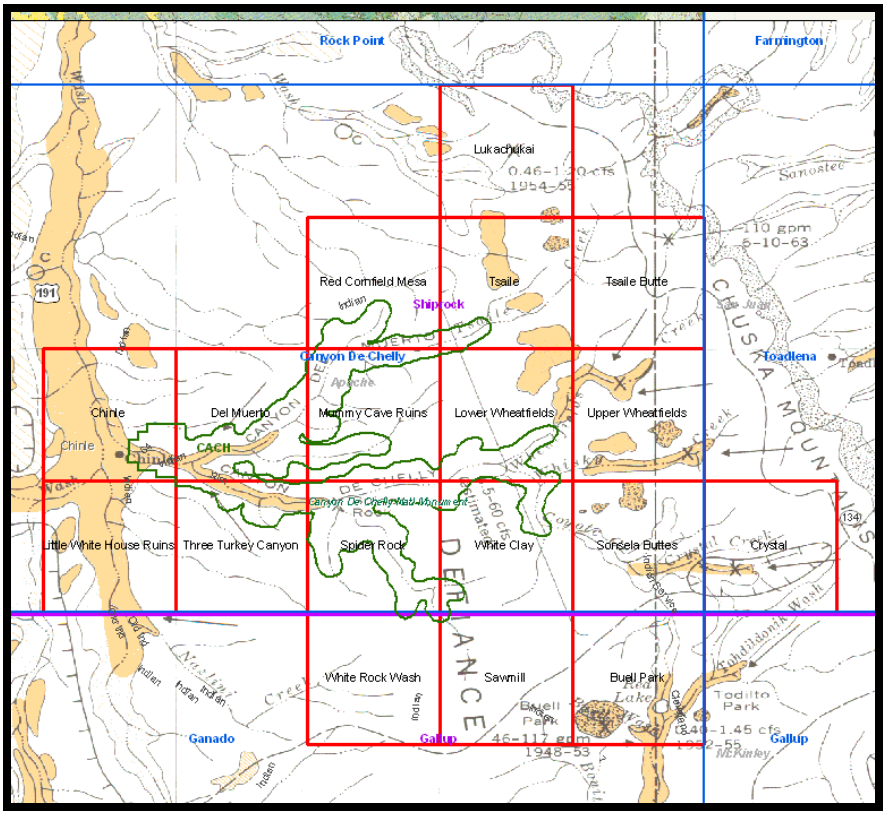

Figure 3. Footprint of Surficial Geology from USGS Professional Paper 521-A (plate 2). The figure shows USGS 7.5' quadrangles (red outline, black labels), 30' × 60' sheets (blue outline and labels), and 1° × 2° sheets (purple outline and labels). The green outline represents the boundary of Canyon de Chelly National Monument.

Geologic Resource Management Issues

The scoping session for Canyon de Chelly National Monument provided the opportunity to develop a list of issues that may be of concern to park managers, as well as a list of geologic features and processes occurring at the monument. These issues, features, and process will be further explained in the final GRE report. During the meeting, participants selected the "top three" issues with respect to resource management: (1) fluvial features and processes, (2) hillslope features and processes, and (3) disturbed lands. The highest priority research need is an inventory of paleontological resources in the monument. The top-priority issues are listed

first, followed by a section about paleontological resources; the other issues, features, and processes are listed in alphabetical order afterwards.

Fluvial Features and Processes

Under natural conditions, Chinle Wash would be a braided stream; however, anthropogenic perturbations have altered the natural system to one of arroyo cutting. Pronounced incision in the canyon has occurred in recent history (<100 years). Recent alluvial processes at work in Canyon de Chelly are significant and not relics of the Pleistocene. As anecdotal evidence, fences on the sides of the canyon walls are hanging in midair only 20–30 years after they were constructed (Margaret Hiza Redsteer, USGS, e-mail communication, June 1, 2007). This may be attributable to a climatic signal, but it would be useful to look at the age of Quaternary deposits and conduct repeat photography to be certain that the incision is part of a regional trend, rather than related to local land-use problems. USGS investigators are already conducting these types of studies to test work done by John Hack in the 1940s and Thor Karlstrom in the 1980s in Tsegi Canyon and the Pueblo Colorado wash. The incision history of Canyon de Chelly could be done in conjunction or collaboration with detailed surficial mapping and compared to the results of this other work (Margaret Hiza Redsteer, USGS, e-mail communication, June 1, 2007).

During the past 70 years, significant human-caused disturbances have become part of the canyons' landscape; for instance, dams, roads, diversions, encroachments, riprap, channel stabilization structures, and the introduction of nonnative species have altered the stream geomorphology (Pranger, 2005). Until recently, almost all natural resource issues within the national monument were left up to management of the Navajo Nation. However, aggressive infestation by tamarisk (*Tamarix ramosissima*, *T. chinensis*, and their hybrids) and Russian olive (*Elaeaganus angustifolia*) in combination with intensive historic grazing (see "Disturbed Lands" section) and tour operations within the riparian corridors of the canyon floor have created the need for an integrated and collaborative approach to managing both natural and cultural resources within the canyons and their associated watersheds (National Park Service, 2004).

In natural systems, changes take place in channels during high-stream flows, and the relationship between channel and floodplain is an important factor in channel stability. Stable channels generally have the ability to carry water and sediment while maintaining their dimension, pattern, and profile. This is not the case with most of the channels within Canyon de Chelly and Canyon del Muerto, which are unstable and prone to rapid vertical and lateral channel adjustments. As such, erosion has been a major problem along the canyon floor in the monument. Rapid heavy flows of water from the canyon rims and from areas upstream of the monument, continual shifting of the water courses within the canyons, and severe downcutting and bank erosion contribute to overall instability of the channels.

Although natural processes influence erosion and shifts in streamflow within the canyons, human perturbations are the primary cause and include the following: (1) past and present grazing of horses, sheep, goats, and cattle (see "Disturbed Lands" section); (2) invasion of nonnative plant species, which have shaded out understory plants that bind the soil and help to stabilize stream banks; (3) roads in the canyons; and (4) the construction of the Tsaile and Wheatfields dams upstream of the monument, which altered peak flows in the canyons, enabled vegetation to confine channels, and may have increased the erosive potential of the flow (Natural Resources Conservation Service, 2000).

Invasive plant infestations have seriously altered stream processes, creating unnatural rates of channel incision and erosion, and consequently reducing the land area available for traditional farming. These changes, and the accompanying reduction of natural biological diversity, have dramatically altered the appearance of the landscape. Currently, extensive erosion and the establishment of excessive woody fuels and increased fire hazards seriously threaten valuable and irreplaceable archaeological resources (e.g., rock art). As part of a three-year study, researchers from Colorado State University are investigating how the channel

responds to removal of exotic species. The primary contacts for this project are Ellen Wohl (ellen.wohl@colostate.edu, 970-491-5298) and David Cooper (david.cooper@colostate.edu, 970-491-5430).

Heavy vehicle traffic from tours is unregulated and appears to be one of the causes of extensive localized downcutting over the last 15 years, especially in Canyon del Muerto (National Park Service, 2004). The cumulative impacts of this activity have added to localized stream-bank erosion and soil instability. Based on analysis of alien plant removal, the Geologic Resources Division can provide assistance with developing alternatives for improved crossing designs, roadbed stabilization, and road rehabilitation (National Park Service, 2004).

Tsaile Dam and reservoir were built in 1963 for recreation and irrigation. Both Tsaile and Wheatfields dams are designed to capture early season runoff and provide irrigation water during the later growing season; however, the timing and amount of water release is often not adequate to meet the needs of canyon farmers. With some input from the Bureau of Reclamation, the Navajo Nation manages both dams. The Tsaile Dam has more variable flows than the Wheatfields Dam. Nevertheless, with the lack of flooding and sediment input, Tsaile Dam has eliminated the natural scouring that regulates vegetation along the channel. The impacts of Wheatfields Dam are much less than Tsaile Dam. Even if the entire flow in Wheatfields Creek, a tributary of Chinle Wash, was diverted into the reservoir, it would account for only about 6% of the entire Canyon de Chelly watershed. As such, this dam has only minor effects on the natural peak flows of Canyon de Chelly (National Park Service, 2004). However, both dams, which are earthen, pose public safety risks, if they were to fail.

In addition to Tsaile and Wheatfield dams, numerous small impoundments (i.e., check dams) exist on the rim and upper drainages of the canyons. Many of these water catchments have been filled with trash. The cumulative hydrologic effect of these impoundments is to reduce peak flows or alter the timing of peak flows to some degree (National Park Service, 2004).

Additionally, stream processes at cut banks are compromising some cultural resources (e.g., Ute Raid area). Stream bank erosion control efforts began in the 1930s and have been successful in some places such as White House Ruins and Antelope House Ruins where gabions were installed. Park staff is making an inventory of these structures (i.e., geo-referenced with GPS) and monitoring them in order to check their effects on accelerated erosion. Park managers, Navajo Nation leaders, and canyon residents want to minimize these impacts because erosion along the stream continues to threaten agricultural fields, burials, and archaeological sites along the floors of Canyon de Chelly, Canyon del Muerto, and their tributary canyons. According to Pranger (2005), if human disturbances are removed from an arroyo system, the channel generally will adjust relatively rapidly to a more naturally functioning condition.

Hillslope Processes

The primary concerns with hillslope processes at Canyon de Chelly National Monument are rockfall hazards and the resulting loss of cultural information such as pictographs (e.g., “Doe Panel” in the Spider Rock area). During the field trip, Keith Lyons (CACH) pointed out some areas of recent rockfall. Large pillars have fallen at Big Cave in Canyon del Muerto, Junction Ruin, and Massacre Cave. Rockfall also is evident near Spider Rock and Standing Rock. Big Cave was the site of a major rockfall event in 2002; minor rockfalls regularly occur throughout the canyon system (Keith Lyons, CACH, written communication, May 8, 2007). Depending on the location, rockfall could be a safety hazard for canyon residents, hikers, and campers. For instance, people often congregate in the shade of the cliffs, and some residents use alcoves for livestock penning. Also, in Canyon Del Muerto, segments of the road follow the contours of overhangs. In these situations, spalling or rockfall can certainly be considered a threat to visitors, residents, and staff (Keith Lyons, CACH, written communication, May 8, 2007).

Disturbed Lands

In addition to the anthropogenic disruption to fluvial processes (see "Fluvial Features and Processes" section), scoping participants identified other human practices that have resulted in disturbed lands at Canyon de Chelly National Monument. Disturbed lands are those park lands where the natural conditions and processes have been directly impacted by development (e.g., facilities, roads, dams, abandoned campgrounds, and user trails), agricultural practices (e.g., farming, grazing, timber harvest, and abandoned irrigation ditches), overuse, or inappropriate use. Usually, lands disturbed by natural phenomena such as landslides, earthquakes, floods, hurricanes, tornadoes, and fires are not considered for restoration unless influenced by human activities. More than 315,000 acres (127,480 ha) in 195 National Park System units have been disturbed by modern human activities. Some of these features may be of historical significance, but most are not in keeping with the mandates of the National Park Service.

Restoration returns the quality and quantity of an area, watershed, or landscape to some previous condition, often some desirable historic baseline. Restoration activities at disturbed areas directly treat the disturbance to accelerate site recovery and aim to permanently resolve the disturbance and its effects. For more information about disturbed lands restoration, contact Dave Steensen (GRD, Restoration Program lead) at dave_steensen@nps.gov or 303-969-2014.

At Canyon de Chelly, disturbances include grazing in the canyon and rim, historic (1940s–1980s) logging on the rim, modern wood collecting on the canyon rim and in the canyons, off-road driving (which has increased 30-fold in the last decade), the creation of an unauthorized road system on the rim, and social trails in the canyon and rim. Social trails and roads are detrimentally impacting biological soil crusts in the monument.

Paleontological Resources

During scoping, park staff identified an inventory of the paleontological resources at the national monument as the highest priority, geologic research need. Lisa Norby (GRD) mentioned the possibility of getting assistance for such an inventory through the GeoScientists-in-the-Parks (GIP) Program (see http://www2.nature.nps.gov/geology/gip/). Of the rocks exposed in the monument, the Chinle (Triassic) is known to be fossiliferous. Keith Lyons (CACH) told participants about plant fossils near the visitor center. Potential fossils from the Chinle Formation include bones, trackways, bioturbation, petrified wood, and other fossil flora. Interestingly, the first Triassic plant fossils to be collected from Arizona were found in the monument in 1849. The fossils include lycopods, cycadophytes, conifers, and several taxa of uncertain classification. The most interesting fossil flora is *Dechellyia*, which combines features that usually occur in separate groups (Ash, 1993). Participants mentioned trackways at Slim Canyon, Chinle Wash, and the Junction area. Currently, the Western Archaeological Conservation Center in Tucson, Arizona, maintains all the paleontological specimens from Canyon de Chelly National Monument.

Caves

Over time, erosion of the De Chelly Sandstone has produced many caves and rock shelters called "alcoves" in the canyon walls. However, the De Chelly Sandstone is not karstic, and no carbonate rocks occur at the surface or in the subsurface of the national monument. Alcoves form at the bounding surfaces of ancient sand dunes; the horizontal surfaces serve as conduits for water. The prolonged flow of water along these surfaces ultimately dissolves the calcium carbonate cement, which holds the sand grains together, and loosens individual sand particles and blocks of sandstone, thus forming a void that enlarges with time.

Scoping participants noted that alcoves typically form at meanders (bends) of the stream, rather than along straight reaches. Alcoves are distinctive archaeologically and culturally because the Anasazi and Navajo peoples used them throughout prehistoric and historic times. A hazard associated with alcoves is spalling of rock debris as a result of wind and water erosion.

Distinctive Geologic Features

Spider Rock, Fortress Rock, Dog Rock, Sleeping Duck Rock—all of these features serve as geographic locators at Canyon de Chelly National Monument. Possibly the most recognizable is Spider Rock, which has appeared in many television commercials. Rising 825 feet (251 m) from the floor of Canyon de Chelly, Spider Rock is a geologic keystone of the national monument because it displays the three rock formations exposed here: Pennsylvanian sandstone of the Supai Group, Permian De Chelly Sandstone, and the Triassic Shinarump Member of the Chinle Formation (see "Park and Geologic Setting" section). As the home of Spider Woman, Spider Rock is also a culturally important location. Spider Woman is a highly honored deity for the Navajo. She has two important roles in Navajo stories: one as the teacher of weaving and the other to enforce obedience in children. Navajo children learn that if they do not behave, Spider Woman will carry them away to be eaten. The top of Spider Rock is said to be white because of the discarded bones of disobedient children.

The following are other distinctive geologic features identified during scoping. Like Spider Rock, the author would like to incorporate both geologic and cultural descriptions of these features in the final GRE report. Park staff and Margaret Hiza Redsteer are resources for such information.

- Slot canyon unconformity along White House Trail in De Chelly Sandstone
- Variety of desert varnish
- Styles of canyon incision (classic "youthful" stream features)
- Spring Canyon hoodoos in Chinle, Monument Canyon, and the upper portion of Canyon de Chelly past Spider Rock

Eolian Features and Processes

Eolian features include windblown dust (loess) and sand dunes. During scoping park staff commented, "We love dunes." Dunes are a distinctive resource, which park staff presumably enjoys interpreting for visitors. Some park staff refer to the periodic dust storms as "pink outs." Blowing sand may cause pitting on cultural features. One dune appears on the park map, south of the visitor center, but many active dunes occur in the national monument, particularly in side canyons (e.g., Tunnel Canyon, Junction, upper White House Ruin, Cottonwood Canyon, and White Sands). Blowouts occur on the dune in Tunnel Canyon. Active dune migration in the canyon may negatively affect farming. Dunes provide sources for native grasses and habitat for other endemic species. Margaret Hiza (USGS) has been studying reactivation of dunes due to drought (mhiza@usgs.gov, 928-556-7366).

Mineral Resources and Mining

Observations recorded during scoping highlight the presence of uranium in the Chinle Formation: the high-uranium content of water in pothole wells dug for livestock and the existence of a uranium mine in upper Canyon del Muerto. However, correspondence with Perry Charley (Diné College–Shiprock, Uranium Education Program) did not corroborate the existence of any such mine. Charley worked on reclamation of abandoned uranium mines under the Navajo Nation for many years prior to his tenure at Diné College and knows of no mines within the immediate canyon area and more specifically within the Canyon del Muerto area (Perry Charley, Diné College, e-mail communication, March 26, 2007). Charley surmised that participants must be referring to several, possibly three, small mine plots where the Atomic Energy Commission conducted exploratory drilling for uranium and vanadium in the northwestern edge of the Canyon de Chelly National Monument in the early 1950s. These sites are located near the Canyon del Muerto area. Due to the low grade of the deposits, no active mining resulted from any of these drilling operations. The nearest mines are located at Black Mesa, approximately 30 miles (50 km) to the west of Canyon de Chelly; 13 properties were mined in this area. Charley suggested two reports for further information:

U.S. Atomic Energy Commission, 1953, The geology and production of history of the uranium deposits in the Toreva Formation, Black Mesa, Apache County, Arizona [unpublished data]: Grand Junction, Colorado, U.S. Atomic Energy Commission.

Scarbouough, R., 1981, Radioactive occurrences and uranium production in Arizona, final report: State of Arizona Bureau of Geology and Mineral Technology Open File Report 81-1 (March 1981).

Participants also mentioned the NPS use of sand and gravel from two borrow pits in the monument: one at Spider Rock Overlook and the other at White House Overlook. The National Park Service used the sand and gravel for the road project many years ago, and extraction for routine road maintenance continued until about 1994 (Elaine Leslie, [formerly CACH] NPS Biological Resource Management Division, e-mail communication, March 26, 2007)

Seismic Features and Processes

The U.S. Geological Survey classifies this area as having a low seismic hazard potential. The closest active fault is to the west near the Grand Canyon and Flagstaff, Arizona. The national monument does host an EarthScope seismic station for measuring plate motions, however. EarthScope is funded by the National Science Foundation and conducted in partnership with the U.S. Geological Survey and NASA (see http://www.earthscope.org/overview/index.php).

Soil Resources

A soil resources inventory is currently underway at Canyon de Chelly National Monument. This inventory is separate from the geologic inventory conducted by the Geologic Resource Evaluation Program. However, as the soils inventory was a topic of discussion during GRE scoping, information is included here. A completed soils inventory of the 83,840 acres (33,930 ha) of the national monument is scheduled for September 2007, and initial deliverables provided to the NPS Soils Program manager for review and comments by December 2007. For more information, contact Pete Biggam (NPS Soils Program) at pete_biggam@nps.gov or 303-987-6948.

Soils mapping is done to National Cooperative Soil Survey (NCSS) Order 2 level standards. The NPS Soil Resources Inventory Program has worked with the USDA Natural Resources Conservation Service (NRCS) to set up a soil survey crew out of Page, Arizona, to map units within the NPS Southern Colorado Plateau Network. Two soil scientists and a range ecologist are currently funded and dedicated to these projects.

The survey at Canyon de Chelly National Monument is emphasizing the soil-geomorphic-vegetative relationships in the canyons and on upland areas. Project scientists will develop ecological site descriptions to meet park and network needs; site descriptions will contain state and transition models to portray the current situations regarding the various invasive plant communities and their impact on soil function and dynamics. Products will focus on the physical, chemical, and biological properties of soils and data about potential uses and limitations of each soil type in sufficient detail for park staff, planners, and researchers to use for soil conservation and soil resource management. Specific products will be a geospatial digital soils map, MS Access database exported from the National Soil Information System (NASIS), FGDC-compliant metadata, soil survey report in both a hardcopy and interactive CD format, soil maps on an ortho-photo base in both digital and hardcopy formats (scale 1:12,000), and digital images of soil pedons and soil landscapes.

Related to the soil inventory currently underway at the monument, swelling soils are associated with the Chinle Formation. The Shinarump Member of the Chinle Formation is exposed in the national monument. Issues related to swelling soils may include heaving sidewalks and roads and failing foundations. However, heaving and subsidence may be a result of other factors such as building sites located on improperly

compacted (subsiding) fill material or improper drainage around foundations (Pete Biggam, GRD, e-mail communication, February 23, 2007).

Type Sections

The quadrangles of interest for Canyon de Chelly National Monument and the geographic names of features in the vicinity read like a type-section junkie's dream: Sonsela Buttes 7.5' quadrangle and the Sonsela sandstone of the Chinle Formation (Triassic), Lukachukai 7.5' quadrangle and the Lukachukai Member of the Wingate Sandstone (Jurassic), and the Chuska Mountains and Chuska sandstone (Eocene-Oligocene). Types sections are the originally described layers of rock and serve as a standard for comparison for all other rocks (in different places) of the same name and age. In other words, although there may be many "typical sections" of a named unit, there is only one type section. Depending on one's perspective, this distinction makes seeing a type section simply noteworthy or truly remarkable.

Canyon de Chelly is designated as the type section for the De Chelly Sandstone. In 1917, H. E. Gregory and R.W. Stone named the De Chelly Sandstone during a geologic reconnaissance of parts of Arizona, New Mexico, and Utah (see http://3dparks.wr.usgs.gov/coloradoplateau/lexicon/dechelly.htm). Although Gregory and Stone did not designate a specific type locality, they named the rock formation for Canyon de Chelly. Their results are published in U.S. Geological Survey Professional Paper 93. During this same reconnaissance, Gregory and Stone also named the Chinle Formation for the Chinle Valley in Apache County, Arizona (see http://3dparks.wr.usgs.gov/coloradoplateau/lexicon/chinle.htm); the Shinarump Member of the Chinle Formation outcrops in the national monument (see "Park and Geologic Setting").

Volcanic Features and Processes

During scoping, Steve Semken (Arizona State University) presented information about volcanism in the vicinity of Canyon de Chelly National Monument. The last volcanic eruption in the area occurred about 20 million years ago. The nearest mapped volcanic feature is Black Rock Mesa at the head of Canyon de Chelly. Possibly with more detailed mapping, additional feeder dikes would be discovered within or around the park. This is important because though many remnant volcanic features (e.g., necks, diatremes, and maars) occur on the Colorado Plateau, only a comparatively small amount of feeder dikes have been discovered. This and other features in the area are part of the Navajo volcanic field and include volcanoes, dikes, and sills. According to Semken (2003), these features are products of structurally controlled magma ascent, explosive eruptions, and deep post-eruptive exhumation (e.g., Shiprock). Investigators have used the crustal and mantle-derived, igneous rocks that have been brought to the surface to map the petrology and history of the lithosphere and upper mantle beneath the Colorado Plateau (Semken, 2003). The volcanic landforms of the Navajo volcanic field also figure prominently in the empirical knowledge and culture of the indigenous Navajo people (Semken, 2003).

References

Ash, S., 1993, Plant megafossils of the upper Triassic Chinle formation, Canyon de Chelly National Monument, Arizona, *in* Santucci, V.L., ed., National Park Service paleontological research abstract volume, technical report NPS/NRPEFO/NRTR-93/11: Lakewood, Colorado, Geologic Resources Division, http://www2.nature.nps.gov/geology/paleontology/nps_paleo_vol1/cach.htm (accessed March 23, 2007).

Baars, D.L., 1998, The rocks and time of Canyon de Chelly National Monument—a visitor's introduction: Grand Junction, Colorado, Cañon Publishers Ltd., 13 p.

Blakey, R.C., 1996, Permian eolian deposits, sequences, and sequence boundaries, Colorado Plateau, *in* Sonnenfeld, M.D., and Longman, M.W., eds., Paleozoic systems of the Rocky Mountain Region: Denver, Colorado, SEPM (Society for Sedimentary Geology), Rocky Mountain Section, p. 405–426.

Gregory, H.E., and Stone, R.W., 1917, Geology of the Navajo country—a reconnaissance of parts of Arizona, New Mexico, and Utah: U.S. Geological Survey Professional Paper 93, 161 p.

Hack, J.T., 1942, The changing physical environment of the Hopi Indians of Arizona: Cambridge, Harvard University, Papers of the Peabody Museum of American Archaeology and Ethnology, v. 35, no. 1, 85 p.

Karlstrom, E.T., and Karlstrom T.N.V., 1986, Late Quaternary alluvial stratigraphy and soils of the Black Mesa–Little Colorado River areas, northeastern Arizona, *in* Nations, J.D., Conway, C.M., and Swann, G.A., Field trip guidebook for Geological Society of America Rocky Mountain Section meeting, Flagstaff, Arizona, p. 71–92.

Kocurek, G., Robinson, N.I., and Sharp, J.M., 2001, The response of the water table in coastal aeolian systems to changes in sea level: Sedimentary Geology, v. 139, no. 1, p., 1–13.

National Park Service, 2004, Memorandum from Eckert, G., Greco, D., Wagner, J., Martin, M., Benjamin, P., Deuser, C., Hansen, M., and Rees, M., through Gregory, R., to Superintendent, Canyon de Chelly National Monument, regarding October 2003 natural resource assessment trip report (January 18, 2004): Fort Collins, Colorado, National Park Service, Natural Resource Program Center, 51 p.

Natural Resources Conservation Service, 2000, Natural resource plan—Canyon del Muerto/Tsaile Creek watershed, Chinle, Arizona: USDA Natural Resources Conservation Service, 76 p.

Pranger, H., 2005, Recommendations for temporary road crossing and arroyo restoration, Canyon de Chelly National Monument, Arizona: Lakewood, Colorado, National Park Service, Geologic Resources Division, 18 p.

Semken, S., 2003, Black rocks protruding up—the Navajo volcanic field: New Mexico Geological Society Guidebook, 54th Field Conference, Geology of the Zuni Plateau, p. 133–138.

Stokes, W.L., 1968, Multiple parallel-truncation bedding planes—a feature of wind deposited sandstone formations: Journal of Sedimentary Petrology, v. 38, p. 510–515.

Thybony, S., 1997, Canyon de Chelly National Monument: Tucson, Arizona, Western National Parks Association, 15 p.

Table 1. Scoping Meeting Cooperators

Name	Affiliation	Position	Phone	E-Mail
Ailema Benally	NPS-CACH	Interpreter	928-674-5500 x. 227	ailema_benally@nps.gov
Arthur Benally	NPS-CACH	Biological Technician	928-674-5500	arthur_benally@nps.gov
Pamela Benjamen	NPS, Intermountain Region	Natural Resource Manager	303-969-2865	pamela_benjamin@nps.gov
Ron Blakey	Northern Arizona University	Geologist	928-523-2740	ronald.blakey@nau.edu
Tim Connors	NPS-GRD	Geologist	303-969-2093	tim_connors@nps.gov
Hank Hayou	NPS-CACH	Biological Technician	928-674-5500	hank_hayou@nps.gov
Deanna Greco	NPS-GRD	Geomorphologist	303-969-2351	deanna_greco@nps.gov
Katie KellerLynn	Colorado State University	Research Associate/Geologist	801-608-7114	katiekellerlynn@msn.com
Elaine Leslie	NPS-CACH	Deputy Superintendent	928-674-5500 x. 225	elaine_leslie@nps.gov
Keith Lyons	NPS-CACH	Archaeologist	928-674-5500 x. 272	keith_lyons@nps.gov
Lisa Norby	NPS-GRD	Geologist	303-969-2318	lisa_norby@nps.gov
Margaret Hiza Redsteer	USGS	Navajo Land Use Planning Project	928-556-7366	mhiza@usgs.gov
Steve Semken	Arizona State University	Geologist	480-965-7965	semken@asu.edu
Lisa Skinner	Northern Arizona University	Geologist/GIS	928-699-1352	lisa.skinner@nau.edu
Phil Stoffer	USGS	Geologist	650-329-5028	pstoffer@usgs.gov
Scott Travis	NPS-CACH	Superintendent	928-674-5500 x. 224	scott_travis@nps.gov
Paul Umhoefer	Northern Arizona University	Geologist	928-523-6464	paul.umhoefer@nau.edu

Table 2. GRE List of Maps for Canyon de Chelly National Monument

GMAP ID	Reference	Appraisal	GRE action required	URL	Scale
1093	Thaden, R.E., 1990, Geologic map of the Buell Park quadrangle, Apache County, Arizona, and McKinley County, New Mexico: U.S. Geological Survey Geologic Quadrangle Map GQ-1649, scale 1:24,000.	2007-0302: CACH staff requested inclusion of Buell Park quadrangle because of watershed implications; GRE needs to decide whether to include or not	Digitization	E:\gis-nps_by_gmap_id\1093_buell_park_AZ-NM_7.5'	24000
1095	Byers, V.P., 1980, Geologic map and sections of the Sonsela Butte 4 SE quadrangle, Apache County, Arizona, and San Juan and McKinley counties, New Mexico: U.S. Geological Survey Open-File Report OF-80-788, scale 1:24,000.	2007-0302: CACH staff requested inclusion of Sonsela Butte quadrangle because of watershed implications; GRE needs to decide whether to include or not; would also need to be evaluated to make sure it supercedes GMAP 74602; black-and-white	Digitization	http://ngmdb.usgs.gov/Prodesc/proddesc_11765.htm	24000
15897	Byers, V.P., 1979, Geologic map and sections of the Crystal quadrangle, San Juan and McKinley counties, New Mexico: U.S. Geological Survey Open-File Report OF-79-599, scale 1:24,000.	2007-0302: CACH staff requested inclusion of Crystal quadrangle because of watershed implications; GRE needs to decide whether to include or not; would also need to be evaluated to make sure it supercedes GMAP 74604; black-and-white map; because it's in CACH, likely has matching coal map	Digitization	http://ngmdb.usgs.gov/Prodesc/proddesc_11325.htm	24000
74602	Cooley, M.E., Harshbarger, J.W., Akers, J.P., Hardt, W.F., and Hicks, O.N., 1969, Geologic map of the Navajo and Hopi Indian reservations, Arizona, New Mexico, and Utah (sheet 5 of plate 1), *in* Regional hydrogeology of the Navajo and Hopi Indian Reservations, Arizona, New Mexico, and Utah: U.S. Geological Survey Professional Paper 521-A, 5 plates, scale 1:125,000.	2007-0302: covers CACH quadrangles of interest (QOI) for Tsaile, Red Cornfield Mesa, Lower Wheatfields, Mummy Cave Ruins, Del Muerto, Chinle, White Clay, Spider Rock, Turkey Canyon, White House Ruins 7.5' quadrangles. Also covers CACH “requested” quadrangles for Roof Butte, Lucachukai, Tsaile Butte, Upper Wheatfields, Sonsela Buttes. GRE staff need to decide how to handle “requested” quadrangles	Digitization	E:\gis-nps_by_gmap_id\74602_navajo-hopi_hydro_plate-1_sheet-5	125000
74603	Cooley, M.E., Harshbarger, J.W., Akers, J.P., Hardt, W.F., and Hicks, O.N., 1969, Geologic map of the Navajo and Hopi Indian reservations, Arizona, New Mexico, and Utah (sheet 6 of plate 1), *in* Regional hydrogeology of the Navajo and Hopi Indian reservations, Arizona, New Mexico, and Utah: U.S. Geological Survey Professional Paper 521-A, 5 plates, scale 1:125,000.	2007-0302: covers CACH QOIs for Sawmill and White Rock Wash. Also covers CACH “requested” quadrangle for Buell Park (which is also covered by dedicated 7.5' GMAP 1093)	Digitization	E:\gis-nps_by_gmap_id\74603_navajo-hopi_hydro_plate-1_sheet-6	125000
74606	Cooley, M.E., Harshbarger, J.W., Akers, J.P., Hardt, W.F., and Hicks, O.N., 1969, Map showing surficial deposits, volcanic provinces, internally drained areas, streamflow data, and occurrence of water in the alluvium in the Navajo and Hopi Indian reservations, Arizona, New Mexico, and Utah, *in* Regional hydrogeology of the Navajo and Hopi Indian reservations, Arizona, New Mexico, and Utah with a section on vegetation (plate 2): U.S. Geological Survey Professional Paper 521-A, 5 plates, scale 1:500,000.	2007-0305: covers CACH QOIs at 500k; looks very coarsely detailed for what GRE observed during field visit. GRE will crop this larger work to the 18-7.5' QOIs and digitize as it's not known to exist in digital format. Detail may be revisited in the future, after evaluating proposal from Paul Umhoefer (NAU) for detailed geomorphology of canyon floor	Digitization	E:\gis-nps_by_gmap_id\74606_navajo-hopi_hydro_plate-2	500000