# ARCHES NATIONAL PARK
# RESEARCH SUMMARY 2010

**1) Study Title:** The Moab Project Site Environmental Air Monitoring Program Conducted by the U.S. Department of Energy's Grand Junction Office
**Permit No.:** ARCH-2010-SCI-0001
**Principal Investigator:** Ed Baker
**Purpose of Scientific Study:** DOE's environmental air monitoring program will monitor local and background air quality for various radioparticulates (Uranium, Th-230, Ra-226 and radon-222) and radon gas and direct gamma.
**Findings/Accomplishments for 2010:** The air monitoring station at Arches (east side of visitor's center) is one of 14 stations operated by the US Department of energy to detect levels of radiation on the DOE mill tailings site and surrounding locations. The Arches stations is ~ 1/4 mile downwind of the project activity. No elevated levels of radiation have been detected at Arches. As the tailings pile is excavated and transported to Crescent Junction, the Arches station will continue to record data. See DOE "Environmental Air Monitoring Data Quarterly Report" on the Moab UMTRA Project web site: http://www.gjem.energy.gov/moab for more information.

**2) Study Title:** Ecological effects of vehicle-generated particulate matter and the use of magnesium chloride as a dust suppressant in Arches National Park, UT
**Permit No.:** ARCH-2010-SCI-0002
**Principal Investigator:** Scott Hoffmann
**Purpose of Scientific Study:** This research seeks to compare and contrast the impacts of fugitive road dust on vegetation versus the impacts associated with the use of a chemical dust suppressant. The proposed work addresses relationships between accepting some level of impact due to vehicular dust and particulate matter (PM) deposition versus the costs, benefits, and associated consequences of management interventions to reduce dust levels. The examination of roadside dust deposition, and the specific evaluation of a road surface treated with magnesium chloride ($MgCl_2$), is grounded on the premise that while some desert plants may be adapted to ambient levels of PM deposition, it is possible that a change in the amount and/or type of particle deposited may result in novel and problematic effects for a leaf and plant.
The research objectives are as follows: 1) examine the community structure of vegetation and biological soil crust (BSC) on both upwind and downwind sides of the unpaved Salt Valley Road, and develop hypotheses on potential PM-related mechanisms that may result in community transitions; 2) examine relationships between morphological characteristics of individual leaves and PM deposition, and develop hypotheses on potential tolerance and sensitivity of specific plant species to vehicular dust; 3) estimate the amount of PM generated by vehicular passes and blown by wind away from an untreated road; 4) estimate the amount of PM generated by vehicular passes and blown by wind away from a $MgCl_2$-treated road; 5) measure the extent to which $MgCl_2$ and its ionic constituents $Mg^{2+}$ and $Cl^-$ are transported by wind and water away from unpaved roads on which it is applied 6) investigate developed hypotheses (from objective #1) regarding various ecophysiological dynamics (e.g. photosynthetic yield, gas exchange) of leaves before and after coating by PM from an unpaved road and from a road treated with $MgCl_2$; and 7) develop a protocol for National Park managers to implement for the long-term monitoring of dust production, transport, and deposition, and related effects on individual plants and on plant and BSC community composition.
**Findings/Accomplishments for 2010:** The original proposal submitted in 2009 focused only on the ecological effects of $MgCl_2$ as a dust suppressant. A research addendum

was submitted to the NPS and approved for funding in 2010 to expand the study to include the broader research questions of dust production and particulate deposition, and the development of a monitoring protocol as outlined above. The 2010 field season was aimed primarily at site selection and development for field experiments to commence in spring 2011. Sites were identified and mapped along the Salt Valley Road, and an initial treatment of a 100 m stretch of road with MgCl2 was completed in August. A control site was also established adjacent to this treated site. Soil sampling was conducted at specified distances from the road and at specified depths both prior to and immediately following MgCl2 application. Subsequent soil sampling was conducted in November and December. Analysis of soil samples to examine soil variability within the site, and to measure initial transport of Mg2+ and Cl through the roadside soil is currently underway. Big Spring Number Eight (BSNE) aspirated dust samplers were purchased, painted to match the surrounding landscape, and installed within the study sites at specified distances from the road. These will be used for vehicular pass experiments in spring 2011 to measure the amount of dust generated by specified traffic loads.

**3) Study Title:** Impacts of Climatic Change and Land Use on the Southwestern U.S.
**Permit No.:** ARCH-2010-SCI-0003
**Principal Investigator:** Jayne Belnap
**Purpose of Scientific Study:** The population of the southwestern United States has grown rapidly over the past two decades and is projected to increase greatly over the next several decades. As the population has grown, climatic variations that would have affected relatively few people in the past will impact the lives of millions. Rapid and wide-spread climatic changes, such as those seen thousands and hundreds of years ago in the region and those projected for the future, may profoundly change the character of the region. Arid and semi-arid regions of the southwestern U.S. are among the most sensitive regions to changes in climate and land use, but the potential interactions between climatic change and land use are largely unknown (http://climweb.cr.usgs.gov/info/sw_new/swmap.html). U.S. Geological Survey and collaborating scientists are seeking to understand how climate and how land use has influenced surface geologic processes that modify landscapes and ecosystems. Such understanding is then used to model the landscape's response to future changes in climate and land use over time scales of seasons, of a few years, and of a few decades, so that information and interpretations can be applied by federal, state, and local agencies, as well as by Native American governments, for their land-use planning and management of resources. Project scientists work with ecologists, hydrologists, geographers, cartographers, and archeologists to address questions about:
(1) the causes and timing of changes in alluvial environments (rivers, streams, hillslopes), such as flooding, the cutting and filling of arroyos, and sediment discharge;
(2) the role of eolian dust for soil fertility, invasion of exotic species, hydrology, and surface stability in deserts;
(3) the interaction of physical and biologic processes critical for ecosystem functions;
(4) how climate in the southwest has varied over decades, centuries, and millennia;
(5) how future climatic variations will affect the Southwestern land surface (in terms of erosion, sand-dune activity, dust-storm frequency, flooding, landslides,);
(6) how past climatic changes and environments affected prehistoric cultures.

General Project Goals
-- Understand how past climatic change affected land surface: soil loss, fluvial erosion and alluviation, sand-dune mobilization, ecosystems, under time frames of past decades, centuries, and millennia.
-- Understand today's interplay among climate, land use and surface processes (geologic and ecologic).

-- Understand the impacts of future climate on land surface under the following time frames: seasons; El Nino/La Nina cycles; multiyear wet/drought periods; and decades, as atmospheric CO2 increases.
A major goal is to interact with federal, state, and local government agencies as well as non-governmental organizations to provide information useful for management decisions regarding land-surface vulnerability to wind erosion. Another goal is to provide to managers and other parties ongoing remote sensing and meteorological monitoring bearing on the vulnerability of the land to natural and human disturbances.
**Findings/Accomplishments for 2010:** This is a long-term project, with which we hope to understand climatic variability and its effects on dust projection and soil fertility.
Multiple years will be required to capture the full range of variability so that we may better understand the role of extreme events, as well as normal regimes.

**4) Study Title:** NCPN Integrated Upland Monitoring in Arches National Park
**Permit No.:** ARCH-2010-SCI-0004
**Principal Investigator:** Rebecca Weissinger
**Purpose of Scientific Study:** The Northern Colorado Plateau Inventory and Monitoring Network (NCPN) of the National Park Service has identified upland ecosystem characteristics, processes, vegetation, and other biota as vital signs to be monitored. Upland monitoring is intended to strike a balance between increasing fundamental understanding of dryland systems and providing managers early warning of undesirable change. It will document the variability in these systems while providing information needed for resource management decisions. Addressing these two goals will be accomplished partly through sampling design and data analysis. Some sites may be selected as representative of large portions of the landscape, others because of their management history. Evaluation of upland monitoring data in relation to other vital signs will facilitate identification of drivers and distinguishing â naturalâ from anthropogenic change. Additionally, plot data from this effort will be used in the classification and interpretation of remotely sensed data.
NCPN upland monitoring objectives for selected ecological sites:
1. Determine annual status and trends in ground cover (live and standing dead vegetation, litter, rock, biological soil crust, and bare ground); spatial pattern of vegetation by life form; soil aggregate stability and compaction as indicators of soil/site stability; hydrologic function, and nutrient cycling.
2. Determine annual status and trends in cover of biological soil crusts by species or morphological group.
3. Determine annual status and trends in cover of exotic plants in upland areas.
**Findings/Accomplishments for 2010:** Long-term monitoring was implemented for the first time in 2010. NCPN designed a monitoring plan in consultation with SEUG staff.
Deep blackbrush, grassland and PJ/blackbrush ecosite types were selected for monitoring. Eight plots of each type will be monitored each year on a rotating panel design.
NCPN crew established and sampled 24 plots in 2010. Reconnaissance of potential future monitoring plots was completed for the deep blackbrush and grassland ecosite types and was nearly completed for the PJ/blackbrush ecosite type. All plots were checked for cultural resources during reconnaissance and again during establishment.

**5) Study Title:** NCPN Integrated Riparian Monitoring in Arches National Park
**Permit No.:** ARCH-2010-SCI-0005
**Principal Investigator:** I&M/NCPN
**Purpose of Scientific Study:** The National Park Serviceâ s Inventory and Monitoring Program (NPS I&M), in collaboration with 32 monitoring networks, are charged with monitoring natural resources. Vital signs represent a select set of physical, chemical and biological elements and processed of park ecosystems that are chosen to represent the overall health and condition of a park's resources. Together, the Northern and Southern

Colorado plateau Networks (NCPN and SCPN) have developed conceptual models of key ecosystems and identified an integrated set of vital signs for tracking resource conditions at 35 NPS units within or near the Colorado Plateau (Thomas et al. 2004, Oâ Dell et al. 2005) Riparian systems are a high priority vital sign for the NCPN (Oâ Dell et al. 2005). Riparian systems are disproportionately high in biodiversity relative to their spatial extent due to the year-round or at least frequent availability of water. In turn, healthy and natural riparian systems serve as a predictable source of water, and function to maintain the natural diversity of riparian-adapted plants and animals across the Colorado Plateau region. Various dynamics interact to influence riparian systems. Ground-water levels, flood disturbance intensity and frequency, plant population, dynamics, and even upland conditions and dynamics collectively interact to shape the in-stream conditions and vegetative features of a riparian zone. Monitoring the status and trends in representative attributes and effects of an array of patterns and processes is an overarching goal of the NCPN Integrated Riparian Monitoring effort. This effort is intended to provide park managers with information on the variability of riparian systems, and to provide early warning of system degradation. In the latter case, monitoring information can be used to determine the potential for mitigating actions, and where such actions are implemented, monitoring efforts can contribute to understanding the effects of these actions. The full set of procedures for the NCPN Integrated Riparian Monitoring effort needs field testing for feasibility and refinement. However, the basic framework for selecting sites, for establishing stream-reach plots, for monitoring riparian vegetation, for surveying geomorphic surfaces across the riparian zone, and for measuring shallow groundwater levels and surface water stage is in place. These procedures can be implemented at this time as pilot implementation of the Integrated Riparian protocol. Pilot implementation is proposed for Courthouse Wash in ARCH. Specific objectives of the overall riparian monitoring effort are to determine the status and trends in:
1) the areal extent, cover, species composition and structure of riparian vegetation
2) exotic plant species
3) channel morphology of surveyed cross sections and the channel thalweg
4) floodplain ground-water levels and stream flow/discharge (This objective will not be implement in 2010.) Procedures for riparian monitoring incorporated pieces of the USGS Water Quality Assessment Program (Moulton et al. 2002) and EMAP procedures (Kaufmann et al. 1999) and were initially developed by Scott and Reynolds (draft). Further refinement has been completed by NCPN staff and by Steve Monroe and Ellen Soles of the SCPN.
**Findings/Accomplishments for 2010:** NCPN field crews established and sampled vegetation at Reach 1 and Reach 2 in Courthouse Wash. An instream well and one shallow groundwater piezometer was installed at Reach 1. Hydrologic data were collected continuously and downloaded quarterly. Reconnaissance of potential future monitoring reaches was also completed.

**6) Study Title:** Inventory of rare plants at hanging gardens in Arches National Park
**Permit No.:** ARCH-2010-SCI-0006
**Principal Investigator:** Rebecca Weissinger
**Purpose of Scientific Study:** Seeps and springs have been identified by the Northern Colorado Plateau Network as a habitat of extreme importance. It is of such importance that seeps and springs have been selected as a vital sign for parks on the Colorado Plateau. This resource is one of the most significant and endangered habitats in the parks of the Southeast Utah Group. Seeps and springs contain a disproportionately high amount of rare, sensitive, and endemic plants of the general region. Thus, this habitat is of high sensitivity and importance even though it constitutes only 1-3 % of the land surface. There has been no monitoring of sensitive species in Arches National Park. Seeps and springs have been recognized as highly significant and singled out as a habitat with its own management objectives the Arches National Park Resource Management Plan (1995). The Southeast Utah

Group Research Plan (1993) specifically states that riparian resources, such as seeps and springs, should be better understood due to their disproportionate importance to the ecology of the parks. The objective of this study is to inventory and map seeps and springs in Arches National Park and document sensitive plant species found in each. Data from this project will be used to develop a long-term monitoring plan for sensitive plant species and hanging gardens at Southeast Utah Group parks.
**Findings/Accomplishments for 2010:** Inventory work was completed at ARCH in FY10. Sixty-four hanging garden locations were documented with their associated rare plant populations. A draft final report was submitted to SEUG in Dec. 2010, and the final report is expected to be completed in February 2011.

**7) Study Title:** Colonial waterbird nesting survey
**Permit No.:** ARCH-2010-SCI-0007
**Principal Investigator:** Valerie Frokjer
**Purpose of Scientific Study:** We are currently conducting a colonial waterbird nesting survey for the USFWS through the Weber State University Avian Ecology Laboratory. We are locating nesting sites for all of the following species of birds using scopes, binoculars, boat or walking, whichever means are necessary for the situation to locate these birds.
Eared, Western, Clark Grebe; American white pelican; Cormorant Great blue heron; Great, Snowy, Cattle Egret; Black crowned night heron; White-faced ibis; Franklin's, Ring-billed, California Gull; Caspian, Black, Forster's Tern. The prioritized objectives of this survey are: 1) inventory and atlas of current waterbird colonies; 2) inventory of historical sites; and 3) locating new colonies.
**Findings/Accomplishments for 2010:** No activity was conducted this report year.

**8) Study Title:** NCPN Springs Monitoring Pilot Testing
**Permit No.:** ARCH-2010-SCI-0008
**Principal Investigator:** Rebecca Weissinger
**Purpose of Scientific Study:** Monitoring the status and trends in representative attributes and effects of an array of patterns and processes is an overarching goal of the NCPN Springs Monitoring effort. This effort is intended to provide park managers with information on the variability of spring systems and to provide early warning of system degradation. In the latter case, monitoring information can be used to determine the potential for mitigating actions, and where such actions are implemented, monitoring efforts can contribute to understanding the effects of these actions. The full set of procedures for the NCPN Springs Monitoring effort is still in development. Water quantity and quality methods are relatively standard and can be implemented immediately. However, vegetation measures and assessments of site condition need field testing for feasibility and refinement. At this time we propose testing field measures of vegetation structure, cover and diversity and site condition (visible natural and anthropogenic disturbances, etc.) at a subset of selected springs. Water quantity and quality may also be sampled at the same time. Future monitoring efforts may also include aquatic macroinvertebrate sampling, but those methods will be included in future permits as the need arises.
Methods testing is proposed for selected springs within SEUG park units. Final springs will be selected in conjunction with SEUG staff. Specific objectives of the overall springs monitoring effort are: for a selected spring, seep, or hanging garden, determine the status of and trends in any or all of the following:
1) the areal extent, cover, species composition and structure of spring-related vegetation (trees, shrubs, forbs, grasses)
2) target species such as rare plants and exotic plants
3) spring discharge
4) spring water quality

**Findings/Accomplishments for 2010:** Systematic vegetation sampling methods were tested at Freshwater Spring and Poison Ivy Spring. Further testing was suspended due to concerns about excessive sampling impacts.

**9) Study Title:** Three-Dimensional Characterisation of Faults and Their Influence on Fluid Migration.
**Permit No.:** ARCH-2010-SCI-0010
**Principal Investigator:** Stuart Clarke
**Purpose of Scientific Study:** Post-doctoral research to study the effects of faults on the migration within, and subsequent extraction of hydrocarbons from, sedimentary basins on basin- field- and trap-scale.
**Findings/Accomplishments for 2010:** Fieldwork completed and the final report (Master's Level scientific paper manuscript) will be completed by October 2011.

**10) Study Title:** What controls the locations and orientations of the Arches of Arches National Park, Utah?
**Permit No.:** ARCH-2010-SCI-0011
**Principal Investigator:** Christian Klimczak
**Purpose of Scientific Study:** The dense concentration of arches (>700) in Arches National Park is unique and therefore suggests unique conditions for arch formation and localization. Despite extensive work on arch formation, relations of arch locations and orientations have not been studied. Most recent work emphasizes the role of structure and jointing in arch localization, but besides broad relationships to salt migration at depth along with flexure of strata above, a process found abundantly on Earth, particular causes for location and orientation of the arches at Arches National Park are unknown. Interestingly, arches occur along several intersecting joint sets that seem to form a triple junction. Furthermore, within this joint system, the majority of arches are found in only 3 specific places in the Park. This relationship has not been noticed before and will be investigated in order to understand what controls the locations and orientations of the arches in Arches National Park.
Arches National Park is situated on the Colorado Plateau in the Paradox Basin, comprising Pennsylvanian to Cretaceous rock formations. Pennsylvanian-age evaporites of the up to 10,000ft thick Paradox Formation affected the overlying strata by salt diapirism and created the present morphologic features. The most prominent tectonic structure of this diapirism is the salt-cored Salt Valley Anticline related to flexure of the overlying layers. Large-scale joints, sub-parallel to the Salt Valley Anticline, reflect this flexure in the topmost rocks, including the Jurassic sandstones, of which the arches are composed. The majority of arches are formed in the Entrada Sandstone but some also occur in over- and underlying strata. An arch is defined by a perforation in the rock wall larger than 3ft and its formation is widely accepted to be due to a development of secondary joints as interacting fractures from shearing along preexisting joints. These secondary fractures form so closely spaced to each other that these parts of the rock become more susceptible to erosion and, hence, form the arch. Although the role of joining has been recognized for arch localization in Arches National Park, both the flexure of the surface layers with associated large-scale jointing due to salt diapirism and the development of secondary joints account for an even distribution of arches along the major tectonic structures. But as mentioned above, we observe that the majority of arches cluster at 3 distinct areas. In addition, these 3 areas seem to be related to 3 large-scale joint sets that branch into each other, forming a triple junction. In particular, the clusters of arches appear to be exactly at the locations where the joints branch off. This study will for the first time identify why the conditions for arch formation in Arches National Park are special and enhance the awareness of joints as important tectonic structures. Moreover, it will be of interest to structural geologist who study interactions of

fluid flow in tectonic joint systems both in salt tectonic settings and in general and to the broader geologic and lay public who wonder what caused the spectacular scenery in Arches National Park.
For our proposed research we have two main objectives: (1)Investigating in the overall jointing pattern throughout the entire National Park and its relation to the locations and orientation of the Arches. (2)Determination of the relative timing and propagation directions of jointing in order to relate it to the timing and location of the salt movement in depth.
**Findings/Accomplishments for 2010:** The aim of the field work was to record the location (by GPS) and orientation (by compass measurement) of the arches in order to specify the controls of arch localization and cause of the perforations in the rock fins. The controls of arch formation have been previously narrowed down to typical geometries at the tips (ends) of large-scale joints (cracks) found in the park. This study was intended to build upon these findings and relate the previously described deformation to the overall jointing pattern in the park. During field work, 38 arches were visited at The Windows, Fiery Furnace, Devils Garden, Delicate Arch, and Klondike Bluffs areas. At most visited arches, the previous formation hypothesis did not sufficiently explain the observed phenomena in this study. Collected data are currently processed for detailed structural analyses to develop a modified formation theory that better matches the observations and relates the location and orientation in the overall scheme.
Preliminary results show that the localization and orientation of the arches is closely linked to the reason of why they exist. Several sets of large-scale joints form a triple junction at which the joint sets interact with each other at very acute angles. The large scale jointing is responsible for the formation of the rock fins and the interaction between the large cracks has generated secondary cracks, similar to the previously described structures at the end of the cracks, but they are mostly not forming at the end of the joints. These secondary cracks formed so densely and at an angle to the larger joints that they would facilitate the formation of the perforation in the rock fins.

**11) Study Title:** Carbon and Nitrogen Cycles in Arid Lands: The Role of Biological Soil Crusts as Influenced by Soil Surface Disturbance, Climate
Change and Annual Grass Invasion
**Permit No.:** ARCH-2010-SCI-0012
**Principal Investigator:** Jayne Belnap
**Purpose of Scientific Study:** Models indicate the presence of a large carbon (C) sink at temperate latitudes in the northern hemisphere. Over thirty percent of lands both globally and in the United States consist of semi-arid or arid landscapes. Very little is known about carbon dynamics in these regions. Biological soil crusts, composed primarily of cyanobacteria, algae, lichens and mosses, can completely cover plant interspaces in undisturbed areas, and constitute 70 percent or more of the living ground cover. These soil crusts can be the dominant source of nitrogen (N) for vascular plants. They fix C at a high rate and are critical for soil stability and aggregate formation, which is important in C storage. They also absorb significant amounts of CH4. In areas where precipitation is low and soils have low fertility, native plants often rely on intact biological soil crusts to provide increased water and nutrient flow to the broadly scattered vegetation.
Thus, there are many ways in which biological soil crusts influence biogeochemical cycles and the structure and productivity of the vascular plant community.
Soil surface disturbance, invasive plants, and climate change have the potential to dramatically alter the structure and function of biological soil crusts. The current combination of recreational use and livestock grazing is resulting in unprecedented levels of surface disturbance on many arid lands. In regions that did not have substantial amounts of surface disturbance in the Holocene, biological soil crusts disappear readily when trampled by animals or vehicles. Exotic annual grasses are invading many of these areas. Trampling and invasion results in reduced cover and changes in the species composition of biological

soil crusts. This, in turn, leads to changes in processes such as decomposition, N and C fluxes, soil moisture, and nutrient availability to vascular plants. Decreases of only 1 percent of soil organic carbon in the top 10 cm of rangeland soils is equivalent to the total C emissions from all croplands nation-wide. Changes in climate regimes, such as a shift in the summer monsoonal boundaries in the western United States, are expected to influence the composition and physiological functioning of biological soil crusts. Various crust components have different photosynthetic and respiration responses to temperature and moisture. In addition, different crusts have different methane fluxes.
Therefore, changes in the timing or amount of temperature and precipitation is expected to alter soil C and N fluxes through changes in physiological response or crustal composition. This, in turn, can significantly impact vascular plant productivity.
This project will establish how alterations in species composition by surface disturbance, invasive grasses, and/or climate change may affect N and C inputs and fluxes, in different soils under different climatic regimes. Because current and expected changes in land use and climate will occur over millions of acres in western rangelands, impacts to soil crusts have the potential for dramatically affecting C cycles, N cycles, and vascular plant productivity over much of the western United States. In addition, semi-arid and arid ecosystems represent over one-third of the Earth's terrestrial surface, and most are covered by biological soil crusts. As human impacts are escalating both regionally and globally in these drier regions, the research questions posed in this proposal have significant implications for global C budgets as well.
**Findings/Accomplishments for 2010:** With this ongoing project, we are continuing to maintain the treatments within our experimental plots and collect data. As we are looking at long-term effects of soil surface disturbance, we will continue to annually monitor change, and analyze data in the future.

**12) Study Title:** Southern Utah Visitor Profile Study 2010
**Permit No.:** ARCH-2010-SCI-0013
**Principal Investigator:** Emmett Steed
**Purpose of Scientific Study:** The purpose of this study is to understand Southern Utah's tourists, who stay overnight and travel more than 50 miles from their homes. The research seeks to answer the following questions:
1. What are the demographic characteristics of Southern Utah visitors?
2. What relationships exist among Southern Utah visitors in regard to place of origin, Southern Utah destinations visited, transportation utilized, activities selected while in Southern Utah, and trip expenditures?
3. Are there seasonal differences in origin, destinations, activities, and expenditures?
4. What are the information sources utilized by Southern Utah visitors?
**Findings/Accomplishments for 2010:**
Upon completion of 2/4 seasons of data collection we have initial demographic information and an initial count of the most influential information sources utilized by Southern Utah visitors. Below are descriptive statistics from initial data analysis (n-456).
Specific to national parks:
79% of visitor surveyed are visiting national parks;
71% are influenced by the internet;
62% are influenced by past knowledge in their travel plans; 53% are influenced by friends/family.
Demographics of survey visitors:
Gender: 50% male;
Ages: 27% 45-54; 24% 55-64; 18% 35-44;
Originating area codes:
27% mountain zone;

26% foreign zones;
16% pacific zone;
Marital status: 74% married
Education level: 38% graduated college; 38% post graduate degree
Profession: 25% professional; 16% managerial/executive; 18% retired; 13% education
Travel club affiliation: 47% belong to AAA; 26% belong to AARP
Household income: 41% >$100,000; 25% $60,000-$99,999; <$59,999 16%

**14) Study Title:** Quantitative parameterisation of Fault zones in outcrop for inclusion in reservoir Flow models
**Permit No.:** ARCH-2010-SCI-0014
**Principal Investigator:** Tom Manzocchi
**Purpose of Scientific Study:** The fieldwork carried out in Arches National Park during Autumn 2010 was part of the Fault Analysis Group's ongoing QUAFF project, an oil industry funded research project to obtain quantitative data about the internal structure of faults with the ultimate aim of improving our general understanding of the evolution of fault zones and how they are represented in hydrocarbon flow simulations. The specific aim of the work in Arches National Park was to map a number of deformation bands, low displacement faults formed in porous rocks, that are continuous over a distance >10 metres. These faults were mapped by hand, but also with the help of low altitude, helium balloon, aerial photography. The work in the park was centred on two localities. The first was the sandstone pavements south east of Park Avenue, between the access road and Courthouse Wash. In this area we mapped three sinuous, branching and stepping fault traces for which we could measure displacement from the offsets of sedimentary markers. The second locality was the sandstone pavements above and to the northwest of the visitors centre, accessible from the north along old Highway 191. The geometries of four fault traces were mapped in detail onto low-level air photographs. Air photographs were taken from a height of 10 to 40 m using a camera suspended below a helium-filled balloon. The equipment used for the balloon aerial photography was basic but provided very satisfactory results. A 5.5 foot diameter white latex party balloon was filled from a helium tank (rented in Moab) to provide a lift of ~2 kg. Photographs were taken using a Canon Powershot G10 hanging below the balloon in a cradle constructed of coarse plastic netting and 30lb fishing line. The balloon was controlled by two ??? lb kite lines which were tethered above the aperture of the balloon and were held by members of the research team. Walking either side of the photo target with the balloon centred directly above was the most efficient method for taking the pictures along the lengths of fault traces. Photographs were taken at 10 s intervals controlled by a *** intervalometer attached to the camera. The photographs were montaged and printed as base-maps for detailed mapping and were supplemented with measurements on the ground of distances between selected points and GPS data needed for scale and georeferencing. The main draw backs with the method used for acquiring air photos is that it requires calm conditions and that the camera is not always precisely vertical so that precise georeferencing is difficult; this was not a requirement for our study. The data collected during this period of field work has yet to be fully analysedbeen analysed and used to create a better understanding of fault zones.
**Findings/Accomplishments for 2010:** This period of fieldwork, carried out in Arches National Park during Autumn 2010, is part of the Fault Analysis Group's wider ranging and ongoing QUAFF project. This project is due to run until October 2012 and, as a result, no final conclusions have yet been reached. The maps created and data collected in Arches will be compiled with previous work, ongoing work and future work from a number of localities around the world to give a better overall understanding of the evolution of fault zones. Nevertheless the work done in Arches has yielded some preliminary results. Our detailed mapping highlights and accurately records the sinuous nature of fault traces exposed in Arches. We hope that further analysis of these data will allow us to evaluate

competing models for the formation of sinuous fault traces. This sinuosity is thought to either be a result of linkage between fault segments or irregular fracture propagation pathways. In addition, the data collected has helped us to better understand and quantify the relationships between different slip surfaces within a fault zone, their connectivity and the relative amounts of displacement on each. These measurements provide quantitative descriptions of the internal structure of fault zones in Arches which we hope will contribute to the development of a general and quantitative model for the evolution of fault zones.