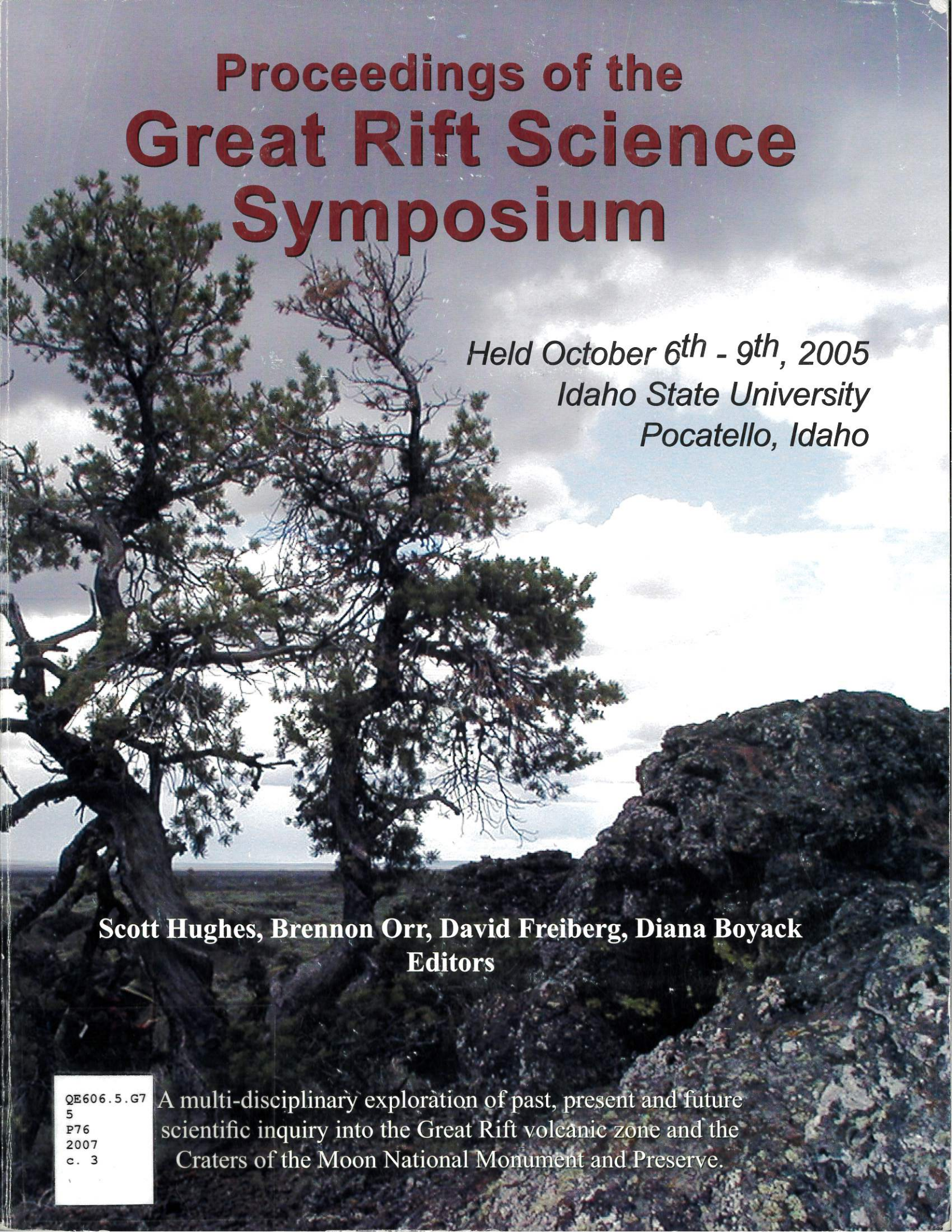
Proceedings of the Great Rift Science Symposium

Held October 6th - 9th, 2005
Idaho State University
Pocatello, Idaho



Scott Hughes, Brennon Orr, David Freiberg, Diana Boyack
Editors

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A multi-disciplinary exploration of past, present and future scientific inquiry into the Great Rift volcanic zone and the Craters of the Moon National Monument and Preserve.

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professor in the Department of Geosciences at Idaho State University.

Photographs throughout this volume by Roger Boe, Tim Frazier, and Scott Hughes unless otherwise noted. Roger Boe is an active amateur photographer from Pocatello who over the past 20 years has explored and photographed the Great Rift. Tim Frazier is currently a professor in the Idaho State University Mass Communication Department.

Will Peterson is the author of the poetry throughout this volume unless otherwise noted.

Artwork, cover design and layout throughout this volume by Diana Boyack and students in the Digital Mapping Laboratory in Department of Geosciences at Idaho State University.

(The First)
Great Rift Science Symposium

"The strangest 75 square miles on the North American Continent."
– description by an early traveler

The Great Rift Science Symposium was a gathering of scientists, educators, regional community leaders and the general public who shared an interest in the unique landforms, biology and history of the great lava desert of Southern Idaho. Most of the Great Rift areas are now protected within the Craters of the Moon National Monument and Preserve. Created in 1924 as a 53,545 acre National Monument, the Craters of the Moon area was expanded November 2000 based on Presidential Proclamation #7373 to 753,863 acres. The Monument contains the youngest and most geologically diverse basalt lava terrain of the Snake River Plain and the largest basaltic lava field of Holocene age in the United States. This unique lava supports some of the most intact sage-steppe ecosystem remaining in the world. Finally the Great Rift area has been a significant challenge to the human community over the past 15,000 years and still defies habitation and use: the strangest 75 square miles on the continent.

The four-day symposium was held October 6-9, 2005 at Idaho State University, Pocatello, Idaho. The event was a mixture of keynote speakers, concurrent scientific panels, plenary sessions, poster sessions, breakout meetings and evening cultural events. It coincided with Idaho teacher in-service days so that educators could easily attend and gain academic credits. Professional presentations were followed by site tours, including North Laidlaw Park, the Pioneer Mountains interface, Headquarters area, Pillar Butte, and the Wapi Flows.

This Proceedings Volume, is published by Idaho State University in cooperation with the Bureau of Land Management. and the National Park Service. It is intended to serve as an information base to guide resource management and interpretation for students, educators and the regional community.

Mission Statement:

The mission of the symposium is to support understanding, appreciation and protection of the geological, ecological, and cultural objects and resources found within the Great Rift region, including Craters of the Moon National Monument and Preserve, through sharing information from past research and encouraging future collaborative research efforts and education.

Special Thanks To:

***Rick VanderVoet** - Monument Manager, Bureau of Land Management, for his creativity, expertise and persistence in conceiving and cultivating this unique event.*

***Steering Committee Members and Others** - Tom Blanchard, Emily Dekker-Fiala, Dave Freiberg, Chris Gertschen, Scott Hughes, Nancy Huntly, Mel Kuntz, Doug Owen, Ralph Peterson and Rick VanderVoet .*

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The Wapi Highway
now a wagon trail
that wanders the west side
of the rift
from the Ice Caves to Wapi Park
used to be the best way
to cross the desert
if you were afoot:
protected from the sun
protected from the cold
and hard to get lost
until you saw the river.

And camped beside the caves
with direct descent to darkness
there was access to dreams:
of who they were
before they became humans
following this path.

- Will Peterson

Photo by Susan Sakimoto & Scott Hughes

Introduction

By Brennon Orr

The Great Rift transects the eastern Snake River Plain as a stark and rugged volcanic scar of cinder cones, elongate vents, lava flows and deep fissures that extends from northwest to southeast across the plain. The Great Rift not only forms an extensive feature visible from space, but it exerts a strong influence on the cultural history, geology, and ecology of the plain.

The rich cultural history of the Great Rift has encompassed thousands of years. The Great Rift was home to early Native Americans, providing lava tubes for shelter, lithic materials for tools, and animals and plants for sustenance. The Great Rift has since been an important factor in the lives of those who live on and near the Snake River Plain and others who come to visit.

The Great Rift is a window to the geologic history of the eastern Snake River Plain. The complex series of volcanic eruptions, extensive basalt flows, and intervening sedimentary deposits provides a record of the long and sometimes violent development of the plain.

The Great Rift affects flow within and recharge to the Snake River Plain aquifer, one of the more productive aquifers in the United States. In its vicinity, the water table steepens, indicating that constructional rift features locally reduce the capability of the aquifer to transmit water. This restriction controls the rate and movement of groundwater across the Great Rift toward major points of aquifer discharge from large springs along the Snake River approximately seventy miles to the southwest. Accumulated basalts on the Great Rift have formed topographic highlands that are characterized by increased precipitation and potential for aquifer recharge. These same highlands have diverted the surficial drainage of the Big Lost River, forcing its channel to the north, modifying sedimentary depositional centers and areas of streamflow infiltration.

Subsequent papers represent a substantial body of scientific work in progress on and around the Great Rift. This work ultimately focuses on the extensive influence of the Great Rift on the cultural, historical, geologic, hydrologic, and ecological features of the eastern Snake River Plain.



Photo by Scott Hughes

HISTORY



Photo by Roger Boe

There are places water flows
under aspen and alder
through deadly hemlock
and lily of the valley:

it has then
a dark metallic sheen
with silvery edges
where the rocks resist:

that's the way the Flows look
looking into the sun
the sun behind the clouds.

-by Will Peterson

Native Waters

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ABSTRACT

This research project is called Native Waters, and it has two main subjects. Water is one. Water connects all people together. Much of the Idaho's landscape including the Great Rift was and is still being affected by water.

Research questions about water arise. For example, how clean is the water in the Pocatello area or the other water streams in Idaho? How can we test this? Who can test it and what do the test numbers mean?

The other subject is education. One of my passions is Native American education, and I want to look at how we can understand and integrate traditional ways of knowing about many topics like water with scientific ways of knowing. I feel this is but one tool to help keep Native American students interested in school.

PROJECT DESCRIPTION

Water connects all of us as people. Water is life; water is sacred for all things that live on this planet. Even today with all our technology, without at least four inches of good topsoil and rain/water to grow food for us, we will cease to exit as a species.

The knowledge of water is important to know, and to pass on. Many Native Americans have been using their knowledge for survival for a very long time, including the Native people that are in the Great Rift area today, the Shoshone-Bannock people.

Water in some Native communities is so important that it is considered sacred medicine. Many Native ceremonies begin and end with a prayer of water. Water is an important gift for all.

Education is a way of protecting that special gift of water. I am looking at various ways to understand and integrate traditional ways of knowing and scientific ways of knowing. Why? We know today that most water resource problems are multidimensional. Science alone cannot solve water pollution problems. The solution to solving our water problems is also a problem of changing attitudes and actions.

Education and knowledge are some of the best tools we can give Native American students that I work with for a brighter future for their tribe, family and self.

TRADITIONAL KNOWLEDGE

Traditional Knowledge (TK) includes knowing a place. It covers knowledge of the environment, such as snow, ice, weather resources, and the relationship between all these things. Traditional knowledge is a holistic way of looking at the world. A friend from the Shoshone-Bannock tribe told me, "We are finally getting to the point where we can put our ancient knowledge to use in the modern

world, side by side with Western science this is a good thing" (Lavern Broncho Sr., Shoshone-Bannock Tribal member, 2004).

BEAVER STORY

A good example of Traditional Knowledge and western science overlap in my opinion is the Beaver story.

A view held by many Shoshone-Bannock tribal members is that the Beaver was and is one of the sacred animals that helped the Creator make the earth. The beaver is considered an animal that lives in the water and helps the land survive. This story is repeated in western science as well. The Beaver is sometimes referred to as a keystone animal for the environment. According to this story, the Beaver is a key player in the environment. The Beaver's actions affect many other species as well as the land.

According to some Native folks I work with, the beaver story is very similar. He shares his water gift with many others. For example, the beaver makes a home and has a family. The family and his clan work to hold back the water in a stream. In building their home/lodge, they make a dam. This dam does not hold all the water in a stream from ever going down stream. It is a water filter.

The filter slows the water down, deposits sediments and enhances the ability of plants to grow on the banks of a stream. The riparian zone starts to grow. Trees and shrubs grow, thus cooling the stream down for the finned ones. This invites birds to makes their homes in the tress. Grass grows along the stream. Deer come to eat the grass. The cycle is complete on the land. Water enables plants to grow, and animals to live.

In the water itself, another story is told. The beaver's home and dams slow down the silt in the stream. It is deposited on the bottom of the stream. The water becomes clear. The small insects now move in. Other small animals move in as well. Now the finned ones move in, have food, they have families and they grow. The Beaver have completed the water cycle of life. Students can be shown and understand that all is connected with water. Both water stories can be shared with Native students.

What happens when the water is not "clean?" The system becomes sick, and all that live in the world of water become sick, including man. This story is not so much different in Western science. It is the story of cause and effect. What are some "causes and effects?" Low or high pH levels (the acid or base of a stream), high nitrates/nitrites, low dissolved oxygen content in the stream, high temperature of the stream, high bacteria (E-coli) content of a stream, are all examples. These are but a few of the many tests that can be done by students. The question I ask students is, why are these tests important? Why do we need to know stream chemistry and life forms?

Teachers can teach basic chemistry and biology from standard set curricula. Many teachers are doing a fine job of teaching this way. Teachers are also under a lot of pressure to have students meet or exceed state standards. The teachers I know have always been interested in how their students are doing in their classes. They did not need the state to mandate a passion for student success. The question becomes, do students use critical thinking skills, or is rote memory of Idaho standard test facts what teachers should focus on?

DROP-INS

This project is aimed at helping those students that may not stay in school. The Native American population I am working with has the highest dropout rate in the Nation (41%, American Indian Report, 2004). When I asked why some Native students dropped out of school the response was varied. However, some themes have emerged. The students often state for example, "I do not understand how knowledge of chemistry or biology is important in my life." I believe a positive environmental science that combines hands on field learning with basic knowledge of science is the best approach to keeping students in school. Students start to see a connection to science and life.

SUMMARY

The TK model in the Western science view can help keep students in school. For example, many Native students have not heard the tribal stories of the water. Many more do not understand how knowledge of stream side chemistry and biological principals could help them understand the water story. Why is this important? Because TK gives the Native student cultural validity with Western science and learning. One story is not MORE important that the other. Both are important to know. Both require knowledge of many things. Both require critical thinking skills, to see an even bigger picture. Both state that we are all truly connected. What humans do to the environment including the water, affects us all on Mother Earth.

With this approach of TK and western knowledge, and a caring positive attitude about education and the student, I feel we can find success as educators and keep more Native students in school. We all need clean water, we all need students trained to be critical thinkers and question things. Teaching students about why clean water is important, what they can do to keep it clean, and why we should have respect for the environment, is truly our best hope for a brighter tomorrow for all the life forms on this planet.

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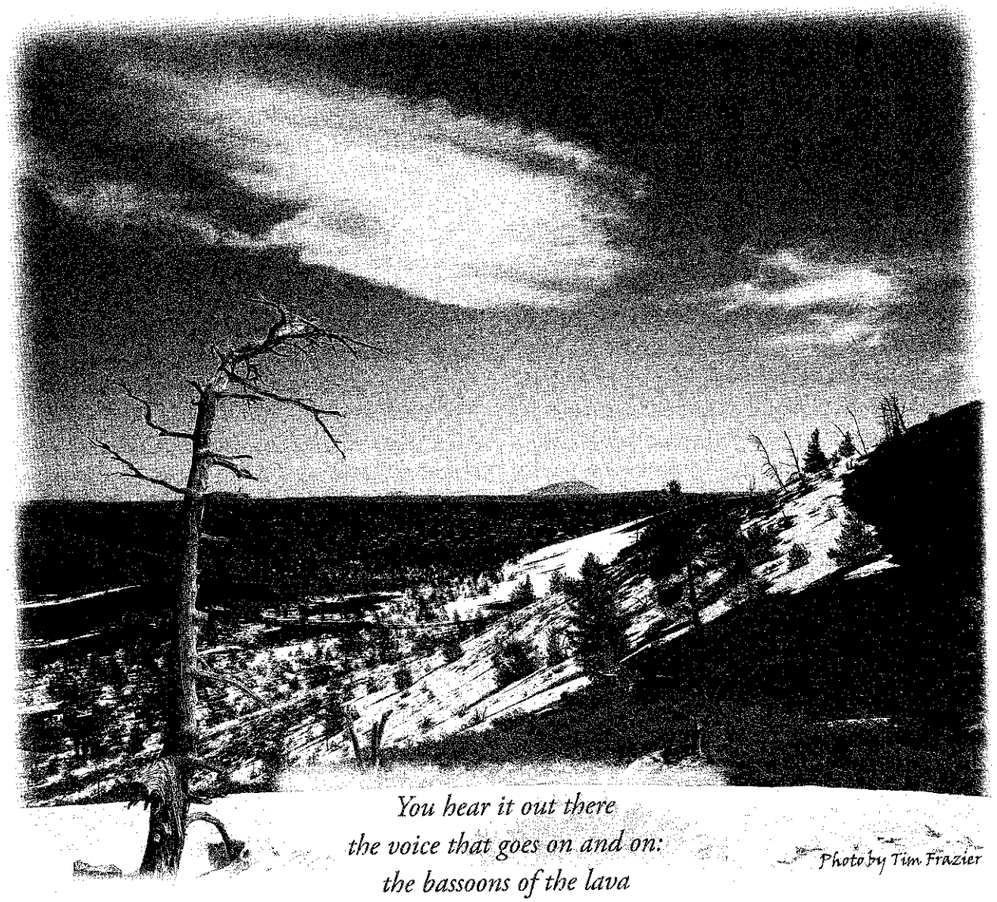


Photo by Tim Frazier

You hear it out there
the voice that goes on and on:
the bassoons of the lava
deep and ponderous;

and the violins
when the winds sweep through
the wildflower and serviceberry;

those flutes and piccolos
as meadowlarks and wrens
flit along a pressure ridge;

and the high bright note
when the sun breaks through the clouds.

- Will Peterson

Traditional Cultural Practices of the Shoshone-Bannock in the Great Rift Region

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ABSTRACT

Shoshone-Bannock Tribal members have used the natural resources of the Great Rift region for thousands of years. In addition to the archaeological evidence present, Shoshone-Bannock oral tradition also documents the use of this region. Resources of importance include native plants, animals and even the lava rock itself. This paper presents a preliminary look at the traditional cultural uses of these resources and suggests appropriate protection measures for resources at risk.

A "Traditional Cultural Property" is defined in the National Register of Historic Places Bulletin 38 as a property that is eligible for inclusion on the National Register because of its association with cultural practices or beliefs of a living community that: (1) are rooted in that community's history and (2) are important in maintaining the continuing cultural identity of the community. In the broadest sense, one could argue that the Great Rift area of the Snake River Plain is a traditional cultural property to the Shoshone-Bannock Tribes. This vast, wild landscape of pressure ridges and playas, caves and kipukas, certainly played an important role in the history of the Shoshone-Bannock people, shaping the cultural practices of these native peoples, enabling them to survive in such a harsh environment. Through the combined efforts of Tribal members, BLM representatives, ISU anthropologists, and others, steps are being taken to protect this important cultural resource.

Archaeology and ethnographic accounts both attest to a long history of Tribal occupation in the Great Rift. From radiocarbon dating of archaeological sites, we know that native peoples must have observed volcanic activity on the Snake River Plain first hand. Small, extended family bands moved across the landscape each spring, crossing the Great Rift region, traveling toward the camas fields near present day Fairfield, and into the mountains for the summer hunt. They traveled back again in the fall toward their winter villages on the Snake River.

Shoshone-Bannock oral history most certainly included stories regarding the formation of the lava flows we see today. These stories serve not only to entertain, but to teach and to document historic events orally in lieu of written records. As far as these authors can tell, early ethnographers Julian Steward (1938) and Robert Lowie (1909) did not record any lava-related stories in the course of their research.

Much of the research by anthropologist Sven Liljeblad in the 1950's and 60's has not been published. Even in recent times, little formal research has taken place regarding Shoshone-Bannock verbal arts. We do know that the Shoshoni names of prominent landscape features are held to be sacred and probably have not been shared with ethnographers for that reason.

A broad variety of natural resources were available to the early Shoshone-Bannock living in the Great Rift area, including geologic, plant and animal resources. Many of these resources are still used by the Shoshone-Bannock people today.

Volcanic rock itself was an integral part of native technology. Stone tools of obsidian, ignimbrite and fine-grained basalt were critical to their survival. Men hunted with obsidian projectile points; women processed meat and hides with obsidian knives and basalt scrapers. One of the most well used sources of volcanic glass on the Snake River Plain lies on Big Southern Butte, just east of the Great Rift. Big Southern Butte obsidian was carried and traded across long distances and is found by archaeologists hundreds of miles away from the source. Basalt boulders were used in the construction of hunting blinds, drive lanes, caches and house rings. Lava rock is preferred for sweat lodge fires as well, which is important for ritual purification.

The Shoshone-Bannock took full advantage of the unique geological features of the Great Rift. Playas, or seasonal ponds fed by spring rains, provided water and attracted water fowl and other game. Natural water catchments within the lava flow were used as well. Lava embayments and alcoves provided protection from the elements and ecological niches where Great Basin wild rye and other edible plants could flourish. The hot spring on the north side of the Craters of the Moon National Monument would have been visited, not only because of the water source, but for its medicinal value as well.

The Great Rift is dotted with thousands of lava tube caves. Some lava tubes hold ice, providing water in the fall when the playas and other water sources are dry. Recent archaeological investigations in the Great Rift Region suggest native people were frequently using ice caves to store bison meat (Henrikson 2002), perhaps for the fall trek back to the Snake River when food may have been scarce. The rough a'a lava flows were not a deterrent to native people, as evidenced by the many trails still visible crossing the lava. Indian people would sometimes seek refuge within the interior of the lavas during the early Euro-American settlement of Idaho, knowing no one would follow them there. They knew how to survive on the plants and animals that live there.

Bitterroot, a traditional plant food of the Shoshone-Bannock, currently grows in great numbers on the cinder cones near the present-day Craters of the Moon National Monument Visitor Center. The roots of this plant were peeled and boiled, after removing the bitter "heart" in the center. Other plant foods available across the Great Rift include Indian rice grass, Great Basin wild rye, wild onion, biscuitroot, arrowleaf balsamroot, chokecherry and prickly pear cactus. Sagebrush is an especially useful plant. The leaves are brewed for medicinal tea, the bark stripped for making cordage, rope and clothing. The wood was used to make arrow shafts and snares, as firewood and to make smoke for tanning hides or ceremonial smudging and sweat lodges.

Many animal species across the Great Rift were hunted by the Shoshone-Bannock and this traditional hunting continues today. One of the most common is the rock chuck or yellow-bellied marmot. Rock chucks are traditionally hunted with snares in June and are prized for their particularly fatty meat. Also taken were ground squirrels, ermine, rabbits and hares. The hides of these small mammals were twisted together to make fur robes.

Sage grouse were certainly used, as were water fowl, usually found near playas or springs. Predators, such as bobcats, mountain lions, bears, wolves, fox and coyotes, were quite

common on the Great Rift. Now extinct from the area, Grizzly bears especially liked to make use of lava tubes for dens, where we find their skeletal remains still today. Bears and mountain lions were not traditionally hunted for food, but were occasionally taken for their pelts. Wolves and coyotes were never hunted or eaten due to their importance in Shoshone-Bannock religion as creators of the world. Likewise, eagles were never killed intentionally, but naturally shed feathers are collected and considered to be especially powerful and sacred.

Large game animals were also available, including bison, elk, mule deer, pronghorn and the occasional moose. Bison probably never roamed the Great Rift in the numbers once seen on the Great Plains, but they did inhabit southern Idaho until the 1850's. Every part of an animal was used: hides and fur for clothing and leather goods, sinew for securing arrows to their shafts, antler and bone for tools and decorative items, hair for sewing and decoration, brains for tanning hides, flesh and organs for food, fat for making pemmican, which are dried cakes of berries, seeds and meat.

Often overlooked are the invertebrates. Ants and grasshoppers were eaten. Grasshoppers were popped like popcorn for a high protein snack. Ants and pupae could be made into puddings or gravies and served with roots. Certain caterpillars were also edible. There is archaeological evidence that native people may have also eaten the freshwater shrimp found in the many playas (Henrikson 1998), although we have yet to confirm this with ethnographic accounts. Through residue analysis, Henrikson et al. (1998) discovered microscopic shrimp residue on groundstone tools found at playa sites. Fairy shrimp and tadpole shrimp, which are similar to brine shrimp, can lay eggs in the desert soil where they can dry out and remain dormant for many years before hatching. In a good water year, the desert playas are teaming with millions of these tiny shrimp.

Curious as to why this potential food source is not mentioned in the ethnographic record, Henrikson and her coworkers suggest that perhaps the introduction of the horse and other elements of Plains culture into the Snake River Plain by 1730 A.D. may have redirected or completely replaced certain facets of the preexisting subsistence schedule. Such change perhaps decreased, or even eliminated, the importance of all ephemeral lake resources (1998).

Even today, both plant and animal food gathering are considered sacred activities, as native people believe that every creature has a spirit. Before killing an animal or digging a plant, prayers are said to explain why it is necessary to take a creature's life and to ask permission from the creator. Waste plant parts, such as unused flowers or stems, are disposed of away from the root grounds and a prayer of thanks said over them. When Tribal people collect plant resources, they don't take every plant in the patch. They always leave some plants to grow for the future, as well as rotating their collection areas to allow previously collected areas to rest.

For the most part, Shoshone-Bannock Tribal members have tried to continue their traditional hunting and gathering practices in the Great Rift Region. In the early days of the Fort Hall Indian reservation, Tribal members were encouraged by the Indian Agent to leave the reservation in the summer to make their traditional rounds. Later, as hostilities between Indians and settlers increased, it was not safe for Tribal members to leave the reservation and many families stopped traveling to these areas (Liljeblad 1972).

In recent years, many federal agencies have recognized Tribal rights to hunt and gather on federal lands. Because of previous negative experiences with the federal government, tribes have been understandably reluctant to share information regarding traditional cultural properties. The rebuilding of that trust is a slow process that takes time.

The Shoshone BLM Office is currently working with Tribal members to identify areas of traditional Shoshone-Bannock use and to

develop protective measures for those areas where necessary. Many historically used areas are no longer open to Tribal members, due to private property ownership and access issues. Much like archaeological sites, traditional use areas on public lands can be threatened by Off Highway Vehicle use, livestock overgrazing, mineral material extraction, wildfires, firefighting activities and noxious weed invasions. Some possible protective measures available to federal agencies are the installation of fences, road closures to limit vehicle traffic, formal withdrawal of land from mineral entry, public education/interpretation and the designation of Areas of Critical Environmental Concern (ACEC) as formal recognition of an area's importance. Agencies can reseed areas with native plants after wildfires and spray for noxious weeds. An example of a recent success, in 2004 the BLM worked with the adjacent private landowner to fence livestock out of Carey Hot Spring and preserve the natural vegetation, which includes traditional plants like willow and bull rush.

We hope through our continued and combined efforts we can protect more traditional use areas like Carey Hot Springs. In addition, we will continue to identify new areas where Tribal members can once again collect natural resources in this vast traditional cultural property now known as the Great Rift.

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Using Geospatial Data to Interpret the Holocene Archaeological Record on the Craters of the Moon National Monument and Preserve

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INTRODUCTION

Archaeologists have, for decades, searched for "patterns" that might reveal the myriad of variables that influence where humans choose to live. This is based on the widely held assumption that: 1) environmental factors play a strong role in such patterns, and 2) these patterns can be quantified and explained (Wheatley and Gillings, 2002). The development of Geographic Information Systems (GIS) and their ability to analyze large quantities of data has provided archaeologists with an extremely valuable tool. Programs such as ArcView and ArcMap, that utilize GIS concepts, can integrate archaeological information with geologic, topographic, hydrographic and other data sources within hours rather than months or years (Wheatley and Gillings, 2002).

The National Park Service has asked the University of Oregon Museum of Natural and Cultural History to apply GIS in the analysis of new and existing archaeological data at the Craters of the Moon National Monument and Preserve in order to develop a management plan for its cultural resources. The ultimate goal of this research is to test the archaeological data from the Preserve against a model already developed for the eastern Snake River Plain (Henrikson, 2002).

ENVIRONMENTAL BACKGROUND

The Craters of the Moon National Monument and Preserve (henceforth referred to as The Preserve) is comprised of 750,000 acres of which almost 500,000 are covered by late Pleistocene and Holocene basalt flows. The remaining acres are primarily contained within "kipukas", a Hawaiian term that refers to an island of land surrounded by lava on all sides. The Preserve can boast of containing the largest kipuka in the world, referred to as Laidlaw Park.

Volcanism is an important consideration that is often overlooked in the investigation of Snake River Plain prehistory. The current character of the plain was established roughly 10 million years ago by continuous pahoehoe flows from fissure eruptions or vents that range between 1 and 2 kilometers across (Kuntz et al., 1986, 1992). There are eight lava fields on the eastern Snake River Plain that formed during the terminal Pleistocene and Holocene, well within the timeframe of human occupation. The Craters of the Moon lava field is the largest in the continental United States and represents eight separate eruptive periods ranging in age from roughly 15,000 years ago to 2000 years ago (Kuntz et al., 1986, 1992).

Specific eruption phases may have had significant impacts on the pre-contact Shoshone seasonal round. These impacts may have come as harmonic tremors with the opening of fissures

and steam vents, the eruption of lava fountains and tephra cones and large quantities of lava exuding from open fissures. Some extended eruptions may have lasted for months or a few years. The Wapi lava field, dating to around 2000 years ago, probably remained active for several months, while the massive Minidoka flow, which occurred around 4000 years ago, may have created unsuitable air quality and temperatures in the vicinity for years (Kuntz et al., 1986). The Minidoka flow may have also closed the area to game animals and people alike for an extended period, until creatures began entering the resultant "kipuka" at a later date when the eruptions ceased (Henrikson, 2002).

Many GIS analyses have included elevation, slope, aspect, distance to water, vegetation communities and soil type as independent variables (Carmichael, 1990; Ringe, 1992). In 1992, Brenda Pace tested a predictive model for the Idaho National Laboratory, located just northeast of the Preserve and found that variables such as slope and aspect do not appear to have a significant influence on prehistoric site distributions. Instead, she discovered higher frequencies of sites near the edge of the Cerro Grande flow than elsewhere and argued that the prominent ridgelines that characterize these edges could have formed their own productive microenvironments (Ringe, 1992). Her striking results indicated that although lava flows may have been barriers during and immediately following volcanic eruptions, they eventually became highly productive areas surrounded by less productive sagebrush steppe.

A geospatial analysis of archaeological data on BLM lands in southeastern Idaho indicates that the ephemeral ponds that dot the landscape of the Snake River Plain also influenced the distribution of prehistoric sites (Henrikson, 2002). Ephemeral ponds provided a critical source of water and food for humans, large and small game, and waterfowl in the spring and early summer. The numerous archaeological sites that surround these features suggest that they were indeed a significant resource to the Shoshone. Because the Preserve contains extensive lava edges as well as hundreds of ephemeral ponds, our current research efforts posed a tremendous opportunity to understand the role of these landscape features in the Shoshone seasonal round.

SPATIAL ANALYSIS OF ARCHAEOLOGICAL DATA

Due to the combined efforts of the BLM, NPS, and the University of Oregon, roughly 60,000 acres of the Preserve have been intensively inventoried for archaeological resources. As a result of these efforts, a total of 275 prehistoric sites have been recorded. In order to delineate the different types of archaeological sites encountered in the Preserve, each site was assigned a category based on the variety of artifacts encountered. These categories include residential base, short-term base camp, and field camp.

Residential bases include projectile points, drills, scrapers, edge-modified flakes, groundstone and ceramics. The presence of such items suggests multiple activities performed by small family groups (including women and children). Significantly, residential bases also include more permanent site furniture such as house floors, storage pits and fire pits (Thomas, 1983). Short-term base camps lack physical evidence of houses or other more permanent structures that would suggest intensive, sustained occupation. The occupation of base camps is expected to last only a few weeks and would contain evidence of the processing and consumption of only seasonal resources. Field camps are associated with the procurement of a single resource and occupied for a very brief period of a day or two (Thomas, 1983:79). Field camps are usually representative of hunting activities (e.g., kill sites, game surveillance locations or over-night "stop-off" points between kill sites and base camps). These are the most common site types found on the Preserve.

A geospatial analysis of the distribution of residential bases, base camps, and field camps

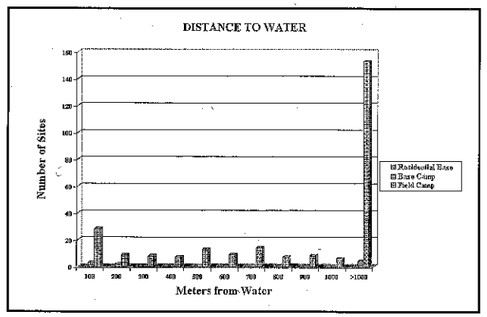


Figure 1 - Cumulative graph showing the location of archaeological sites in relation to permanent and ephemeral water sources.

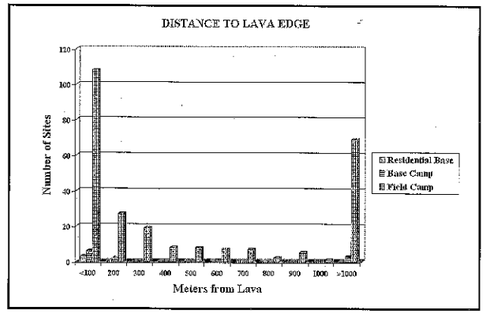


Figure 2 - Cumulative graph showing the location of archaeological sites in relation to the lava edge.

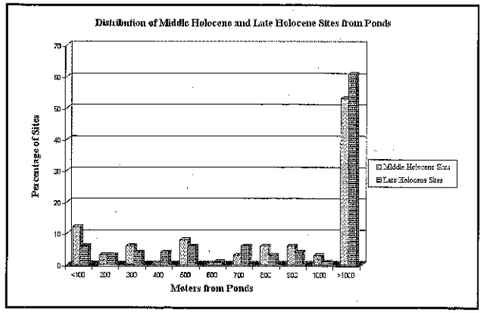


Figure 3 - Cumulative graph showing the location of middle and late Holocene sites in relation to permanent and ephemeral water.

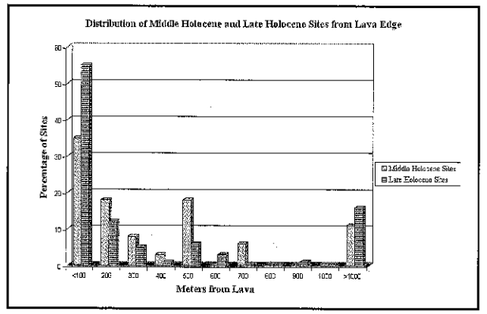


Figure 4 - Cumulative graph showing the location of middle and late Holocene sites in relation to the lava edge.

in relation to ephemeral ponds suggests that there is not a strong correlation between ponds and archaeological sites on the Preserve (Figure 1). In contrast, there appears to be a very strong positive correlation between lava edges and the distribution of archaeological sites (Figure 2). In fact, all of the residential bases, 8 of the 12 base camps and a large percentage of field camps documented on the Preserve are located at the lava edge. In other words, if people had a choice between camping at ponds or against lava flows, they preferred the latter.

As stated earlier, some potential advantages of residing at lava edges have already been brought to light by Pace's (1992) analysis of site distributions on the Idaho National Laboratory. During the winter, the lava edge captures drifting snow, which during spring and early summer months, provides essential moisture for grasses such as Great Basin Wild Rye, Indian Rice Grass and various forbs. These highly productive vegetation communities would have been attractive for both animals and humans. In addition, numerous alcoves and rock shelters along the lava edge provided shelter from the ever blowing wind.

Depressions in the lava flow, created by excavating basalt, have been previously recorded near archaeological sites. Although previously suspected to contain water, recent work by Mark O'Brien (2005) indicates that these features may contain water or ice through April. Continued research will involve revisits to a number of sites to confirm the presence of water in these catchments.

SNAKE RIVER PLAIN PROJECTILE POINT CHRONOLOGY

In order to gain additional insight regarding the role of ephemeral ponds and lava flows in the

Shoshone seasonal round, it was important to test whether this pattern of utilization remained stable over the past 7500 years. It was therefore necessary to examine the archaeological data through time. Because projectile point styles on the Eastern Snake River Plain have changed over the last 12,000 years, these artifacts can be used to assign a period or periods of occupation when found at archaeological sites (Reed et al., 1986). A projectile point chronology for the eastern Snake River Plain has been presented, with slight variations, by Butler (1986), Franzen (1981), Reed et al. (1986), and Ringe (1992). Diagnostic projectile points were recovered from about 100 sites within the Preserve, allowing us to identify when sites along the lava edge and at ephemeral ponds were occupied. However, before discussing the results of our analysis, a brief overview of the projectile point chronology of the eastern Snake River Plain is in order.

The early Holocene on the eastern Snake River Plain is generally characterized by large fluted and stemmed points dating from about 12,000 to roughly 7,500 years ago (Reed et al., 1986). It should be noted that projectile points from the Early Holocene have not been recovered from the Preserve, suggesting that this portion of the Snake River Plain was initially occupied at the beginning of the middle Holocene, around 7,500 years ago.

The earliest points found on the Preserve are smaller stemmed and notched dart points. These are thought to have been manufactured for use in harvesting bison, antelope, big horn sheep and smaller animals as part of a broad-spectrum subsistence base. The beginning of the late Holocene, around 3500 years ago, was dominated by large corner-notched points; however, with the development and domination of bow and arrow technology, approximately 1,500 years ago, we see an emergence of small corner-notched and side notched projectile points.

DISCUSSION

With the help of project points, GIS analysis has generated some interesting patterns regarding the utilization of lava edges and ephemeral ponds over the last 7,500 years. For example, if we examine the distribution of middle Holocene archaeological sites (sites dating between 7,500 and 4,000 years ago) and late Holocene sites (those dating after 4,000 years ago) in relation to ephemeral ponds, we don't see a notable difference (Figure 3). A slightly greater percentage of middle Holocene sites are located near ponds, but it is not a statistically significant increase. However, if we examine the distribution of middle Holocene versus late Holocene sites in relation to lava edges, we do see a significant increase in the utilization of the lava edge during the last 4,000 years (Figure 4).

What can account for this more intensive use? One possible explanation could be that the productivity of plant communities at lava edges improved due to increased rainfall during the late Holocene. However, existing paleoclimatic data do not indicate any significant changes in effective moisture on the eastern Snake River Plain.

Instead, the more intense utilization of lava edges during the late Holocene may be correlated with an overall increase in site density in the region. The number of archaeological sites dating to the late Holocene on the Preserve is more than double the number of middle Holocene sites, suggesting that human populations were increasing on the eastern Snake River Plain during the last 4,000 years. Although we can't completely eliminate environmental factors without pursuing additional paleoclimatic data, some recent discoveries on the Preserve suggest that, during the last 4,000 years, there were perhaps other incentives for camping at the lava edge.

One of these discoveries includes Site 10BN389, a late Holocene site located in Laidlaw Park. The site contains all of the elements of a base camp, including stone tools, ceramics, ground stone and a rock feature that appears to be a 2,000-year-old bison roasting pit. However, just above the site, along the crest of the lava edge are numerous rock features that are too high above the plain to be hunting blinds and are much more suggestive of defensive structures or lookouts. From these vantage points, individuals could see great distances on the open plain.

This recent discovery has provided new insights regarding the unusual location of a late Holocene residential base located on the eastern edge of the Preserve. Referred to as the Lost Lava Rings, the site consists of thirteen circular basalt features situated in a sheltered lava embayment located about 300 meters inside the Craters of the Moon lava field. Attached to the circular "house floors" are smaller, semi-circular rock rings that may have functioned as storage features (Henrikson, 2002). The selection of this location for a residential base seems odd, given the relatively inhospitable surroundings. (The Minidoka Flow, on which the site is located, is devoid of soil and vegetation). However, a small cave located on the southwest side of the embayment contains a deep pool of water generated from condensation as warm exterior air hits the interior walls of the cave.

Although this water source may have been a very attractive feature that would have encouraged use of the embayment, it is probably not the only factor involved in selecting this location as a residential base (Henrikson, 2002). However, the house features at the Lost Lava Rings Site are not positioned at the highly productive lava edge but are located on barren basalt 300 meters into the flow. Rather, this location is more suggestive of a strategic defense location.

Recent investigations at site 10BN861 have also challenged our assumptions regarding the significance of ephemeral ponds in the distribution of prehistoric sites. One perceived disadvantage of camping at the lava edge has been the absence of water. The availability of water at the Lost Lava Rings site was considered an anomaly. However, this newly documented base camp located across a narrow finger of lava from 10BN389 indicates that water may have been available at the lava edge. An extensive trail system extends from the site into the flow and terminates at deep pits in the basalt.

It is currently suspected that these small depressions may have held water from melting snow during the spring and early summer, however, confirmation will require additional visits to the site. If water is found in these depressions, our current assumptions regarding the role of ephemeral ponds and lava edges in the Shoshone seasonal round may need to be revised.

CONCLUSIONS

Based on the analysis of archaeological data within the Craters of the Moon National Monument and Preserve, Holocene lava flows clearly need to be considered in any investigation of pre-contact Shoshone settlement and subsistence patterns on the eastern Snake River Plain.

The data indicate that the lava edge was a preferred location whether groups intended to stay overnight or for longer periods. This analysis also suggests that human populations were growing during the late Holocene and that utilization of the lava edge also increased over the past 4,000 years. While the attraction of lava edges may be associated with greater effective moisture, we currently do not have paleoclimatic data that support this hypothesis. Instead, the presence of what appear to be defensive structures at base camp 10BN389 and the inhospitable location of the Lost Lava Rings residential base suggest that the variables responsible for site distribution patterns as well as the character of late

Holocene sites on the eastern Snake River Plain may be more complex than previously predicted. Although the availability of food and water were critical in the cold high desert, our recent discoveries on the Preserve suggest that intercommunity stress associated with late Holocene population pressures may have also greatly influenced where people chose to stay. These intriguing developments will be pursued as part of future investigations on the Craters of the Moon National Monument and Preserve.

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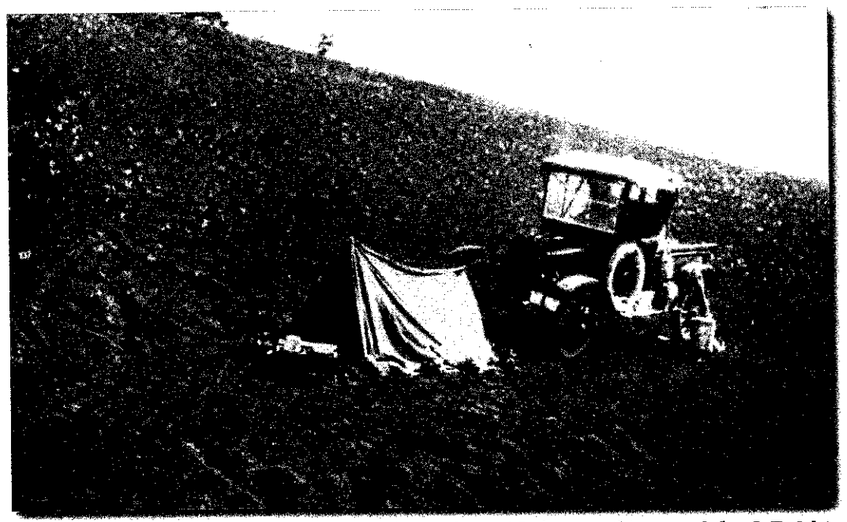
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A picturesque camp made by a lone geologist on the cinders of Inferno. Photograph by O.E. Meinzer, geologist in the United States Geological Survey, who visited the Craters of the Moon in June 1921. He made preliminary plans for a geologic survey of the area.

Prehistoric Use of Lava Tube Caves on the Eastern Snake River Plain

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INTRODUCTION

The archaeology of the Snake River Plain has been dominated by excavations in sheltered cave sites. Southeast of Craters of the Moon National Monument and on the eastern edge of the Great Rift are a series of lava tube caves that were used as locations to make stone tools, process and store food, and escape from the weather. The caves become accessible when sections of the lava tube collapsed creating openings in the ceilings of the hollow tubes. The accessible segments of the lava tube range from short, 50 ft. sections to intact sections over 700 feet long.

The study site contains eleven lava tube caves and the surface area between the cave openings. The caves include Raptor Cave (10BT2200), Coyote Lair Cave, Bat Snack Cave, Roadside Cave (10BT2246), Bat Hangout Cave, Corroded Abode Cave, Hiker's Oasis Cave, Swiss Cheese Ceiling Cave, Unnamed Cave, Bobcat Cave (10BM56), and Condor Cave. The surface surrounding each of the caves is littered with varying quantities of lithic debitage. Most of the cave interiors contain evidence of prehistoric use.

THE CAVES

Raptor Cave (10BT2200) is part of a lava tube system originating from the Serviceberry Butte lava flow. The cave is part of a lava tube system with two collapsed cave openings near a depressed but not collapsed section of lava tube. A surface survey located a dense lithic scatter centered near each of the cave openings and extending over 300 meters.

The floor of Raptor Cave is composed of a mixture of sand and boulders. A majority of the ceiling is over six feet high. Depending on the time of day, there is adequate light to allow movement throughout the cave. To the south of the main chamber is a secondary chamber that has a lower floor level and is 8° Fahrenheit colder than the main chamber.

Raptor Cave contains twenty-five well preserved rock art panels painted in vivid colors ranging from yellow and pale red to deep red. The rock art panels depict images of animals, humans, and geometric shapes. Stylistically, the rock art dates from 200 to 1,500 years before the present. (Merrell, 2002)

In 2002, due to extensive pothunter damage, the Idaho Falls District of the Bureau of Land Management and the University of Idaho conducted an excavation within Raptor Cave. The excavation produced flaked lithic tools, modified flakes, a quantity of debitage, and a single pottery shard. In addition to lithic artifacts the excavation produced a variety of faunal artifacts and charcoal. The faunal assemblage included elements from small, medium, and large mammals. Charcoal yielded radiocarbon dates that spanned from 420 +/- 40 B.P. to 2,910 +/- 40 B.P. The range of dates confirmed that the site contained undisturbed

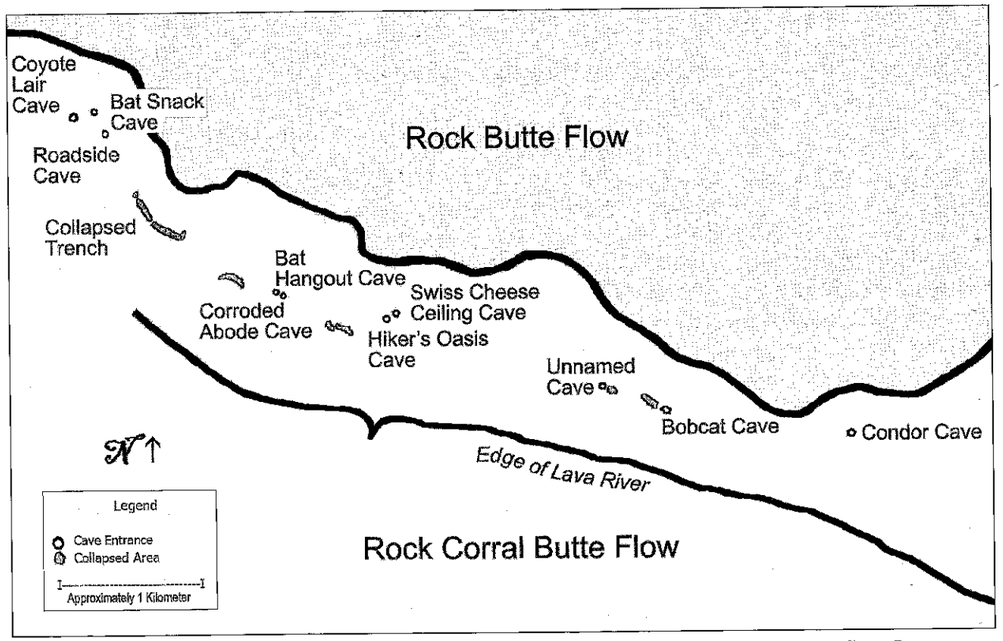


Figure 1. The remaining ten study site caves are located 13.5 miles to the east of Raptor Cave Lava, originating from a vent at Rock Corral Butte which formed a lava river that flowed east along the south edge of Rock Butte flow. Near the center of the lava river is a lava tube containing numerous collapsed segments and cave entrances.

deposits and established a record of cave use that spans nearly three thousand years.

The remaining ten study site caves are located 13.5 miles to the east of Raptor Cave (see Figure 1). Lava originating from a vent at Rock Corral Butte formed a lava river that flowed east along the south edge of the Rock Butte flow. Near the center of the lava river is a lava tube containing numerous collapsed segments and cave entrances.

The most western site, Coyote Lair Cave has a wide opening with little depth. The west facing entrance allows for excellent light and sufficient air circulation for fire building. Lithic debitage is concentrated near the cave entrance and includes a high number of primary decortication flakes, large cores, large broken bifaces, as well as a number of prismatic blade fragments. The close proximity of the obsidian sources at Big Southern Butte and Cedar Butte contributes to the heavy concentration of debitage. Lithic debitage extends from Coyote Lair Cave to the next cave to the east.

Bat Snack Cave is the eastern entrance of a double entrance cave. The cave is surrounded by a dense lithic scatter, and several pottery fragments were found south of the entrance. The cave has a sand floor and adequate air circulation necessary for fire construction. Roadside Cave (10BT2246) is the western entrance into the same section of lava tube (Sappington et al., 2003).

Due to pothunter vandalism, Roadside Cave was excavated by Bureau of Land Management and University of Idaho archaeologists in 2004. The minimal excavation produced flaked lithic tools, battered cobble tools, and extensive quantities of debitage. The excavation also uncovered a variety of faunal remains from small, medium, and large mammals. A high percentage of the bone fragments were burnt.

Excavated artifacts were submitted for protein residue testing and produced positive reactions for rat, chicken (sage grouse), bovine

(bison), and rabbit antiserum (Parr, 2005 in Sappington et al., 2005). The diversity of faunal remains and the results of protein analysis indicate a wide range of faunal utilization within the cave. The non-vandalized areas had intact stratigraphy, and every level contained charcoal. Samples were submitted for radiocarbon dating and produced a datable chronology for the cave spanning from 1,260+/-30 B.P. to 1,890+/-60 B.P. The distribution of radiocarbon dates confirm that the cave contained undisturbed materials and indicated nearly 2,000 years of cave use.

The next entrance to the Rock Corral Butte lava tube is located further to the east. Lithic scatter becomes quite dense approximately 100 feet from the depression containing Bat Hangout Cave. The small overhang creates a sheltered area with little depth. The open, rounded ceiling provides shelter, adequate light, and air circulation adequate for fire construction.

Nearby, the entrance to Corroded Abode Cave is an attractive sheltered area while the depths of the cave are less inviting. An obsidian point midsection was found in the entrance of the cave, and limited lithic scatter extends around the cave opening. The long cave requires additional artificial light, and low air circulation would limit fire construction.

East of Corroded Abode Cave is a section of entirely collapsed lava tube. The collapsed area forms a natural canyon-like depression that is 10 to 20 feet lower than the surrounding area. The collapsed area provides shelter from the ever present wind. There is limited lithic debitage throughout the depression and along the rim of the collapse.

East of the collapsed canyon-like area are the next sets of caves. The lithic scatter progressively becomes thicker as one approaches the collapsed area containing openings to Hiker's Oasis Cave and Swiss Cheese Ceiling Cave. Hiker's Oasis Cave is a short cave with adequate light throughout. The double entrances allow air circulation necessary for fire construction. The open and well lit character of the cave makes it an ideal living area. After climbing out of the north entrance of Hiker's Oasis Cave, the entrance for Swiss Cheese Ceiling Cave becomes visible. The long Swiss Cheese Ceiling Cave is poorly lit and artificial light is needed within thirty feet of the entrance. The awkward entrance and lack of light would have made this cave less inviting for habitation.

The next section of the Rock Corral Butte flow lava tube is composed of a complex of collapsed depressed areas and intact sections of lava tube. The Bobcat Cave complex includes three caves and a number of canyon-like depressed areas. The first cave, Unnamed Cave, has a small entrance and a low ceiling. The small cave has two smaller side channels that are 5-8° Fahrenheit cooler than the main cave. The side channels are partially filled with soil and impossible to enter at this time.

East of Unnamed Cave is a series of collapsed depressions and intact sections of lava tube. The depressions provide protection from the wind and contained limited quantities of lithic debitage. The most eastern collapse is surrounded by a moderate lithic scatter and contains the entrance to Bobcat Cave (10BM56). Bobcat Cave is a double chamber cave with a single small entrance. The upper chamber contains numerous rock art panels composed primarily of groupings of tally marks. The lower chamber maintains a freezing temperature and contained numerous antler tine and hammerstone artifact clusters that may have been used in coordination to chip ice or frozen meet from between boulders in the lower chamber. (Henrikson, 1996)

In 1987 and 1989 members of Idaho State University field schools and the Idaho Falls District BLM archaeologist conducted a series of excavations on the surface and in the lower chamber of Bobcat Cave. Excavations in the lower chamber uncovered two informal fire basins and a constructed sagebrush feature. The sagebrush feature tested positive for antelope and canid antiserum and may have been part of a cold storage area. Samples of burned sagebrush and bone fragments were

submitted for radiocarbon dating and produced dates ranging from 4,360 +/- 70 B.P. to 4,110 +/- 70 B.P. (Henrikson, 1996)

The final cave in the study area is located east of Bobcat Cave. Condor Cave is a deep faunal trap with no easy entrance. The cave is entered by repelling over thirty feet to the bottom of the cave. An extensive survey surrounding the cave entrance revealed only a single flake. There has been extensive historic use of the cave and any evidence of prehistoric use may have been previously collected.

Aerial surveys indicate that Condor Cave is the last opening in the Rock Corral Butte lava tube. Satellite images show a widening and emptying of the lava river approximately one half of a mile east of Condor Cave. The distance from the first cave, Coyote Lair Cave, to the last, Condor Cave, measures 5.6 kilometers.

DISCUSSION

Analysis of these eleven lava tube caves show that they have been used for a variety of purposes including habitation, cold storage, as water sources, and as sites for animal processing and lithic production.

Several caves have features making them more comfortable including flat soft floors, shelter from the wind, light, air circulation, and comfortable temperatures. Habitable caves include Raptor Cave, Coyote Lair Cave, Bat Snack Cave, Roadside Cave, Corroded Abode Cave, and Hiker's Oasis Cave. Each one has large, open, and easily accessible entrances that provide egress as well as admitting light into the cave entrance. The double entrances at Raptor Cave, Roadside Cave, and Hiker's Oasis Cave allow for increased light within the cave as well as increased air circulation. Excavations at Raptor Cave, Roadside Caves, and Bobcat Cave uncovered evidence of repeated fire construction.

Constant air temperature adds to the comfort and habitability of the caves. During the summer of 2005, most of the caves had a constant temperature between 52° and 55° Fahrenheit and were quite cool when compared to the 100° Fahrenheit surface temperature. During the cold winter months the insulating qualities of the lava rock keep the caves significantly warmer than the sub-zero surface temperature. Not all of the caves have a comfortable temperature, and several caves maintain freezing temperatures year-round. Temperatures in the lower chambers of Bobcat Cave and Raptor Cave are below freezing and both caves contain quantities of ice providing an area for frozen food storage and ice collection.

In addition to ice, several caves contain water. Eroded water channels run from the entrance into the interior of Raptor Cave, Bat Snack Cave, Roadside Cave, Corroded Abode Cave, Hiker's Oasis Cave, and Swiss Cheese Ceiling Cave. Water enters during the winter as ice and snow, and once melted the water percolates into cave soil. Water also enters by dripping from the surface, through the ceiling, and into the caves. Cave water may be collected by placing containers below ceiling drips or by excavating pond areas in the cave floor. Excavated areas were found in most caves with eroded floor channels.

Faunal and lithic materials indicate that the caves have been used as locations for the processing of animals for food and hides. The area surrounding the caves provides an excellent opportunity for hunting sage grouse, rabbits, deer, elk and formerly bison. Hunting blinds were located near Raptor Cave and on a rise near Coyote Lair Cave. The areas between the cave entrances provide grassland habitat for grazing animals, and several water containing playa locations contain seasonal water to attract birds and animals.

The cave sites contain archaeological evidence for a wide variety of faunal utilization. Excavations in Roadside Cave and Raptor Cave uncovered fragments of burnt bone indicating cooking activities. Raptor Cave, Roadside Cave, and Bobcat Cave all contained modified and unmodified bone fragments indicating cultural bone fragmentation. Lithic tools such as modified flakes, steep-ended unifaces, and perforators are used to process and prepare food and hides for use.

Excavations at Raptor Cave recovered twenty-three modified flakes and one steep-ended uniface. Roadside Cave excavations uncovered sixty-six modified flakes, seven steep-ended unifaces, and a T-shaped perforator. The presence of steep-ended unifaces and the perforator indicate on-site hide preparation and assembly. Additional steep-ended unifaces were found on the surface near Raptor Cave, Coyote Lair Cave, Bat Snack Cave, Roadside Cave, Corroded Abode Cave, and Bobcat Cave. Modified flakes were found on the surface near all of the caves with the exception of Condor Cave. Evidence of food storage was found in the lower chamber of Bobcat Cave. The cold chamber provided a convenient location to freeze and store bison, antelope, and other animals.

The caves and the cave entrances provided locations to produce and repair lithic tools. Raptor Cave, Coyote Lair Cave, Bat Snack Cave, Roadside Cave, and Bobcat Cave had significant lithic scatters surrounding the cave entrances. The lithic scatter contained primary and secondary flakes as well as finished tools. Lithic scatter at Coyote Lair Cave, Bat Snack Cave, and Roadside Cave included a number of large cores and cortex containing debitage of primary and secondary flakes indicating the initial stages of tool manufacture. A small oval feature in Roadside Cave contained primarily secondary and tertiary lithic flakes. Bat Hangout, Corroded Abode Cave, Swiss Cheese Ceiling Cave, and Unnamed Cave have more limited lithic debitage surrounding the cave entrances. Debitage surrounding these caves include biface fragments, utilized flakes, and secondary flakes indicating on-site tool exhaustion. The absence of lithic debitage at Condor Cave may be attributed to previous surface collection.

Analysis of lava tube caves contributes to an expansion of our understanding of Archaic subsistence strategies on the eastern Snake River Plain. Early theories of subsistence have focused on seasonal cycles of resource acquisition. These theories have failed to see any value in the arid region surrounding the cave sites. The previously unknown caves offer locations for habitation, lithic production, water acquisition, and food processing and storage. Further investigation in lava tube caves will improve our understanding of prehistoric life on the Snake River Plain.

I would like to acknowledge the individuals who made this paper possible. Thanks to Lee Sappington, Carolynne Merrell, and Richard Hill for their help in the field. I am grateful to the individuals who reviewed this article. Final thanks are extended to my family who have helped and supported me throughout my adventures in the Arco desert.

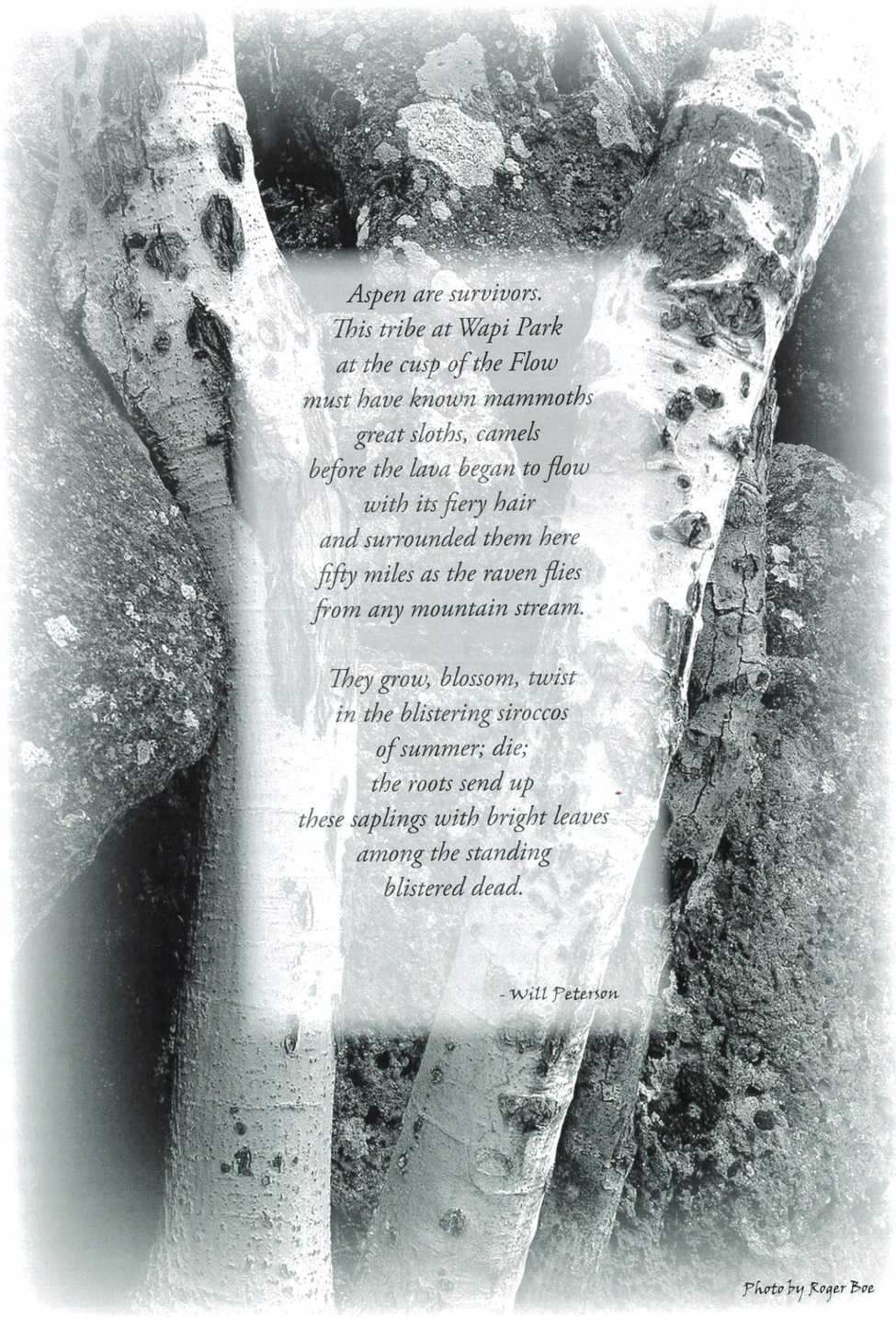
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Seeking the Source: Obsidian XRF Analysis of Projectile Points from the Craters of the Moon National Monument and Preserve

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INTRODUCTION

The National Park Service has asked the University of Oregon Museum of Natural and Cultural History to apply GIS in the analysis of new and existing archaeological data at the Craters of the Moon National Monument and Preserve in south-central Idaho in order to develop a management plan for its cultural resources. While the ultimate goal of this research is to test the archaeological data from the Preserve against a deductive model already developed for the entire eastern Snake River Plain, this paper focuses on the results of an X-Ray Fluorescence, or "XRF" analysis, of volcanic glass artifacts recovered from the Preserve over the last 20 years.

In areas characterized by volcanic activity, such as the Snake River Plain and surrounding mountains, basaltic flows of tool quality obsidian are fairly common. Thus obsidian artifacts dominate the assemblage from most prehistoric archaeological sites in the region. Obsidian was selected by aboriginal groups for its unique qualities. Although not as durable as silicates, it is very accessible, easily knapped, and is extremely sharp.

METHODS

While obsidian scrapers, knifes, multipurpose tools, and waste flakes are often found during survey and recovered during excavations, only diagnostic projectile points that could be assigned a temporal period were used during this research. By sourcing a wide range of projectile points recovered from sites throughout the study area we hoped to address questions regarding changes in volcanic glass source utilization through time. We also hope to be able to detect possible prehistoric trade routes and changes in the seasonal round which we will examine against the deductive model.

XRF analysis is a nondestructive analytical technique used to diagnose trace elements in volcanic glass. This technique looks at the molecular make-up of different elements in various samples. Since the percentage of trace elements in obsidian, the most common of the volcanic glasses, varies from source to source, it is possible to locate the specific geographic locations from which the raw stone used in the manufacture of individual artifacts originated. This is done by comparing the element values used to characterize the samples to those for known obsidian sources reported in the literature and with unpublished trace element data collected through analysis of geological source samples. The projectile points used in this study were analyzed by Northwest Research Obsidian Laboratory, and were attributed to a source if their trace element values fell within two standard deviations of the known upper

and lower limits of a source's chemical finger print. The sources identified in the current investigation were originally described by Bailey, Holmer, and Plager.

Projectile point types on the Eastern Snake River Plain have changed through time, possibly reflecting variability in technologies, shifts in subsistence strategies and/or diffusion of stylistic traits. A projectile point chronology for the eastern Snake River Plain has been presented, with slight variations, in the previous paper. This chronology will be applied to our study to structure the analysis of source data from the Craters of the Moon National Monument and Preserve. Large fluted and stemmed points characterize the early Holocene on the eastern Snake River Plain. The beginning of the middle Holocene, roughly 7,500 years ago, is marked by the appearance of smaller stemmed and notched dart points. These include Northern Side-notched, Stemmed-indented base, and McKean type projectile points. The beginning of the late Holocene, around 3500 years ago, was dominated by Elko Corner-notched points, however, approximately 1,500 years ago, we see an emergence of small corner-notched projectile points. These points include the Rosespring, Desert Side-notched, Avonlea, and the Cottonwood Triangular. During the initial stage of our analysis, we applied intuitive methods to categorize points; however, a statistical analysis of the points is currently underway.

To ensure that projectile points from all segments of the study area were included, I created a shape file in ArcView GIS that presented all recorded prehistoric finds with diagnostic projectile points in the research area. Since the study area has had very limited subsurface excavations, the majority of the projectile points used in this analysis were collected during intensive pedestrian survey. I selected 78 diagnostic projectile points for XRF analysis. Most of these projectile points were selected based on information provided in the Idaho State Historic Preservation database and then procured from the collections at Idaho State University. In addition to these, I utilized points that were collected from the Craters of the Moon National Monument and Preserve during the 2004 and 2005 University of Oregon Summer Field Schools. In order to get a varied sample, I selected points from recorded isolated finds as well as sites designated as field camps, base camps, residential bases, and lava tubes. I also selected a range of projectile points from many of the multicomponent sites to document changes in source utilization through time.

RESULTS

Of the projectile points submitted for source analysis we included 29 projectile points from the middle Holocene and 49 projectile points dating to the late Holocene. As of yet, no projectile points from the early Holocene have been recorded or collected from within the Craters of the Moon National Monument and Preserve. The complete lack of early Holocene sites in this area is fascinating in itself and deserves future investigation.

From the middle Holocene we sourced 11 Northern Side-notched, and 8 Stemmed-indented base and 10 McKean projectile points. From the late Holocene we sourced 24 Elko type projectile points, 12 Rosespring, one Gatecliff Split-stemmed, 9 Desert Side-notched points, two Avonlea type points, and one Cottonwood Triangular point. A larger number of late Holocene specimens were sourced because they represented a larger percentage of the assemblage.

Results of the research indicate that the obsidian utilized in projectile point manufacture originated from twelve different sources. These includes obsidian from the American Falls source, Bear Gulch, Big Southern Butte, Brown's Bench, Cannonball Mountain, Malad, Owyhee, Timber Butte, Wedge Butte, Butte Valley Group A, and two unknown sources. Of these twelve known obsidian sources, three make up the bulk of the assemblage. These include Big Southern Butte, Brown's Bench, and American Falls. Big Southern Butte, located just to the northeast of the project area,

is the most commonly utilized source in the sample. Sourcing results indicated that a total of 29 points, or 37 percent of the sample group, originated here. 21 points are from the Brown's Bench source, located near the Nevada/Idaho border, these comprise 27 percent of the sample group. Fourteen projectile points originated from the American Falls source, located just south of the project near the Snake River, and make up 18 percent of the sample group.

The remaining sources are all located within Idaho as well. The Bear Gulch obsidian source is located in eastern Idaho near Island Park and is represented by five points. The Owyhee source, represented by 2 points, is located in the southwest corner of Idaho, although, the exact geographic location of the Owyhee source is still undetermined as obsidian with a similar signature is found over a large region. One projectile point was sourced to the Timber Butte quarry is western Idaho. The Wedge Butte source, located just north of the Shoshone ice caves, is represented by one point. The Malad source, also represented by one projectile point, is located in the southeast corner of Idaho. The Cannonball Mountain source, located in the Soldier Mountains to the west of the project area, is represented by one point. One point was sourced to the Butte Valley Group A quarry. This source's location is still unknown but is suspected to be located on the Nevada/Idaho border. Obsidian material used in the manufacture of two points in the sample originated from an unknown location.

If we examine variations in the distribution of obsidian sources through time, we see a glimpse of what may have been an overall pattern of obsidian utilization over the past 7,500 years. The middle Holocene is represented by Northern Side-notched, Stemmed-indented base, and McKean type projectile points. Based on absolute dating methods, of points found in stratified contexts, Northern Side-notched type projectiles date from 7500 - 5000 B.P. in the study area. Although the sample group is dominated by Big Southern Butte and American Falls obsidian, sources nearest to the study area, the Northern Side-notch sample has the widest range of obsidian for the middle Holocene points (Figure 1). Other sources include Brown's Bench, the Malad source and Cannonball Mountain.

Our selected sample of Stemmed-indented base projectile points originates from only three lithic sources (Figure 1). Brown's Bench is represented by 37.5 percent of the sample group, Big Southern Butte is represented 37.5 percent of the sample group and American Falls is represented by 25 percent of the sample group.

Our sample of McKean type projectile points is dominated by obsidian originating from American Falls, 40 % sample group, and Big Southern Butte, comprising 30% of the sample (Figure 2). Brown's Bench is represented by two points and Butte Valley A

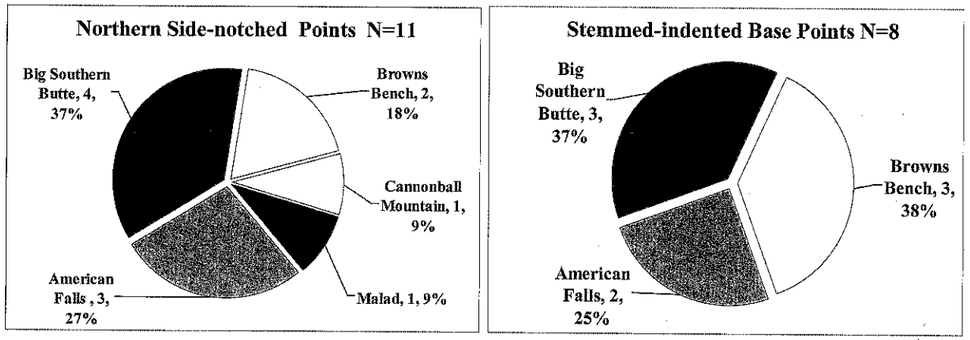


Figure 1. Total number of samples, percentage of sample group, and source locations for Northern Side-notched and Stemmed-indented base projectile points.

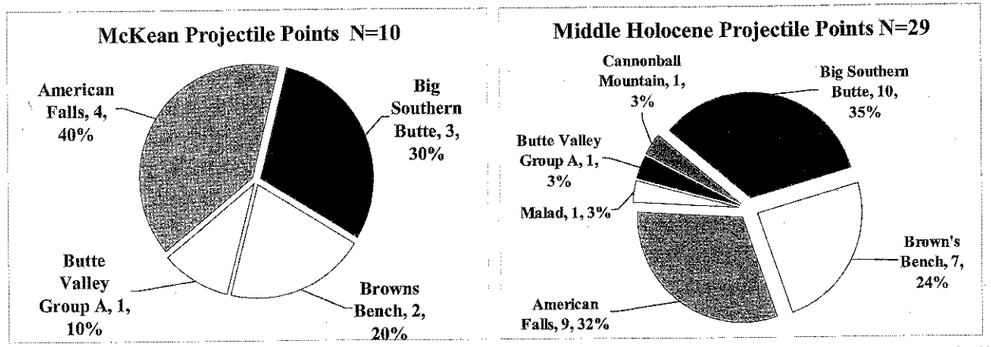


Figure 2. Total number of samples, percentage of sample group, and source locations for McKean and all of the Middle Holocene projectile points.

by one point.

When examining all the middle Holocene projectile points, three sources appear to dominate the assemblage (Figure 2). Lithic material originating from Big Southern Butte, American Falls, and Brown's Bench each make up from 24 percent to 35 percent of the sample group. The remaining 9 percent of the sample group is split between the Malad, the Butte Valley Group A, and the Cannonball Mountain sources.

Projectile points dating to the late Holocene in the study area include Elko, Gatecliff Split-stemmed, Rosespring, Avonlea, Desert Side-notch, and Cottonwood Triangular. We sourced a total of twenty-four Elko projectile points from the study area. 34 percent of the tool stone originated from the Brown's Bench source (Figure 3). Big Southern Butte and American Falls are also well represented. Two points were identified as Bear Gulch obsidian, two points are from an unknown source, and one Elko point originated from the Timber Butte source.

From the 12 projectile points that fell in to the Rosespring classification, a total of six projectiles, or 50%, of the sample group were identified as Big Southern Butte obsidian (Figure 3). The next largest obsidian group is Brown's Bench which makes up 33 % of the total sample. Rosespring points from Wedge Butte and an unknown basalt group each make up eight percent of the total sample.

Nine projectile points were identified as the Desert Side-notch type. This group is dominated, 33%, by Bear Gulch lithic material

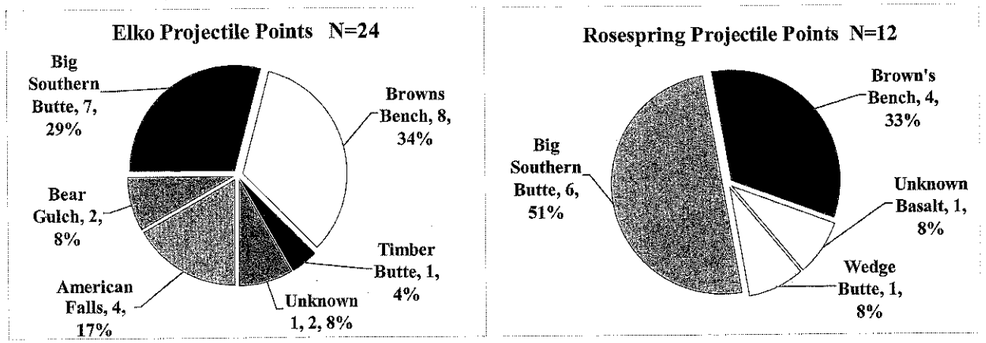


Figure 3. Total number of samples, percentage of sample group, and source locations for Elko and Rosespring projectile points.

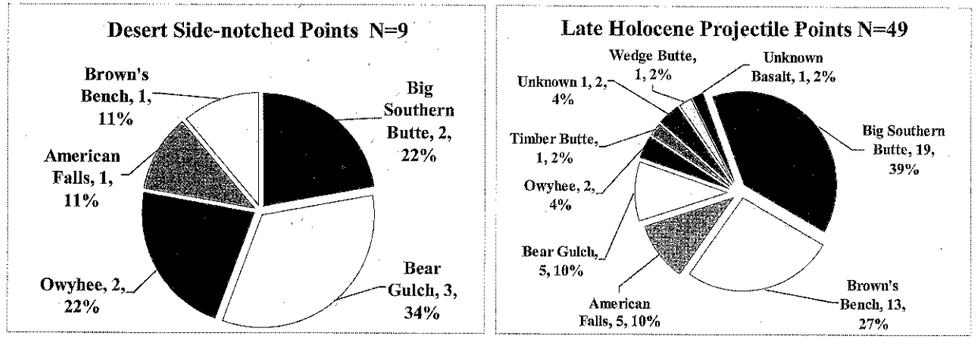


Figure 4. Total number of samples, percentage of sample group, and source locations for Desert Side-notched and all the late Holocene projectile points.

(Figure 4). The Big Southern Butte and Owyhee sources are represented by 22% of the sample group. The Brown's Bench and the American Falls sources are each represented by 11% of the sample group.

During this preliminary analysis, due to funding limitations, we were unable to source a large enough representative sample of Gatecliff Spit-stemmed, Avonlea, or Cottonwood Triangular projectile points to have scientific validity. Although individual analysis of these points was not possible, I have still included the small sample with the broader late Holocene sample group. A total of nine lithic sources were utilized during the late Holocene by groups in the study area (Figure 4). The primary sources being Big Southern Butte, represented by 39 percent of the sample group, and the Brown's Bench source represented by 27 percent of the sample group. Five points come from each Bear Gulch and American Falls with the remaining lithic sources are represented by one or two points each.

CONCLUSIONS

When comparing all the middle Holocene lithic sources to the sources of late Holocene points a pattern emerges (See Figures 2 and 4). It appears that during the late Holocene groups on the eastern Snake River Plain utilized tool quality stone from a wider variety of obsidian sources and from greater distances away from the project area. Although it does appear that obsidian originating from Big Southern Butte and Brown's Bench dominate both sets, during the middle Holocene we see a increased use of American Falls obsidian while during the late Holocene we see evidence of utilization of a greater number of more distant sources. This phenomenon could be the result of increased population densities resulting in increased group contact. More people in this region would also result in greater utilization of possible site locations and thus greater number of late Holocene period sites.

Henrikson's research on the eastern Snake River Plain suggests continuity of subsistence strategies and material acquisition in the Shoshone-Bannock's seasonal round. Based on the preliminary results of the XRF analysis, obsidian sources utilized, the geographic locations of recovered specimens, and evaluating the site types from which these specimens were recovered, evidence resulting from this study agrees with the current theory of a fairly stable subsistence strategy. All obsidian utilized by the Shoshone-Bannock and sourced during this study originated from sources within Idaho.

The three dominate obsidian sources include American Falls, Brown's Bench, and Big Southern Butte. These localities all fall within the ethnographic seasonal round of the Shoshone-Bannock. The other sources identified during this study are located in areas from which acquisition on the eastern Snake River plain would not have been difficult. Ethnographic

reports state that Native American groups from all portions of Idaho would congregate in the Camas Prairie during the late summer. The presence of these less utilized obsidian sources from the project area suggests evidence of an inter-regional trade network with acquisition perhaps occurring during these gatherings or during random encounters with other groups.

The lack of other obsidians in the projectile point assemblage indicates that the Idaho sources were of sufficient quality and quantity to preclude acquisition of obsidian from areas outside the seasonal round of the aboriginal Shoshone groups. Although a complete understanding of the implications of this study would require considerable investigations, perhaps Idaho obsidian was "flowing out" as a trade export while other goods unavailable in Idaho were being imported.

In the next year I plan to submit at least fifty additional projectile points for XRF analysis. Although 78 sourced projectiles is a good start, this is just a drop in the bucket compared to the number of sites and diagnostic artifacts in the completer assemblage.

A possible interesting continuation of this study would be to source projectile points from collections outside of Idaho. A recent study conducted by Randy Thompson of the U.S Forest Service traced Malad obsidian as far south as Texas. This type of investigation would be effective in discerning the extent and direction of the flow of other obsidians such as Big Southern Butte, American Falls, and Brown's Bench. I believe XRF analysis of prehistoric stone artifacts has the potential of greatly increasing our knowledge of aboriginal lithic material acquisition, trade networks and prehistoric life ways in Idaho and beyond.

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Photo by Roger Boe

American Material Culture: Investigating a World War II Trash Dump

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"The past is given new dimensions by studying the small things so often forgotten...

objects so plain they would never be displayed in a museum".

– James Deetz

Historical archaeologists love trash, the older the better. One such trash dump lies relatively untouched on the Department of Energy's Idaho National Laboratory (INL). The U.S. military dumped its trash in dry irrigation canals during and after their World War II activities and shortly before the federal government designated this arid and desolate place as the nation's nuclear reactor testing station in 1949. When examined critically and combined with memories, photographs, and other documents, the 60-year old trash provides a glimpse into 1940s' culture and the everyday lives of ordinary people who lived and worked during this time on Idaho's desert.

The story begins in the fall of 1942. After months of rumors and speculation, the U.S. Navy opened the Naval Ordnance Plant two miles north of Pocatello. Here they manufactured, assembled, and repaired a wide variety of weapons and ammunition. The size of ordnance ranged from light caliber to sixteen-inch guns. Before being sent from this dry, inland locale onto Navy battleships, the ordnance first had to be test fired to ensure its accuracy and dependability. The dangers associated with test firing, called proofing, required an isolated, relatively flat area with gravelly soil and no outcrops or other obstructions that could cause shells to ricochet. After inspecting several possible test sites, Naval Commander J. A. Scoville selected a long, narrow stretch of sand and sagebrush approximately sixty miles northwest of Pocatello and seventeen miles northeast of Arco. After site selection, the Navy was quick to initiate construction at the new proving ground, one of only six in the country and the only one used to test fire the Pacific Fleet's "Big Guns" (U.S. DOE, 2005; Arco Advertiser, 1942 and 1946).

By the end of 1942 the war with Japan was accelerating and the Navy had no time to waste in getting weapons into battle. Construction workers and equipment soon swarmed over the once deserted and barren land. By the following summer, Navy officers, civilian workers and their families, and Marines with guard dogs had arrived at the site. The Navy called it the Arco Naval Proving Ground, later shortened to the NPG (Wyle Laboratories, p.1-1, 2-5) .

On November 11, 1943, the Navy celebrated Armistice Day and the NPG's formal opening by inviting curious local town folks to a special program. Although the nearly eighty-thousand acre firing range was off-limits, dozens of

visitors toured the southern portion of the NPG. The tour included two separate sectors that together covered a little over two hundred acres. The northern-most "Proofing Area" was the business end of the NPG. It consisted of a railroad spur and 250-ton gantry crane that civilian workers used to unload ordnance after its arrival by rail from the Pocatello Plant. The area also included an office building, rows of wooden and concrete gun mounts, earthen and concrete munitions bunkers, and a fire control tower that sat atop a heavily reinforced eight-foot wide concussion wall. The wall served to protect the men and women, known as Women Ordnance Workers (WOWs), who loaded and test fired the weapons (Arco Advertiser, 1943).

On the south side of the concussion wall and about a half mile away from the Proofing Area was the "Residential Area" where military and civilian workers, with their families, lived. The area contained solid, red brick bungalows that served as officers' quarters, matching red brick barracks for the Marine guards, and a cinder block commissary that residents called simply "the store" (Stacy, p. 11).

At first, unlike the Navy officers and Marine guards, most civilian workers and their families lived in communities around the NPG. However, rough roads and severe winters made the drive to the NPG treacherous. This danger, combined with the scarcity of available housing, led the Navy to build their own houses and barracks on the isolated base. Some residents lived at the NPG until 1949 when the Navy transferred the site to the newly formed Atomic Energy Commission, leaving behind shell casings, empty buildings, and piles of garbage to prove they were there (Stacy, pp. 11-15).

Some of the homes and other NPG buildings and structures were reused by the Atomic Energy Commission's nascent nuclear reactor program that was intended to maximize the use of the atom for military and peaceful uses. However, nearly fifty years would pass before another thought was given to their garbage or the lives and culture it represented. For example, the trash dump's location revealed clues to society's attitude about the environment during the 1940s. Although the trash dump lies just off the main highway between Idaho Falls and Arco, passers-by would never know it was there.

As evidenced by the scattered debris, the NPG cleanup crews apparently backed up to an old, dry irrigation canal and shoveled the trash into it. The gently undulating terrain and large sagebrush concealed debris that missed the canal. Unless one accidentally stumbled across it, the existence of the dump would have remained unknown. However, the dump's location was not accidental and illustrates the "out-of-sight, out-of-mind" mentality about refuse that existed at the time. Unlike today, the military did not even attempt to cover the trash with soil, leaving it exposed to the elements but hidden from human view.

Like the casual passers-by, INL archaeologists were unaware of the dump or its origins until the early 1990s. It was then that an INL project manager called them about the eyesore and need to clean it up. They jumped at the chance to examine the then mysterious debris and determine where it had come from and who might have left it.

The near absence of industrial waste and the wide variety of household items indicated that the trash had probably not come from the INL's scientific activities. Although the depth of the trash varied, in some places exceeding three feet, it extended for well over a mile. The sheer volume of garbage and its uneven distribution suggested that whoever had dumped the trash had made several trips to the same canal, perhaps regularly over an extended period of time. Some of the garbage also appeared to have been intentionally set afire perhaps in a misguided effort to destroy it. However, most of the discarded items remained intact though charred and missing paper labels.

Given its relatively close proximity to the former NPG Residential Area, investigating archaeologists assumed that the trash originated there but further investigation was needed to prove it. A cursory inspection of several of the

artifacts allowed them to be dated. Diagnostic features, such as the structure, composition, and openings of cans, manufacturer trademarks, inclusions in glass bottles, and patterns on china, allowed archaeologists to narrow the dates of the dump to between 1920 and 1960. Knowing the INL area had been closed to the general public and their garbage since 1949 helped to narrow the dates even further.

Archaeologists and a professional historian continued the investigation by searching libraries, newspaper archives, and federal records for information about the NPG. Although the information was scattered and often vague, they did find documents that detailed the size and kind of ordnance tested, the results of many of these tests, and descriptions of the Residential and Proofing areas' infrastructure. However, other than mentioning the commanding officers' names, official reports said nothing about the people who had left the trash. Fortunately, it was soon learned that some of the NPG alumni had stayed in Southeastern Idaho and, over the years, were willing to share their stories punctuated with shows of old family photographs. The stories and photographs described life on the NPG base, often told by people who were just children during World War II.

During subsequent visits to the dump, excitement grew as individual items were identified that supported the stories about the Proving Ground's social activities and residents. For example, one colorful story revealed that the Navy threw fairly wild parties at this area where the government had long ago prohibited the possession of all alcohol. Another story recalled Saturday nights when the NPG engineer drove a locomotive, used to move ordnance, from its shed and talented local musicians played the latest tunes while couples danced and drank the night away. Predictably, after a few hours and many drinks, punches were thrown and the on-duty Marine guards had to break up the fights. The substantial quantity of heavy crown-top beer cans lining the dump lent credence, at least to the first part of this story (Anselmo, 1997).

A toy riding train and baby doll buggy brought to mind another story also involving trouble and the Marine guards but this time the culprits were much younger members of the NPG community. It seems that, while riding the school bus the seventeen miles each way to and from Arco, a few of the restless boys bullied the younger children. In typical military fashion, the Navy stationed a Marine guard to ride the bus to and from school which effectively took care of the problem (Stacy, p. 12).

Old photographs showed a semi-circle of the now nonexistent small, white frame houses the Navy had built. Barely visible in the backyards of many of these tidy homes, appeared gardens. The women who lived at the NPG had apparently tried to make the isolated and barren desert seem more like a friendly small town than a wartime Naval base. They raised and displayed flowers in the once-bright red, yellow, and blue pots and vases that were strewn, broken and faded, throughout the dump. To supplement their families' bland diets the women planted, canned, and served fruits and vegetables from the backyard gardens as evidenced by their now-grown children's fond memories and the dump's bent pressure cooker, broken Mason jars, and fragile, floral patterned crockery pieces. These items lay scattered randomly among the ubiquitous tin cans and bottles that spoke volumes about the NPG's tasteless, military-supplied food. Even shattered, the cobalt-blue of Milk of Magnesia bottles is unmistakable against a backdrop of blackened ketchup bottles and rusted bean and meat cans. Other medicine bottles, including some normally associated with headaches, also languished nearby as, perhaps, reminders of the rowdy Saturday night get-togethers (Anselmo, 1997).

Thanks to priceless stories, hours of research, and historical archaeologists' ability to read the language of artifacts, the dump turned from just another trash heap in need of being cleaned up into a treasure trove of 1940s memorabilia worthy of keeping. Such studies

of "those small things often forgotten" serve to fire imaginations, enrich understanding of past practices, and humanize history. Historical archaeology provides opportunities to integrate inanimate objects with animated narrative and, the more recent the artifacts, the more human the stories they can tell. The study of the INL World War II trash dump provided an opportunity to combine archaeology and history to vividly portray unique events from Idaho's more recent past and to commemorate events and persons who might otherwise also have been forgotten (Hodder, p. 217).

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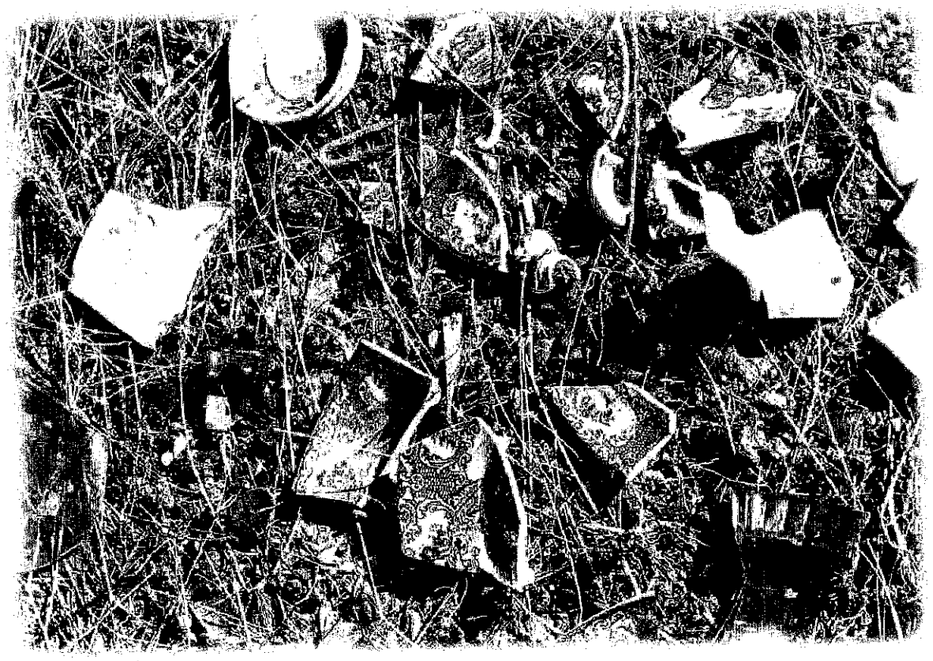
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Geophysical Investigations of Archaeological Resources in Southern Idaho

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INTRODUCTION

Archaeologists today are frequently turning to sophisticated tools, many from the field of geophysics, to use along with traditional shovels and trowels in the study of the past. Long a mainstay in the archaeology of Great Britain, Europe, and the Middle East, the increased deployment of these techniques in U.S. settings is largely due to recent major advances in instrumentation that have increased speed, sensitivity, and digital image processing to allow for rapid, effective identification of low-contrast features such as hearths, middens, and house floors, which characterize prehistoric archaeological sites in the western U.S. (Mussett 2000).

Devices like ground penetrating radar and magnetometers are ideally suited to many archaeological research problems because they provide rapid three-dimensional images of sensitive deposits and do this in a nondestructive manner. One of the primary values of near-surface geophysical methods to the practice of archaeology lies in their cost-effectiveness. Mapping of the basic subsurface structure of a site and the layout of archaeological features within it can guide the placement of traditional excavations to areas of potentially greater interest, saving time and money in the process. Geophysical methods are also attractive because they are non-destructive and allow for the preservation of archaeological deposits for future generations. They permit noninvasive examination of culturally sensitive burial, sacred, or ceremonial sites, which can be essential in maintaining positive relationships among stakeholders and Native American Tribes.

In archaeological contexts, geophysical tools key on basic differences in moisture, compaction, and other physical characteristics of the soil that are associated with cultural features such as fire hearths, activity areas, and various cavity features like burials, caches, or earth ovens. In cave settings, it is also possible to see natural features like roof-fall and buried chambers that are of interest in planning archaeological excavations. So, while a concentration of obsidian debitage left next to a fireplace will not necessarily be visible,

certain devices will highlight the burned soil within the fire pit. Differential compaction and moisture content within the hard-packed soils surrounding the fireplace will also map differently from areas that were used less intensively.

There are a number of tools available for use in archaeological applications. These tools are either active (create and direct their own primary fields of energy), or passive (measure existing fields such as the Earth's magnetic field). In our investigations in southern Idaho, we have achieved success with two active methods, Ground Penetrating Radar (GPR) and Electro-Magnetic Induction (EMI).

GPR is an active method where a transmitter and receiver are pulled along the surface of the ground. Electromagnetic waves are sent through the ground where they continue to travel until they meet an object, which reflects them. The waves bounce back to the surface and the time taken to travel the distance can be measured and imaged.

EMI is another active method where a handheld instrument that contains a transmitter on one end and a receiver at the other is carried across the site surface. Oscillating electromagnetic energy penetrates the ground and induces secondary electromagnetic fields in regions of elevated electrical conductivity. These differences in the electrical properties of soils beneath the instrument can be measured and imaged.

The Idaho National Laboratory (INL) in southeastern Idaho is a storehouse of valuable equipment and scientific expertise and INL scientists have begun to explore opportunities for collaborative research and fieldwork in archaeological geophysics. Both GPR and EMI have been employed successfully by the INL team to successfully map a 1,300 year-old hunting campsite located on INL lands (Pace et al. 2003, Pace 2004) and a lava tube cave known as Kelvin's Cave (Figure 1) on Bureau of Land Management (BLM) property near Twin Falls (Henrikson and Long N.D., Pace et al. 2004).

INVESTIGATIONS ON THE INL AT 10-BT-810

The INL in southeastern Idaho occupies 890 square miles at the base of the Big Lost,

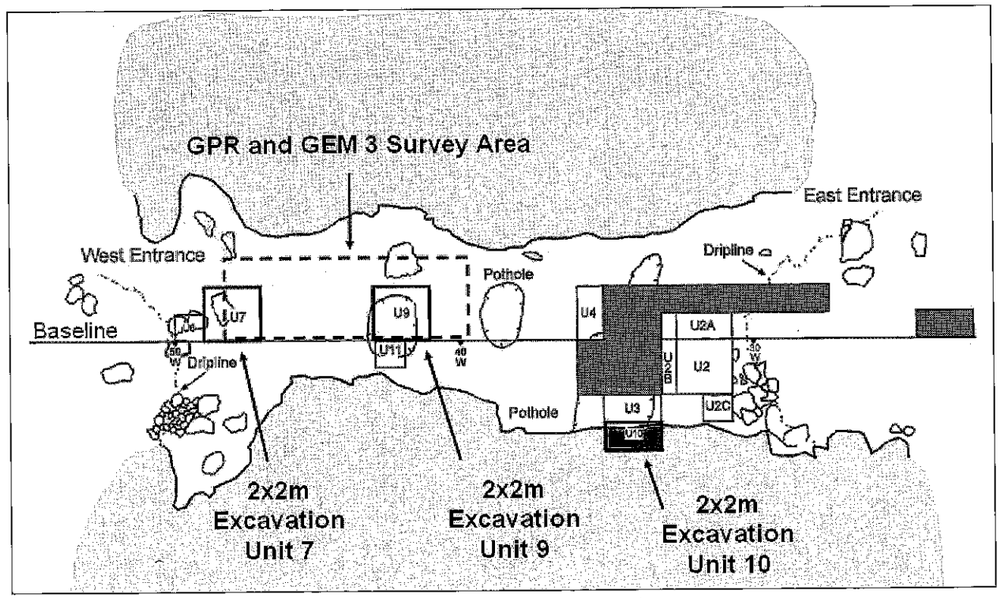


Figure 1. Cutaway of Kelvin's Cave

Lemhi, and Bitterroot Mountains. The Craters of the Moon lava fields lie a short distance to the southwest. This landscape is characterized by rolling sagebrush plains punctuated by volcanic buttes and cut through by the Big Lost River. People have lived here for 12,000 years or more. Throughout most of this time they hunted and gathered, taking advantage of a wide variety of resources like buffalo and other game, fish, edible and useful plants, and tool stone like obsidian. Evidence of their activities is preserved in thousands of archaeological sites within the protected boundaries of the INL (DOE-ID 2005) and on surrounding BLM lands. Contemporary tribal people view these earlier hunter-gatherers as esteemed ancestors and continue to value the resources that this cool desert offers.

Although much of the INL remains undisturbed, there are several main facility areas where development is ongoing. Archaeological compliance at the INL is largely focused on completion of surveys and when necessary, test excavations, in advance of ground disturbing projects in these areas. One of the archaeological sites identified during than INL compliance survey is designated as 10-BT-810 an is located in an area of preferred development at the Firing Range facility.

10-BT-810 is a small hunting campsite, probably 1,500 – 3,500 years old, as evidenced by the large corner-notched points found there over the years. In addition to point and tool fragments, the site assemblage also included debitage and indications of subsurface fire hearths. The information contained at this site is important for its potential to contribute to a greater understanding of prehistoric human use of the region, particularly in the form of datable subsurface cultural materials. As a result, the resource was originally evaluated as eligible for nomination to the National Register of Historic Places, pending confirmation of the significant subsurface cultural deposits.

With funding for homeland security at an all-time high, the Firing Range is currently one of the more active facilities on the INL. This small archaeological site, important as it is, was also quite simply in the way and protecting it had become increasingly difficult given its location in a zone preferred for new development. Since the site was important for the information it contained, under the INL Cultural Resource Management Plan (DOE-ID 2005) it was possible to design a small data recovery effort to preserve the important information before disturbance by new development. On the INL, work of this nature is also completed in consultation with the Shoshone-Bannock Tribes and a tribal representative assisted with all of the investigations completed at 10-BT-810.

The standard INL approach to determine if there are important archaeological features at a site is to excavate a series of systematic 30 x 30 x 30 cm shovel probes and intuitively placed 1 x 1 meter test units across the area to sample the cultural deposits located beneath the ground. These methods were still employed at 10-BT-810 in 2003, but geophysical surveys were completed first and then used to guide the placement of some excavation units.

Although target practice was suspended during the archaeological investigations, the surface of the ground within 10-BT-810 was littered with expended modern projectile points made of metal and plastic. Pedestrian surveys were initially completed at the site to remove as much of this debris as possible because of the impact it would have on the geophysical devices.

After initial cleanup of stray metal, the site area was surveyed with two geophysical instruments. One survey utilizing the GEM-2, an instrument that measures electromagnetic induction, proved unreliable at 10-BT-810 because the instrument was too susceptible to the effect of the metal remaining in and around the site area. More interesting and reliable results at 10-BT-810 were obtained from a GPR unit using antennae of 250 and 500 MHz. The data are still affected by the metal so prevalent on this site however, some interesting patterns probably associated with prehistoric human use of the area were also apparent. Most notably,

a linear feature running through the southern portion of the site area and a less definitive anomaly located along the edge of the linear feature were apparent in the GPR images. These anomalies showed up most clearly around 20 cm below surface, where most of the artifacts were also concentrated.

The linear feature is interpreted as a buried stream channel. Although it was not readily apparent on the current ground surface, the geophysical imaging has clearly shown that this small archaeological site is associated with a now-abandoned side channel of the Big Lost River.

The second geophysical anomaly observed in the survey data appears to be directly related to the ancient human activities represented at the site. Evidence of human activities found in both surface and subsurface contexts at 10-BT-810 included several large corner-notched dart point fragments that are typically found in dated contexts of 1,500 – 3,500 years BP in this area and obsidian debitage, the debris created during stone tool maintenance and/or manufacture and a common component of nearly all archaeological sites on the INL. Nearly 75% of the systematic 30 x 30 x 30 cm shovel probes excavated within the boundaries of 10-BT-810 yielded 1 - 5 flakes of obsidian and the 1m x 1m x 30 cm test units yielded 50 – 80 flakes. In marked contrast, a 30 x 30 x 30 cm shovel probe excavated within the boundaries of the anomaly adjacent to the stream channel yielded more than 100 flakes, significantly more than any other excavation unit on the site. Although the excavations failed to reveal any stratigraphic evidence of a cultural feature, it is still likely that the anomaly is reflecting a small remnant of a surface created from human activity concentrated in this location, probably physically evidenced today by a very subtle differential in soil moisture content.

Once again, it is not likely that the radar unit was actually providing an image of the artifacts, themselves. Instead, the anomaly observed in the imagery indicates that the portion of the site that contained these materials exhibits different soil characteristics, perhaps a higher organic content or a compacted zone, which holds more moisture than the surrounding soils.

By focusing excavation efforts in the area defined by the geophysical anomaly, the INL team was able to maximize the amount of information collected and minimize the number of test units that had to be excavated. This resulted in a cost savings to the INL project. Tribal participants in the work were also pleased by the potential of the equipment to identify archaeological features non-destructively.

INVESTIGATIONS AT KELVIN'S CAVE

After using geophysical surveys to guide test excavations at 10-BT-810 on the INL, the team joined researchers from the Bureau of Land Management and University of Oregon to investigate Kelvin's Cave, a lava tube located approximately 16 miles north of Twin Falls, Idaho. Excavations in the late 1980s at the Cave revealed Pleistocene megafauna in possible association with debitage. Curiosity about this association and an increase in vandalism at this well-known site prompted BLM archaeologist, Lisa Cresswell, to work with Suzann Henrikson and the University of Oregon Field School to conduct new excavations at the site in the summer of 2004 with the hope of confirming the Pleistocene association and establishing the scientific importance of the site.

The goal of the INL geophysics team at Kelvin's Cave was to provide images of the targeted deposits for possible use in directing the excavators to areas that would be most productive for their research questions. Areas of possible interest included zones of roof-fall, probably marking the Pleistocene to Holocene transition and very early human occupation as well as buried chambers of the lava tube where undisturbed deposits may be present. Several types of data were collected:

- *Ground Penetrating Radar data at 250 and 500 MHz within the west interior of the Cave*
- *Electromagnetic survey data (GEM-3 instrument capable of seeing near surface features in detail) within the same western interior area.*
- *Electromagnetic survey data (GEM-2 instrument best suited to larger scale mapping) outside and over the entire Cave.*

The shielded, directional, 500 MHz GPR antenna provided the highest resolution imagery of deposits inside the Cave. It is very responsive to shallow anomalies down to about 1.5 meters below surface. The radar data showed anomalies consistent with roof-fall in several spots. Excavation in Unit 9 confirmed the presence of roof fall at expected depths of approximately 93-19 cm below surface in the noted areas.

The electromagnetic survey data collected with the GEM-3 inside the Cave provided lower resolution imagery because the instrument is unshielded and measured signal from all directions inside the basaltic cavity. As a result, the effective survey depth was limited by interference from the cave roof. However, even the lower resolution images showed shallower deposits to the west with deepening soils to the east. Excavation of Unit 7 in the western end of the Cave confirmed the presence of roof fall in the area indicated by the GEM-3 at 30-35 cm below surface in this area.

In an attempt to reduce the interference from the surrounding basalt, a second electromagnetic induction device, the GEM-2, was used to survey outside the Cave, passing back and forth systematically at 1- meter intervals over the entire roof area and beyond to image the open chambers beneath and investigate the surrounding area for possible buried chambers. The data collected during this survey showed a possible buried chamber to the southeast of the existing open chamber. Deep deposits of soil extending to the south and into the buried chamber that showed up in the imagery were confirmed by the University of Oregon's archaeological excavation of Unit 10.

At Kelvin's Cave, the geophysical survey data was useful in directing the researchers to productive areas for their investigations. Student participants in the project were also introduced to archaeological geophysics and provided with a hands-on learning experience.

FUTURE DIRECTIONS FOR RESEARCH

The INL geophysics team is encouraged by these initial attempts at 10-BT-810 and Kelvin's Cave to incorporate geophysics into archaeological investigations in southeastern Idaho and continues to look for opportunities to practice the new techniques. Our interests are varied but include:

- *Non-intrusive mapping of sensitive sites like Aviators Cave on the INL, where undisturbed artifact and/or food caches are likely and where additional excavation is likely to be objectionable to tribal colleagues*
- *Mapping structural remains and features at the Powell Stage Station, a nineteenth century historic archaeological site*
- *Identification of ruts and alternative routes for Goodales Cutoff, a northern spur of the Oregon Trail, which passes through the southwestern portion of the INL*

There will be continuing challenges in this work, not the least of which will be the overall subtlety of the archaeological record of southern Idaho, with features like fire hearths and activity areas that will likely continue to be elusive targets for the equipment. State-of-the-art equipment available through the INL will help to position our team to address these complexities. We are committed to employing the tools at our disposal during all future INL archaeological research activities and in doing so, should help to advance the field in this region.

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They arrive under cover of night
in pairs or singly-
those who lost their mates
those who remain celibate-

the doves of Mexico
here to create
their Provisional Revolutionary State:

tens of thousands of them
to give the Flows wings...

- Will Peterson

GEOLOGY

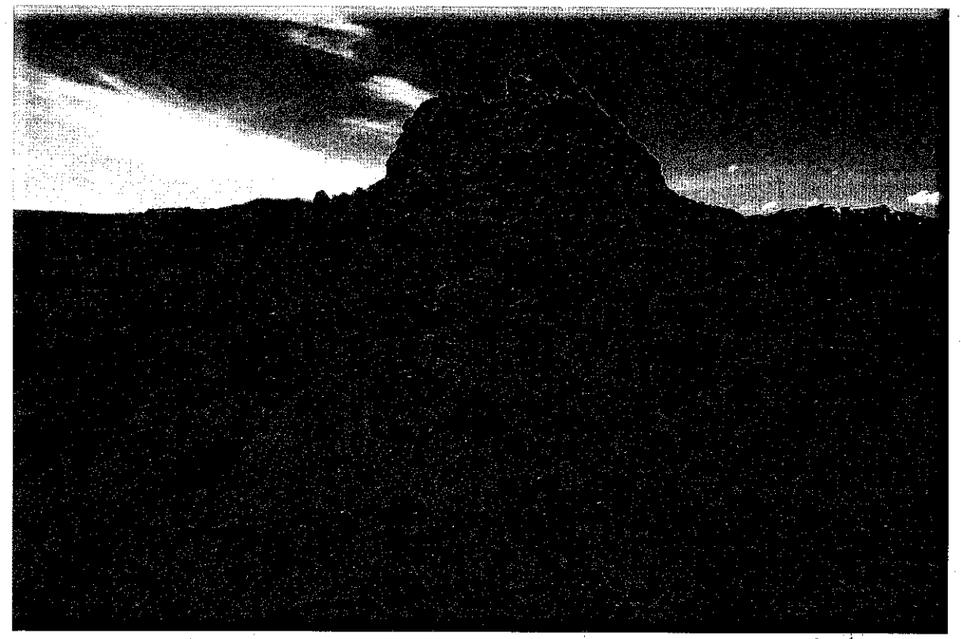
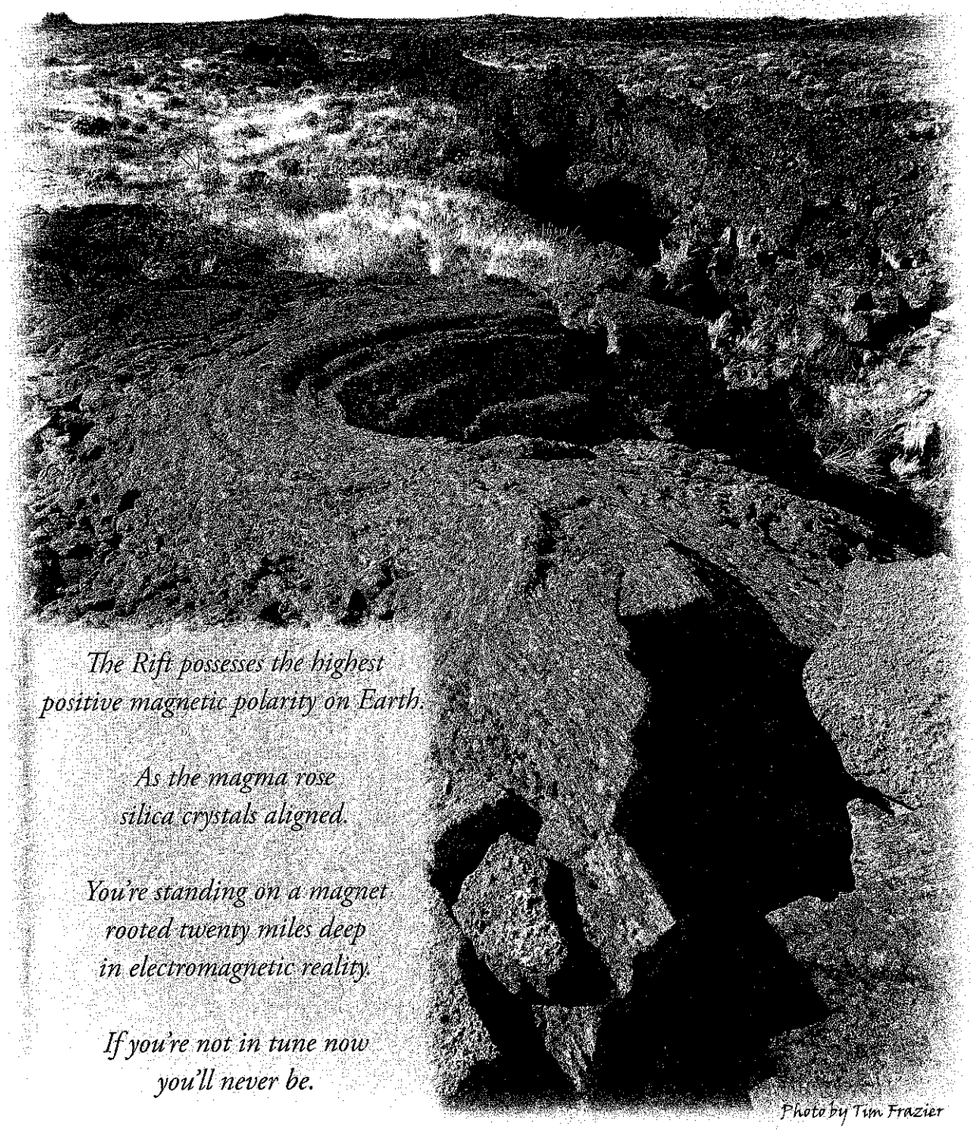


Photo by Roger Boe



The Rift possesses the highest positive magnetic polarity on Earth.

As the magma rose silica crystals aligned.

You're standing on a magnet rooted twenty miles deep in electromagnetic reality.

If you're not in tune now you'll never be.

Photo by Tim Frazier

- Will Peterson

Inside the Great Rift—Deep Inside! A Caver's Perspective

Scott Earl
Director, Idaho Cave Survey, Idaho Falls, Idaho

INTRODUCTION

Anyone who has tried to get a good look at the Great Rift in person can tell you that it is difficult to see very much of the rift due to limited access and really rough terrain. A few people have gone to the extreme effort required to visit the entire length of the rift, requiring backpacking trips of over 50 miles carrying everything needed with them. Additionally a very few people have been privileged to visit the insides of the rift! Over the past 20 years, cavers associated with the Idaho Cave Survey (ICS) have conducted several almost expedition-type trips into the inner workings of the Great Rift. Caving at depths of sometimes over 300 feet below the surface, often while hanging from ropes, they have documented many of the fantastic geological wonders inside the Great Rift. This report documents one such cave.

On September 13, 1994 cavers discovered a magma chamber beneath a nondescript spatter cone in a restricted area in Craters of the Moon National Monument. Six members of Idaho Cave Survey (ICS, a chartered internal organization of the National Speleological Society or NSS); Jeff Baldwin, April Earl, Eirik Fowler, Dean Killian, Steve Peck, and Keith Pincock rappelled into the cave and through a newly opened passage into the chamber below.

Editors Note: The term "magma chamber" used herein refers to a cave feature accessible to entry, and not to the geological term, which refers to a pocket of molten rock in the subsurface.

The trip was initiated by the report of a prior visit by Marshall Neeck, a staff ranger at the Monument, who entered the spatter cone on August 8, 1994 on a cable ladder with rope belay to a depth of 23 feet to retrieve a dropped object. Neeck saw a new opening at floor level on the north edge of what was presumed to be the floor of the spatter cone and entered. He continued down the steep side of a snow slope to a rock landing some 25 feet beyond. He then reported going deeper down an ice slide and seeing another drop in the distance, but was out of belay rope and returned to the surface.

The spatter cone normally has what appears to be a snow floor, but in actuality is a plug of ice lodged in the throat of the spatter cone with a very large void beneath. The unusually light winter of 1993-1994 and the following long, hot, dry summer allowed for the melting of all visible snow on this floor down to exposed rocks that were perched on an ice plug, and—combined with air flow and sublimation of the ice from below—opened up a passage down the north side of the ice plug to two lower passages, one continuing counterclockwise down and around the lower base of the ice plug to the chambers beyond.

HISTORY OF THE SPATTER CONE

H. T. Stearns, in a 1927 unpublished report, talks of entering the spatter cone by way of a wooden ladder. He describes the spatter cone and associated cave as follows:

"The first of the spatter cones is known as Ice Cave. It stands about five feet above the adjacent lava and is made up of clots of lava that adhered to each other when they fell. The throat of the cone, dark red in color, is descended by means of a wooden ladder. It is about 8 feet in diameter at the top but enlarges downward. The original depth of the pit was about 35 feet but it is now partly filled by a heap of ice and snow. With a light, one can enter a small cave about 20 feet long extending north from the bottom of the pit. On the roof and walls of this cave there are many long red stalactites and on the floor short red stalagmites."

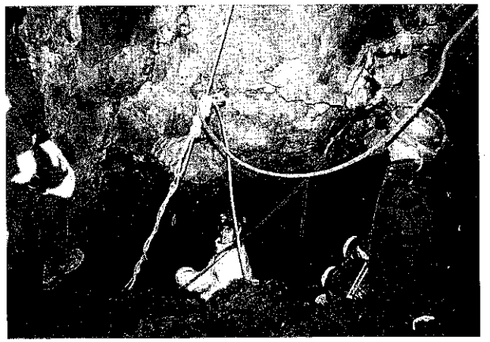


Figure 1. Cavers are on top of the ice plug. They will go down the rope and to the left past the ice plug (Scott Ryan, Diana Gardetto, April Earl).



Figure 2. Huge Ice curtain beneath snow plug (Scott Earl).

The passage that continues to the Balcony Room was apparently blocked by ice at that time and thus was not found by Stearns.

DISCOVERY OF THE BALCONY ROOM

On September 13, 1994 the ICS team entered the spatter cone and continued on down the new opening 17 feet to a rock floor beyond (Figure 1). They laid out a phone line as they proceeded through the cave and reported their discoveries to the author on the surface. The team continued counterclockwise around the lower base of the ice plug, past a huge curtain of clear ice (Figure 2), and down an ice slope to the Balcony Room. The Balcony Room is a shelf on the southwest side of the vent throat. The temperature and humidity in this room were recorded later as 33.8° F. and 92%. The floor of this room is ice-covered rock, as evidenced from below. When standing in the Balcony Room, the ceiling is currently the bottom of the ice plug, which is precariously poised about 16 feet overhead. The ice plug is composed entirely of snow and ice except for a frozen plug of rocks and debris about 6 feet in diameter on the southwest side of the ceiling. This rock plug in the ice plug is currently held in place by frost. As sublimation continues, the exposed rocks and debris occasionally fall to the Balcony Room floor as observed between later trips into the cave.

A low dam of ice forms the edge of the Balcony Room and keeps one from easily falling from the balcony to the Magma Chamber Room floor 65 feet below. This dam is the continuation point for marvelous ice formations that start at the base of the ice plug and flow down to the dam and beyond. The ice columns and icicles, which continue from the dam (Figures 3 & 4), are ribboned together at the dam forming a curtain. This curtain of ice and its source appear to be very recent. The formation was named Surprise Ice Cascade by ICS. Past experience in the King's Bowl area leads the author to believe most of the ice cascade developed in the spring and early summer of 1993 following extremely heavy winter snows and a very wet

spring. In King's Bowl South cave, this large volume of meltwater and spring precipitation carried external heat with it as it flowed into the normally 32° F. cave and melted a perched ice floor. The residual combined water flowed into a colder room below forming huge ice columns in the period of a few months. The ice dam at the edge of the Balcony Room, on the other hand, exhibits seasonal banding and is probably much older, perhaps a remnant of the original ice plug which must have formed after the last eruption at Craters of the Moon had cooled and snow began filling the Balcony Room, forming the now missing base for the current ice plug. It is possible, but unlikely, that the base of the ice plug once reached all the way to the Magma Chamber Room floor. Looking up from the Magma Chamber Room it appears that snow entering the original throat of the spatter cone would soon bridge over the throat at the Balcony Room. It is quite possible that over the past 2000 years the ice plug formed, filled the throat of the spatter cone, and then eroded away from beneath through sublimation until it collapsed. This may have occurred several times and may simply continue to repeat this cycle.

THE MAGMA CHAMBER ROOM

Continuing down to the Magma Chamber Room from the balcony is a real thrill (Figure 5), rappelling 65 feet past the curtain of ice, ice columns, and icicles that are 40 feet long onto the side of the ice mound below and then down its slope to the ice-covered floor (Figure 6). The Magma Chamber Room is kidney shaped and is typically 30 feet wide, 40 feet high, and 170 feet long. The highest point on the floor of this room is directly below the opening in the ceiling, as would be expected since anything coming down the throat of the spatter cone would land here. Much of the floor is covered with breakdown. The southern end of the room contains many huge breakdown blocks. Initially the origin of these blocks was puzzling. Many do not appear to be breakdown from either the ceiling or walls. Later examination of photographs revealed that molten lava had ponded in the chamber for a significant period of time at the end of the eruption, allowing a strand line and bench to form half way up the walls. When the lava finally drained out of the chamber several large pieces of the strand line bench broke from



Figure 3. Ice plug is above. Caver is using a "rack" and is about to go "free" (Dean Killian).



Figure 4. Caver going down against the ice. She was the first person to ever enter the magma chamber (April Earl).

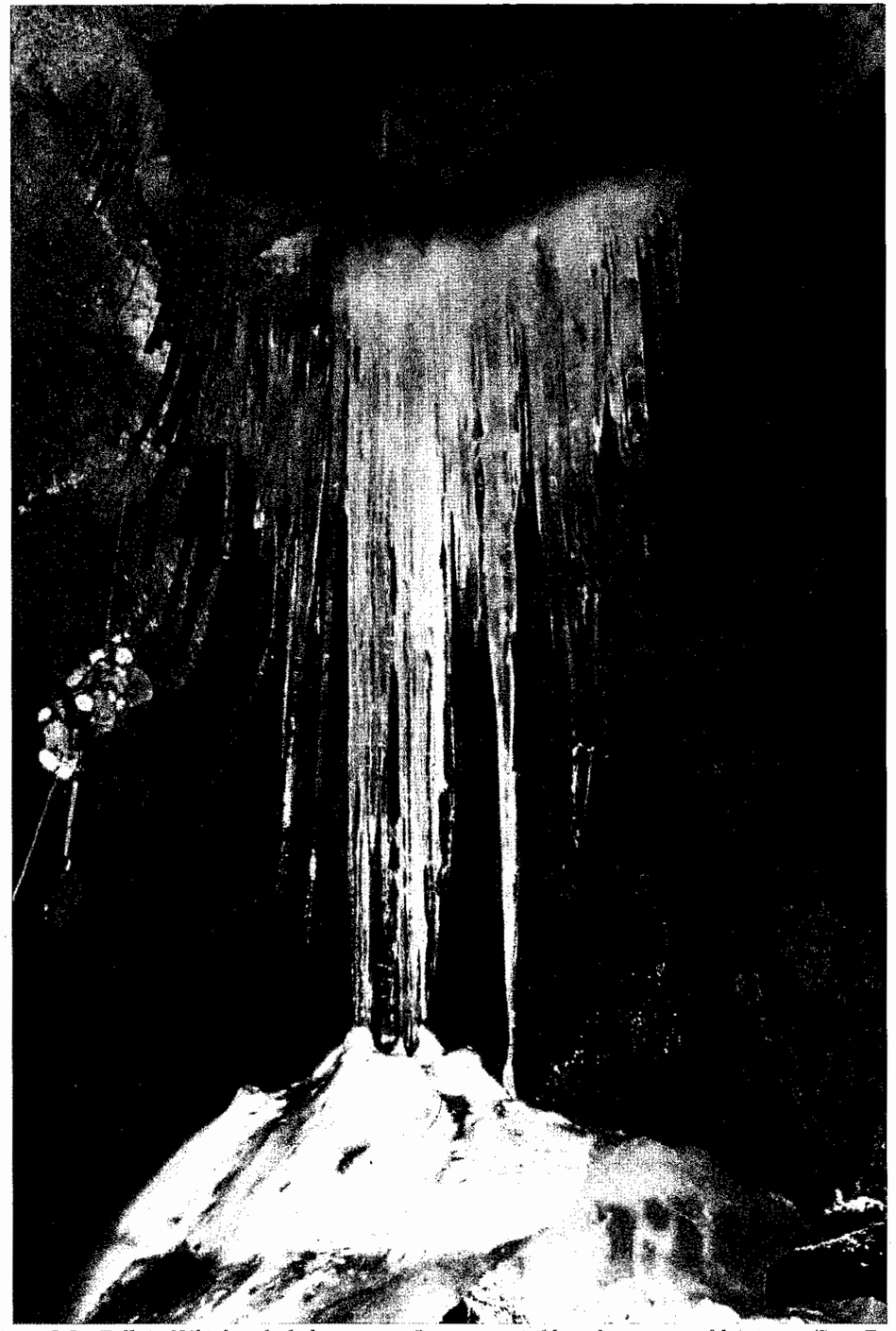


Figure 5. Ice Falls is 65 'high to the balcony room. Ice curtain visible at the very top of the picture (Scott Earl).

the walls generating the breakdown on the floor (Figure 7). On the southwest wall, a huge section of bench and wall has peeled away from the rest of the wall and is leaning out into the room a few feet. This slab varies in height from 15 feet to 25 feet, is 53 feet long, and typically is 1 foot thick at the top and up to 8 feet thick at the base. At the lower end of this leaning wall a very significant vertical slab of rock (Figure 7, right side foreground) is a large section of the previous floor of the cooled stranded lava pool that hinged down into the void below as the lava drained from the magma chamber. It exhibits strange air pockets and inclusions of different colors and textures of lava.

Fine crystals cover most of the breakdown boulders in the room, and in the northern reaches of the room pieces of mineral crust are abundant. It was not readily apparent on our two short surveying trips whether these crusts formed on the floor or fell there from the ceiling or walls. At about the midpoint of the northern half of this room is an area with exceptional crystal growth containing several hexagonal to octagonal shaped clear crystals standing on end on a boulder. Most are very small, about 1/8 inch in height, but one is 3/4 inches tall and 3/8 inches in diameter. (Figure 8) These are likely gypsum. Under a large rock to the west of this spot are a couple of white mineral stalagmites that are 3 inches long and 1/8 inch in diameter. Again the composition is likely gypsum. In the lower end of the north extension are mineral secondary deposits so thick we could not negotiate the area without damaging them and a small alcove on the wall in that area was left unexplored. A very high chimney is situated in the ceiling almost directly above the deepest spot in the cave. The ceiling and this chimney were measured with an optical triangulating rangefinder. A powerful spotlight was brought into the cave for the purpose of lighting this area. The ceiling is 50 feet high in this spot and the chimney extends another 37 feet straight up to a height of 87 feet (Figure 9). Later examination of the 3D survey line plot showed this chimney to be the magma source for the taller of the two spatter cones on the surface just north of the main spatter cone. This chimney appears to have an ice plug at its top, or perhaps a rock plug that is coated with ice crystals. The second highest spot in the ceiling, fairly near the room entrance, is full of huge ice crystals.

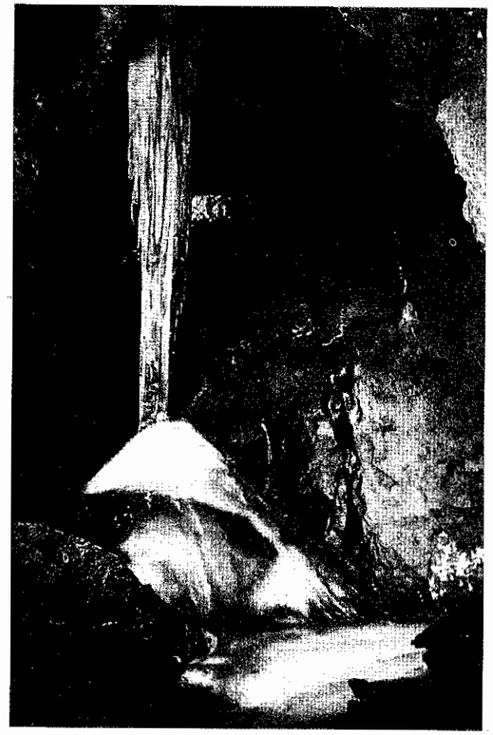


Figure 6. Left side view of the falls & ice cone.



Figure 7. View across the magma chamber from the right. Note the large slab on the right.



Figure 8. Gelfling's Crystal Shard. Tiny 3/4 inch tall perfect crystal. It is unknown whether these crystals are growing from the base or at the top.

Several carcasses of small animals were found throughout the room. Past experience in ice caves indicates that the carcasses that still have fur on them are fairly recent additions to this room. That the animals survived all three falls and then made their way to the far reaches of the cave is intriguing.

SUBLIMATION

It is likely that as sublimation continues over the next several years the ice plug will become unstable and eventually fall into the Magma Chamber Room. This has been documented recently in several ice caves in the Kings Bowl area, a continuation of the Great Rift 42 miles south of the developed portion of Craters of the Moon. These caves include Crystal Ice Cave, Great Cavern, and King's Bowl South cave. Ice in all of these caves is sublimating and floors from upper rooms are collapsing into rooms below—not due to melting, since the temperatures are below freezing—but due to sublimation. They exhibit very similar erosion from below as is currently seen in the ice plug in this cave. Several cavers involved in the mapping of this cave have suggested that future trips require attachment to a rope at all times when on top of the ice plug in case it should give way.

INITIAL RESEARCH

After the initial discovery, a research project was proposed by ICS and accepted by CRMO. Specialists in various sciences were assembled, taught to rappel and ascend the ropes using Single Rope Technique, collected samples of the minerals, fauna, and flora. ICS acted as the trainers and safety monitors. They also surveyed, mapped (Figure 9), and photographed the cave. In order to protect the fragile resources, entry into the cave is not permitted.

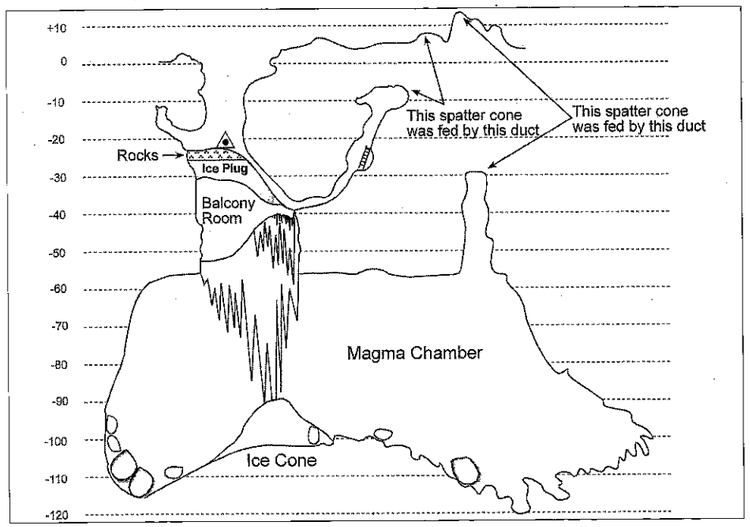


Fig. 9 Profile map of the magma chamber. Total depth is 120.

Petrogenesis of A-type Quaternary Rhyolite and Cogenetic Mafic Magmatic Enclaves at East Butte Volcanic Dome, Eastern Snake River Plain, Idaho

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ABSTRACT

East Butte is one of four compositionally similar Quaternary high-silica rhyolite domes (HSR) on the eastern Snake River Plain (ESRP) segment of the Yellowstone hot spot track. It has geochemical and mineralogical features in common with 'A-type granitic rocks', and may constitute an analog for magmatism leading to production of A-type magmas. The rhyolite contains an anhydrous phenocryst assemblage consisting of 10% sanidine > quartz > fayalite, ferroaugite, Fe-Ti oxides, and accessory zircon, chevkinite and apatite. It also contains a distinctive assemblage of pl+cpx-phyric mafic magmatic enclaves - mostly Craters of the Moon-type basaltic trachyandesite (BTA) - and minor amounts of mafic and felsic crustal xenoliths. Most BTA enclaves are vesicular, suggesting post-mixing degassing, and some contain cumulate-like plagioclase megacrysts, and even more mafic, olivine tholeiite basalt-like magmatic (?) enclaves. BTA enclaves plot on fractional-crystallization-dominated curvilinear trends observed at other intermediate-rock-bearing volcanoes of ESRP (e.g., Craters of the Moon and Cedar Butte). EMP analyses of melt inclusions in pyroxene, olivine and quartz phenocrysts consistently yield high-silica rhyolite compositions and low-totals, suggesting that the original rhyolite magma contained ~4-6% H_2O prior to eruption. A hydrous phase of rhyolite evolution is further supported by the presence of pronounced granophyric textures in one of three texturally distinct populations of sanidine.

INTRODUCTION

East Butte is the easternmost of several Quaternary rhyolite lava domes located in the middle of the Eastern Snake River Plain (ESRP), 30-60 km northeast of the Great Rift (Kuntz et al., 1992). These prominent buttes are anomalous in the otherwise topographically subdued ESRP. They are a product of geochemically distinctive, 'A-type' (Frost et al., 2001) rhyolitic volcanism that has overlapped in space and time with dominant, more primitive basaltic volcanism (McCurry et al., 1999). Both postdate voluminous late Tertiary rhyolitic volcanism of the Yellowstone hot spot track (Pierce and Morgan, 1992). Genesis of rhyolites in such 'bimodal' volcanic fields remains controversial. Processes include recycling of preexisting felsic continental crust by due to heating by basalt intrusions (e.g., Leeman, 1982), low-degrees of fractional melting of basalt-modified crust (e.g., Frost and Frost, 1997), and extreme fractional crystallization of a basaltic parental magma (Nekvasil et al., 2000; McCurry et al., 1999).

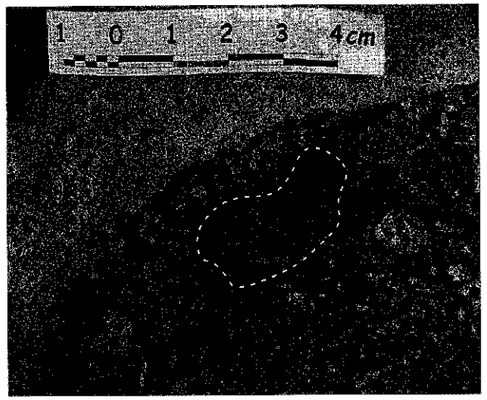


Figure 1. A basaltic trachyandesite enclave (BTA; dark colored) in rhyolite host. Note plagioclase megacrysts and vesicles in BTA. Dashed line shows the outline of an aphyric OTB mafic magatic enclave within the basaltic trachyandesite.

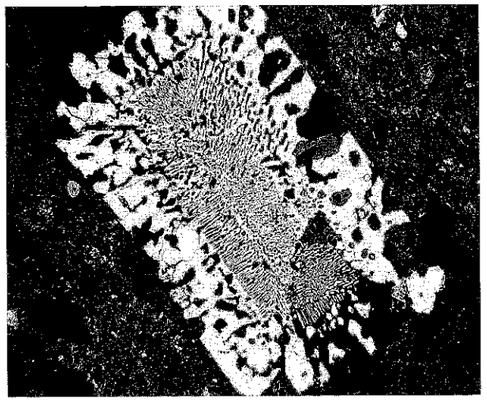


Figure 2. A splendid example of granophyric sandine in the East Butte rhyolite, as viewed under cross-polarized light. Scale across the bottom of the photo is about 5 mm.

In this paper we present new petrological and geochemical data for East Butte rhyolitic lava dome. Specific objectives of this work are to distinguish between conflicting ideas by Spear (1979) and Kuntz and Dalrymple (1979) regarding the magmatic vs. xenolithic origin of mafic enclaves in the dome, to define petrochemical conditions in the source magma chamber including temperature, oxygen fugacity, total pressure, and volatile content, and to produce a model for the formation and evolution of the lava dome. We extend upon previous work in the area by Spear (1979), Kuntz and Dalyrymple (1979) and Bretches (1984), by a more detailed and systematic sampling and analysis of enclaves, measurements of both major- and trace-elements of representative rock types, EMP analyses of major phenocryst types. We also present preliminary EMP compositional data for melt inclusions in phenocrysts.

PETROGRAPHY AND LITHOLOGY

Rhyolite: 16 samples were collected from widely separated parts of East Butte and analyzed petrographically and for their major and trace element compositions (Table 1). All have very similar textures, modes, and chemistry. Detailed (1000 point) point counts of four samples indicates a nearly uniform abundance (10%) and assemblage of phenocrysts consisting of sanidine (6.5%, 1-5 mm across) > quartz (2.4%, 1-3 mm) > ferroaugite (0.8%, 1-3 mm) > olivine (0.2%, 0.1-2 mm) > Fe-Ti oxides (0.1% opaques, magnetite > ilmenite, 1-3 mm), and accessory zircon, chevkinite and apatite. Identities of the accessory phases were confirmed by energy-dispersive X-ray scans of the minerals. Representative electron microprobe analyses of the major phenocryst types are listed in Table 2.

Most phenocrysts are euhedral to subhedral; mafic and accessory minerals commonly occur in small glomeroporphyritic aggregates. Sanidine is dominantly euhedral to subhedral. There are also smaller populations of sanidine grains that exhibit spongy-cellular textures, indicative of partial melting, and prominent, sometimes striking granophyric textures (Figure 2). The latter texture is indicative of 'sudden' oversaturation and rapid crystallization, likely from volatile loss (e.g., Lowenstern et al., 1997).

Enclaves: Prominent, albeit volumetrically minor (<1%) amounts of enclaves occur across the entire East Butte lava dome. This is one of the most distinctive features of this volcano. Enclaves vary from a few millimeters to 30 cm across. We divide them into three groups: mafic magmatic enclaves (MME's), basaltic xenoliths, and granitoid xenoliths.

MME's make up ~90% of the total enclave population (Figure 1). Samples vary from trachybasalt to basaltic trachyandesite in composition (sample 42, Table 1) and have a black to dark reddish-grey color. They have prominent irregular, ovoid or kidney shapes. Many have fine-grained margins and crenulated boundaries. Some also have irregular shaped embayments of rhyolite within them, indicating that both the rhyolite and mafic enclaves were at least partially molten when brought into contact. MME's are distinctive in having abundant large plagioclase (An_{46-52}) phenocrysts, varying in abundance from 10-20%, and from 5 to 10 mm across.

They also contain minor amounts of augite and opaques phenocrysts in a fine-grained intersertal to intergranular matrix. Some have euhedral clear gray megacrysts of calcic andesine up to 3 cm across. Most are vesicular (10-20%). Vesicles are spherical and exhibit no evidence of shearing or compression within the lava. Some MME's contain additional aphyric OTB-like magmatic enclaves (Figure 1). They also have distinctive skeletal mineral textures indicative of rapid cooling. Minerals and textures in these enclave are very similar to those of 'normal' olivine tholeiite basalt. We infer that these are OTB enclaves captured into MME's prior to the later being incorporated into the host rhyolite.

Basaltic xenoliths: ~10% of enclaves are black to dark grey olivine tholeiite basalt. These are angular, lack fine-grained margins, and have textures and mineral assemblages that are typical of SRP OTB (Kuntz et al., 1992).

Granitoid xenoliths are rare. They are angular and have sharp boundaries with the host rhyolite. The xenoliths are fine-grained inequigranular, allotriomorphic to hypidiomorphic, and are massive to weakly foliated containing orthoclase > quartz > plagioclase > biotite. Some orthoclase grains are subhedral, whereas others are irregular shape and have granophyric textures. Xenocrysts of quartz and feldspar occur within rhyolite close to xenolith contacts, indicating that some parts of the xenoliths had disaggregated within the rhyolite.

*Table 1. Representative bulk sample analyses**

Location	EB	EB	EB	EB	TR
Number	Rhy	OTB	42	Gran	Rhy
Type	Bulk	Encl	Encl	Bulk	Tert
Average	11	2		2	509
SiO2	75.5	49.5	52.3	73.93	74.24
TiO2	0.18	1.79	2.50	0.45	0.66
Al2O3	12.2	14.8	14.3	12.96	12.57
FeO*	2.13	10.8	13.3	2.37	2.72
MnO	0.05	0.19	0.28	0.04	0.04
MgO	0.03	7.77	2.89	0.55	0.28
CaO	0.79	11.8	6.91	1.58	1.22
Na2O	4.0	2.4	3.8	3.48	3.05
K2O	5.1	0.6	2.3	4.57	5.14
P2O5	0.02	0.38	1.5	0.07	0.08
Original totals	98.46	98.54	99.95	98.0	
Sc, ppm	0.7	34	24	5	5
Co	1.8	39	21	5	3
Rb	202	12.1	36	100	189
Sr	10	611	298	77	95
Cs	1.8	0.62	0.99	0.9	3
Ba	116	484	1280	1235	990
La	108	24	105	63	79
Ce	221	43	220	134	149
Nd	86	23	126	53	62
Sm	23	6.6	24	9.4	12
Eu	1.3	1.0	7.1	1.5	1.7
Tb	4.4	1.6	4.8	1.9	1.8
Yb	18	4.87	16.5	7.9	6.0
Lu	2.2	0.63	2.3	1.0	0.8
Zr	384	94	1292	310	454
Hf	16	4.3	26	9.3	14
Ta	12	0.90		1.3	3
Th	23	1.42	5.6	14	28
U	6.8	1.30	4.8	2.5	6

** Major elements are shown as eight percent oxides, and they are normalized to 100% on an anhydrous basis, and all iron is expressed as FeO*. TR=average rhyolite composition for hotspot track rhyolites (pre-basalt); Gran = average of two granitoid xenoliths. Pre-normalized major element totals are shown as 'Original totals'. Major and some trace elements (Zr, Sr and Ba) were analyzed by ICP-AES; all other trace elements were analyzed by INAA (e.g., Ford, 2005).*

GEOCHEMISTRY

Whole-rock major- and trace elements: Analyses of representative samples from East Butte are shown in Table 1. Samples from various parts of the rhyolite dome exhibit statistically identical major and trace element compositions. The rhyolites are very similar to high-K, A-type Quaternary rhyolites elsewhere on the ESRP (McCurry et al., 1999). They are geochemically distinguished from older Tertiary rhyolites by lower MgO and CaO contents, and much higher FeO/(FeO+MgO) ratios (Table 1). They are also distinguished in trace element chemistry by lower Sc, lower Sr and Ba, much higher Rb/Sr (~20 vs. 2), high Ta, lower La/Yb ratio and larger Eu-anomaly. Sr- and Nd-isotopes of the rhyolite overlap with those of coeval OTB, and limiting Archean crustal input to the magma of <1% (McCurry et al., 1999). Magmatic enclaves are dominantly trachybasalt-basaltic trachyandesite. Most overlap with curvilinear trends of the Craters-of-the-Moon - Cedar Butte suite (McCurry et al., 1999). Mafic xenoliths overlap with compositions of typical OTB (Fig. 3). Granitoid xenoliths have compositions that are very similar to those of Tertiary SRP rhyolites (Table 1), and may have been derived from plutons that are cogenetic with those rocks.

Representative electron microprobe analyses of major phenocrysts are shown in Table 2. Ferromagnesian compositions are reflective of the extreme depletion of MgO in the bulk rock. Lack of zoning and very high Fe/Mg ratios of phenocryst compositions are consistent with phenocryst-liquid equilibria. Fe-Ti oxides analyses satisfy Mg/Mn equilibrium criteria. QUILF and zircon-saturation thermobarometers yield

*Table 2. Representative electron microprobe analyses**

Sample	EB7	EB7	EB7	EB7	EB7	EB7	EB7	EB25	EB13	EB13
Type	Rhy	Rhy	Rhy	Rhy	Rhy	Rhy	Rhy	Rhy	BTA	BTA
Mineral	MTss	ILMss	OL	CPX	SA	MI(CPX)	MI(Q)	MI(OL)	PL	CPX
Average	5	2	7	8	8	2	2	4	6	4
SiO2	0.12	1.00	30.48	46.14	66.71	77.60	76.84	77.33	56.97	50.90
TiO2	20.02	52.03	0.03	0.23		<0.05	0.01	0.06		0.76
Al2O3	0.73	0.23	<0.05	0.45	18.52	11.84	11.61	12.24	26.56	2.03
FeO	77.52	45.25	66.53	34.55	0.16	1.55	1.67	1.77	0.49	15.81
MnO	0.73	1.09	1.91	1.08		<0.05	<0.05	0.09		0.50
MgO	0.04	0.06	0.49	0.71		<0.05	0.02	<0.05		13.23
CaO	<0.05	0.01	0.22	16.44	0.26	0.51	0.40	0.50	9.63	16.30
Na2O	<0.05	<0.05	<0.05	0.38	5.28	3.21	4.24	2.63	5.75	0.45
K2O				<0.05	9.02	5.02	4.95	5.03	0.56	<0.05
P2O5				<0.05		0.01	<0.05	0.01		<0.05
NiO	<0.05	<0.05	0.01	0.01						0.01
ZnO	0.83	0.32								
Cr2O3	<0.05	<0.05	0.33	0.01						0.02
BaO					0.04	<0.05	<0.05	<0.05	0.03	
SrO					0.01	<0.05	<0.05	<0.05	<0.05	
F						0.05	0.07	0.14		
SO3						0.01	0.01	0.01		
Cl						0.21	0.19	0.18		
TOTAL*	97.00	95.58	100.04	99.50	100.39	96.76	93.72	96.02	99.45	100.92

*Sample number, bulk sample type, mineral or melt inclusion, and number of analyses in average are indicated along the top. Analyses are normalized on an anhydrous basis; original analyses are shown at the bottom of the table. EMP analyses were conducted with a JOEL 8900R electron probe microanalyzer at the Idaho National Laboratory. Standards and calibration procedures are outlined in Ford (2005).

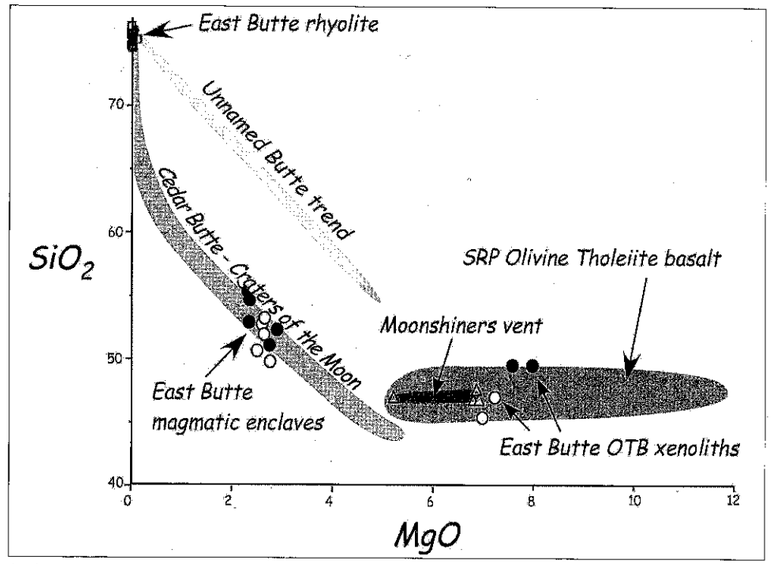


Figure 3. Whole rock MgO-SiO2 chemical variation diagram. Squares are compositions of rhyolite from East Butte. Filled and open circles represent compositios of mafic enclaves respectively from this study, and previous work by Bretches (1984), Spear (1978) and Kuntz and Dalrymple (1978); triangles represent compositions of basalts from Moonshiner Vent shield volcano.

crystallization temperatures for the rhyolite of ~810-850°C and an oxygen fugacity that is slightly below QFM (DQFM = ~ -0.75). BTA enclaves equilibrated at ~1100°C. QUILF and mineral saturation geobarometers (e.g., Putirka et al., 2003) yield equilibration pressures between 0.1 and 0.9 Gpa.

Analyses of melt inclusions in quartz; fayalite and ferroaugite phenocrysts are remarkably consistent, given difficulties of standardization and matrix effects. This preliminary work suggests that the liquid composition was substantially more evolved than the bulk rock composition, having higher SiO_2 and lower TiO_2, FeO* and CaO (Table 2). MI's have F, Cl and S concentrations of ~ 1000, 2000 and ≤100 ppm, respectively. They also have consistently low totals suggesting that they had high pre-eruptive H_2O contents of 4-6%.

CONCLUSIONS

Enclaves within the East Butte rhyolite dome are dominantly magmatic. Some have undergone at least two episodes of magma mixing: one in which OTB mixed into a dominant volume of TB, and a second in which TB was mixed into a dominant volume of rhyolite. Minor OTB xenoliths and fine-grained granitoid xenoliths also occur in the rhyolite. Compositions of most magmatic enclaves plot along curvilinear trends resembling those of Cedar Butte and Craters of the Moon, ruling out their origin as simple mixing between OTB and rhyolite. We infer that they formed by extreme fractionation from a basaltic parental magma (e.g., McCurry et al., 1999, 2007).

Analysis of melt inclusions and mineral equilibria suggest that East Butte rhyolite and parental BTA resided, and partially crystallized, at pressures corresponding to mid- to upper-crustal depths. Crystallization conditions were moderately reducing, hydrous (4-6% H_2O) and at temperatures of ~800-850°C, supporting experimentally derived fractionation pathways suggested by Nekvasil et al. (2000).

A conceptual model for the formation and

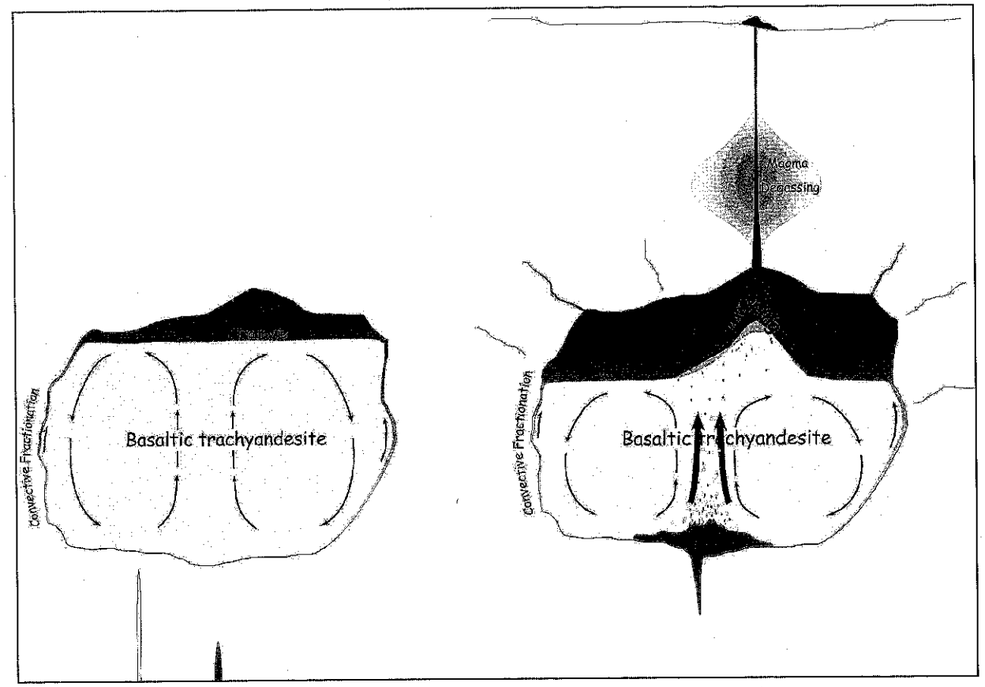


Figure 6. Conceptual model for the evolution of East Butte volcano.

eruption of the rhyolite is shown in Figure 4.

In Figure 4a buoyant, hydrous rhyolite magma is illustrated as having formed by fractional crystallization from a dominant volume of BTA by convective fractionation (Sparks et al., 1984). In Figure 4b the evolving magma reservoir 'accidentally' captures an ascending dike of OTB. Heat transferred to the BTA chamber initiates rapid convection and turbulent entrainment of OTB into BTA. Thermal and mass-induced expansion of the chamber is inferred to have fractured the country rock, allowed escape of rhyolite from upper levels (Figure 4b). A resulting rapid drop in volatile pressure results in strong oversaturation of the magma in liquids minerals, particularly quartz and feldspar, producing granophyric crystallization (cf. Lowenstern et al., 1997). Slow ascent of the rhyolite allows for volatile loss through fractures in the country rocks as the magma ascends through dikes to the surface (e.g., Woods and Koyaguchi, 1994).

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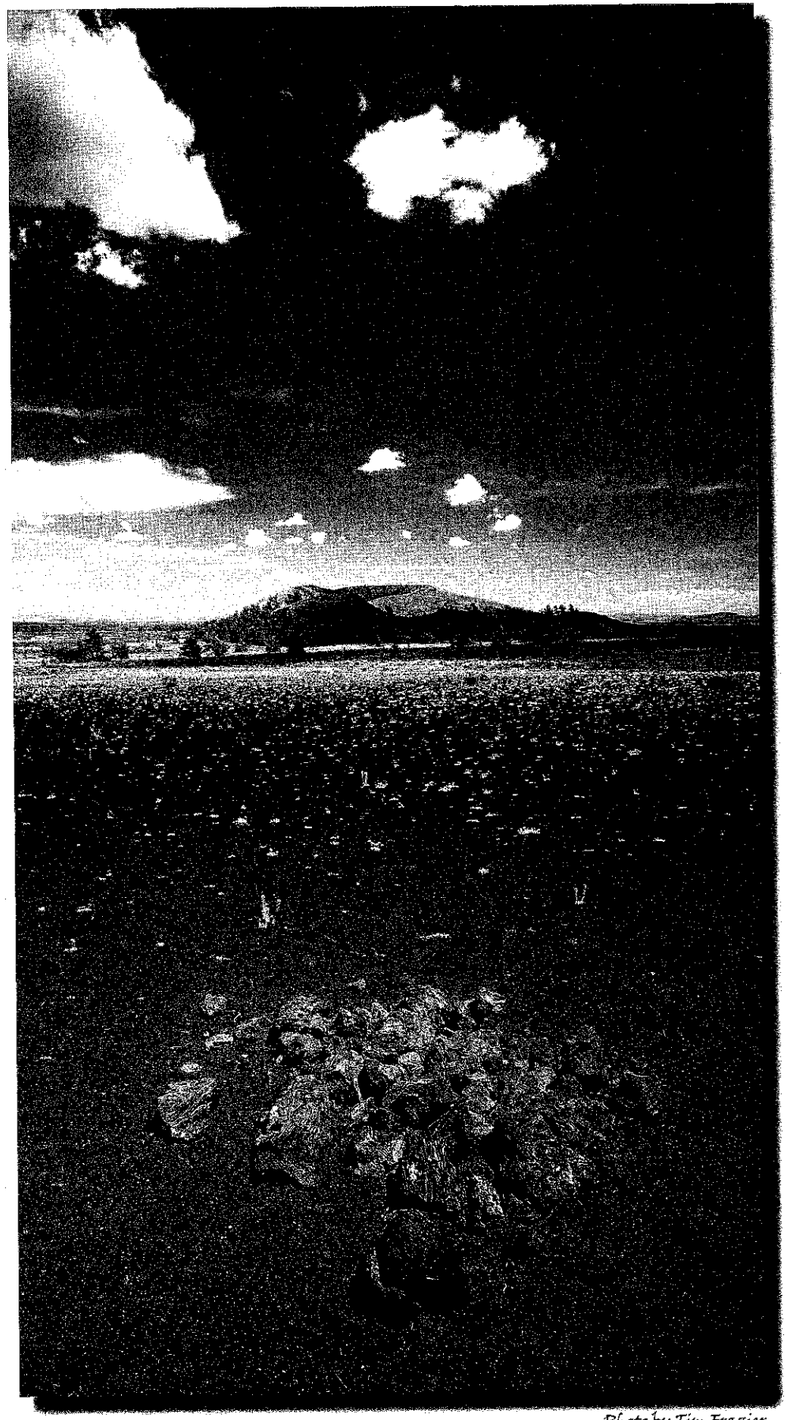


Photo by Tim Frazier

Paleochannels of the Big Lost River, Idaho

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ABSTRACT

The detrital zircon age spectrum of the Big Lost River is absent in 4 Ma beds of the Pliocene Glenns Ferry Formation at Hagerman Fossil Beds National Monument. Based on stratigraphic data south and west of the Great Rift of Idaho, undated gravel-bearing sediments represent possible paleochannels of the ancestral Big Lost River flowing south and west, into playa sinks represented by multiple subsurface clay layers between the Wapi basalt flow and Dietrich Butte. An ancestor of the Pleistocene-to-Holocene Great Rift erupted across these paleochannels, and the Big Lost River was forced to flow north and east into the Big Lost Trough south of the Lemhi Range. After 2 Ma and likely earlier, Big Lost River sediments were deposited in the Big Lost Trough.

INTRODUCTION

Previous research has shown that the Big Lost River was captured within the Big Lost Trough between 2.5 Ma, and 1.8 Ma (Geslin et al., 2002; Bestland et al., 2002; Blair, 2002). The river diversion to the northeast is attributed to the rise of the Axial Volcanic High, a low-relief ridge formed by small low-angle shield volcanoes (figure 1). These conclusions depend on sediment provenance studies using grain-size and detrital zircon analyses and on paleomagnetic correlations and K-Ar and Ar-Ar radiometric age dating.

A recent $^{40}Ar/^{39}Ar$ age date of basalts above delta-margin lacustrine sediments at 422 m (1385 ft) in INL drillhole C1A (Helm-Clark and Rodgers, 2004) suggests that they belong to the Jaramillo Paleomagnetic Subchron of 0.99 to 1.05 Ma instead of the ~2 Ma Olduvai subchron as previously suggested (Champion et al., 1988; Anderson et al., 1997; Blair, 2002). The inference is that the Olduvai sequence is missing at this location or is substantially deeper than originally interpreted (Helm-Clark et al., 2005), which in turn suggests southwestward Pleistocene tilting or differential subsidence within the Big Lost Trough.

METHODS

Data discussed here include geomorphology of regional volcanic rifts zones, stratigraphy from well logs, and provenance information from detrital zircon age spectra, as applied to paleodrainage patterns on the eastern Snake River Plain.

Stratigraphic information was reviewed using well logs from the Idaho National Laboratory and the water-well database of the State of Idaho Department of Water Resources. Well logs from the Idaho National Laboratory cover the Big Lost Trough and its environs in detail. Outside of the Big Lost Trough neighborhood, only drillers' logs in the Idaho database are available. Log quality is variable but most logs contain useable though simplistic stratigraphic information. The database

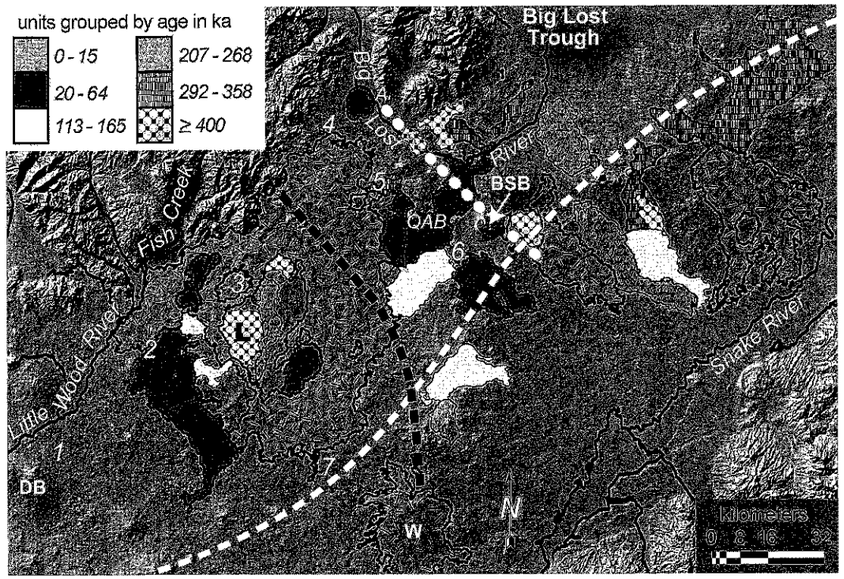


Figure 1. Dated volcanic rock units near the Great Rift of Idaho. Unit boundaries are based on LaPoint (1977), Kuntz et al. (1988), Kuntz et al. (1994) and Helm-Clark (unpublished data, 2002-2005). Major stream and river drainages are labeled. The white dashed line is the trend of the Axial Volcanic High. The black dashed line is the general trend of the Great Rift. The white dotted line is the general trend of the Arco Rift. The Big Lost River currently flows south out of a intermountain valley at Arco (white A, top center). It is blocked from flowing south or west by the elevated volcanic centers at the northern end of the Great Rift and the cluster of shield volcanoes around Quaking Aspen Butte (white QAB, center of figure). It instead turns east upon entering the Eastern Snake River Plain, incising a canyon through basalt across the Arco Rift, and finally flows to the northeast toward its sink in the Big Lost Trough (top center). Southwest of the Great Rift and north of the Axial Volcanic High, a second ridge feature trends northeast to southwest. The most prominent peak on this ridge is Laidlaw Butte (black L, center left). The area with interbedded clays in basalt extends from the Wapi Flow (black W, bottom center) to Dietrich Butte (white DB, bottom left). Numbers in white mark the locations of the seven wells whose stratigraphy is shown in figure 4.

was examined for 97 township-range blocks covering an area of ~9000 km^2 bounded by the Pioneer Mountains in the north, the Little Wood River in the west, the Axial Volcanic High in the south and Rt. 26 in the east. This area is mostly unpopulated and much of it belongs to Craters of the Moon National Monument. Well logs are not abundant in the study area and usually record only basalt; however, twenty-nine well logs did described interbedded sediments.

U-Pb ages were determined for zircon grains in river sands from the Big Lost and Big and Little Wood Rivers using the SHRIMP (Sensitive High Resolution Ion Microprobe) at Australian National University, employing standard detrital zircon techniques (Williams, 1998; Link et al., 2005). Each analysis consisted of 4 scans through the mass range. The data were reduced as described by Williams (1998, and references therein), using the SQUID Excel Macro of Ludwig (2000). Each detrital-zircon sample contains ~60 zircon grains sampled randomly from a mineral-separate.

Detrital-zircon age populations for stream sand within the Snake River system distinguish its provenance (Geslin et al., 1999, 2002; Link et al., 2002, 2005). During the northeastward migration of the Continental Divide and subsidence of the Snake River Plain since 15 Ma, there have been several instances of stream capture and drainage reversal related to lava-flow dams and Snake River Plain subsidence

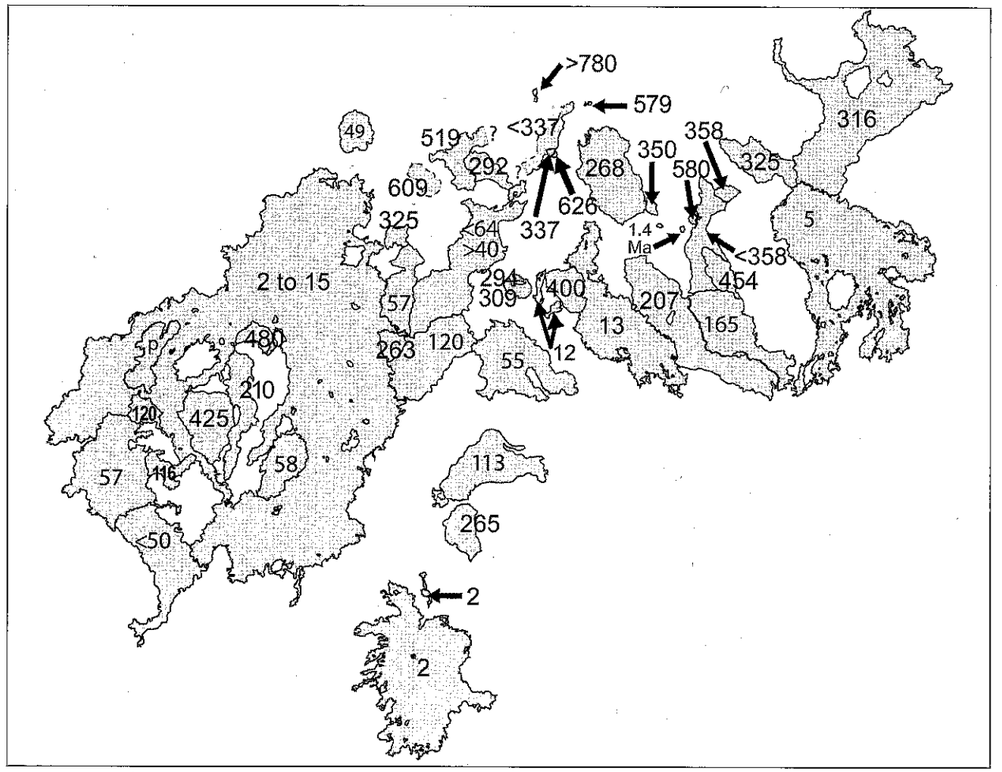


Figure 2. Volcanic units with individual ages in thousands of years (ka, kilo anno) unless otherwise noted. Basalts at Paddleford flat (labeled "p," center left) are estimated as between 20,000 and 40,000 years old. Standard errors on age dates are listed in Table 1.

(Pierce and Morgan, 1992; Beranek et al., 2006).

For data in this paper, Big Lost River samples include the river bed near Chilly, Idaho; Antelope Creek near its mouth; the Big Lost River at the Highway 26 Rest Area; and Big Lost River Pleistocene and Holocene sands 2 miles upstream from Highway 26. Wood River samples include Trail Creek above Corral Creek, the Big Wood River south of Bellevue, and the Little Wood River south of Carey. These data and sample locations are presented in detail in Link et al. (2005).

RESULTS

Active volcanic rifts on the Eastern Snake River Plain are characterized by Holocene and latest Pleistocene lava flows, lines of vents and fissures, and relatively elevated topography (Wood et al., 2007; Helm-Clark, this volume). Figures 1 and 2, and Table 1, catalog the distribution of dated flows on either side of the NNW-striking Great Rift. Working backwards in time, westward water flow of the Big Lost River has been blocked by 2 to 15 ka lava flows erupted from the northern Great Rift at Craters of the Moon National Monument. Starting approximately at 40 ka, flow to the south and southwest was blocked by a elongate cluster of latest Pleistocene and older shield volcanoes in a topographic swell centered on Quaking Aspen Butte (QAB on figures 1 and 3) which is hypothesized to be a volcanic rift zone distinct from the Arco Rift (Helm-Clark, this volume).

Based on young volcanism at the North and South Robbers and Cerro Grande flows plus abundant Quaternary fissures and faulting, the Arco Rift is an active volcanic rift zone running

Table 1. Dated Volcanic Rocks on the Eastern Snake River Plain

Location	Age	Reference	Comments
Blue Dragon Flow	2076±45 yrs	K04	Youngest COM date
Kings Bowl Flow	2222±100 yrs	K88	
Wapi Flow	2270±50 yrs	K88	
Hells Half Acre Flow	5,200±150 yrs	K89	
North and South Robbers Flows	11,980±300 yrs	K94	
Cerro Grande Flow	13,380±350 yrs	K94	
Kimama Flow	15100±160 yrs	K04	Oldest COM date
Arco (Lost River) Flow	49 ka	S&F	
Wildhorse Butte	<50 ka	K04	$^{40}Ar/^{39}Ar$ date; 10 km south of "the Blow Out"
Rock Corral Butte	55±12 ka	K04	
Broken Top lava field	57±30 ka	K04	Spud and Sand Buttes have similar paleomagnetic remanence directions as Broken Top and are probably the same age.
Fingers Butte	57±20 ka	K04	
Bear Den Butte	58±10 ka	K04	
Quaking Aspen Butte	>40 ka, <64 ka	K94, K04	Coyote Butte is overlain by Quaking Aspen Butte basalt
Coyote Butte	64±20 ka	K04	
Split Top Butte	113±10 ka	K04	
"The Blow Out"	116±15 ka	K04	
Serviceberry Butte	120±12 ka	K04	
Wagon Butte	120±25 ka	K04	
Taber Butte	165±22 ka	K94	
Table Legs Butte	207±65 ka	K94	
Big Blowout Butte	210±15 ka	K04	N of Laidlaw Butte
Pratt Butte	263±20 ka	K04	
Mosby Butte	265±30 ka	K04	
Mid Butte	268±32 ka	DC88	Lat 42.51N, Lon 247.23E,
Unnamed flow	292±58 ka	L94	"…collected along Rte. 20/26, 6.15 miles east of the junction of the road to Howe."
Big Southern Butte	294±15 ka	K94	NW side of top of butte, aphyric rhyolite cap of dome
Big Southern Butte	309±10 ka	K94	SE side of top of butte, flow-banded rhyolite core of dome
Kettle Butte	316±75 ka	K94	
Unnamed butte	325±45 ka	K94	Immediately west of Kettle Butte
Wildhorse Butte	325±10 ka	K04	North of Fingers Butte
Unnamed flow	<337 ka		Under 292 ka flow, above 337 ka vent west of AEC Butte
Unnamed vent	337±41 ka	L94	"…half a mile northwest of the top of AEC Butte."
Unnamed vent	350±40 ka	K94	Vent in kipuka immediately north of Middle Butte
Basalt vent on east side of East Butte	<358 ka		Immediately above basalt from vent at Radio Facility
Vent at Radio Facility	358±46 ka	K94	Northeast of East Butte
Cedar Butte	400±19 ka	K94	
Laidlaw Butte	425±25 ka	K04	
Unnamed vent	454±28 ka	K94	Immediately north of Taber Butte flow
Snowdrift Crater	480±50 ka	K04	
Crater Butte	519±52 ka	K94, L94	"…collected about 150 ft east of the Howe junction, very close to the northwestern edge of the Crater Peak flow."
State Butte	579±130 ka	K94	
East Butte	580±90 ka	K94	In rhyolite
Box Canyon	609±92 ka	K94	
AEC Butte	626±67 ka	DC88	
Unnamed rhyolite outcrop	1400±28 ka	K94	Between East and Middle Buttes

Reference key:
DC88 = Champion et al. (1988)
K88 = Kuntz et al. (1988), USGS Map I-1632
K89 = Kuntz et al. (1989)
K94 = Kuntz et al. (1994), USGS Map I-2330
K04 = Kuntz et al. (2004), OFR 2004-1222
L94 = Lanphere, M., USGS memo to Mel Kuntz and Steve Anderson, December 8, 1994.
S&F = Smith and Foeman, unpubl. data
USGS = United States Geological Survey

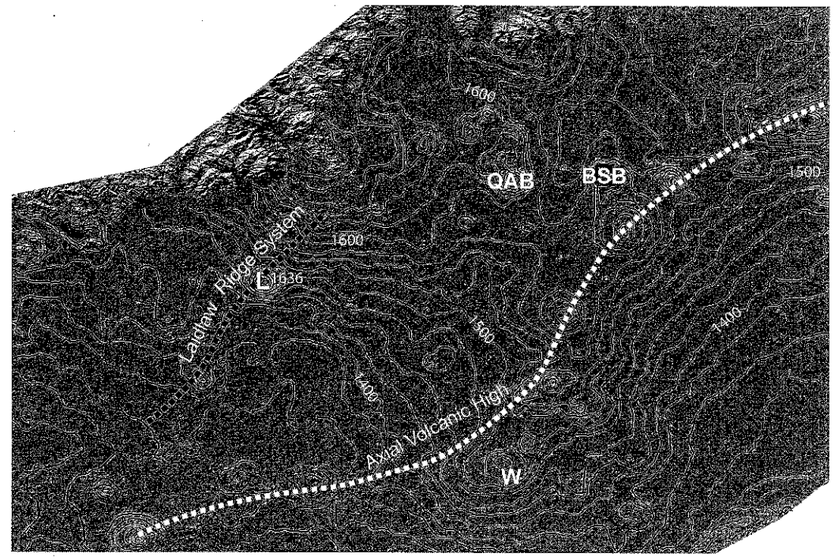


Figure 3. Topographic contours superimposed on a shade relief map of the study area. Contours were constructed using nearest neighbor analysis of USGS digital elevation data (DEM). Contour interval is 25 m. Notations are as follows: BSB = Big Southern Butte, L = Laidlaw Butte, QAB = Quaking Aspen Butte, W = Wapi flow vent at Pillar Butte.

from Arco through Big Southern Butte (BSB on figure 1). It is topographically elevated with respect to its surroundings and yet it does not block the Big Lost River from flowing to the east.

It is lower in elevation, however, than the swell centered on Quaking Aspen Butte to the south and the Great Rift to the southwest. The river crosses this rift as it down-cuts a channel into 519 and 609 ka basalts. Once across the Arco Rift, eastward or southward water flow is prevented by the Axial Volcanic High.

The Axial Volcanic High has been the loci for numerous eruptions (figures 1 and 2). The oldest known date of a surface rock associated with this feature is 1.4 Ma on a rhyolite exposed between East and Middle Buttes (upper right, figure 2). Surface water in the Big Lost Trough is blocked from flowing south by the Axial Volcanic High. Sedimentary data suggests that since sediments have been trapped in the Big Lost Trough for >2.0 Ma, the Axial Volcanic High has been a persistent feature on the Eastern Snake River Plain for at least as long (Bestland et al., 2002; Blair, 2002). South of the Arco Rift, surface water is blocked from flowing south or west by the swell centered on Quaking Aspen Butte, by the north end of the Great Rift, and by a low ridge system between the mountains to the north and the Axial Volcanic High which we will call the Laidlaw Ridge System for convenience (figure 3). This ridge is at least a half a million years old since its two highest buttes, Laidlaw and Snowdrift Crater, are dated at 425 and 480 ka respectively.

The ~0.5 Ma basalts along Laidlaw Ridge immediately southwest of the northern Great Rift and the ~0.5 Ma basalts flooring the Arco Rift are in same elevation range; the topographic barriers of the Quaking Aspen Butte swell and the northern Great Rift are sandwiched between these two features. Here the greater relief is provided by the Great Rift and Quaking Aspen Butte swell, and not by the Axial Volcanic High, so it is the former two elevated features that prevent surface waters from flowing south to the Snake River.

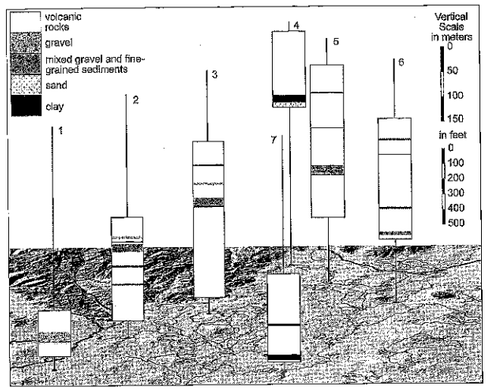


Figure 4. Stratigraphic diagram of representative lithological logs south and west of the modern drainage of the Big Lost River. Well information is listed in Table 2. The vertical line through each stratigraphic column is 488 m long (1600 ft) with a top elevation of 1676 m (5500 ft) MSL.

STRATIGRAPHY

Figure 4 shows seven representative stratigraphic columns for wells in the study area. Details of these wells are listed in Table 2. Our working assumption has been that gravels are only deposited by bed-load transport in rivers at flood (Graf, 1971). Based on this, the columns for wells 2, 3, 4, 5 and 6 show that streams which were likely the paleo-Big Lost River have flowed both to the southeast and to the southwest. The mixed gravel layer in well 6 is at ~235 m depth at a location south of both Big Southern and Quaking Aspen Buttes. The clay and sand units at depth in well 4 show that the river has deposited sediments also to the west, over 15 km from its current channel.

The mixed gravel unit in wells 5, 3 and 2 is similar to modern sediments observed today in the channel of the Big Lost River along its flood plain in the Big Lost Trough (Blair, 2002). This unit is at a slightly lower elevation in well 3 than in well 5. It is 50 m deeper in well 2. Wells 3 and 5 are on opposite sides of the Great Rift but are approximately equidistant from it. The northern Great Rift is uplifted with respect to the rest of the plain so it is not unexpected that the mixed gravel unit is higher in elevation in the wells closer to the rift than in the well at a distance in a quiescent volcanic tableland. While it is possible that the mixed gravel layer in well 2 has its origin in the Little Wood River or Fish Creek, both wells 3 and 5 are north and east of where these streams enter the plain (Figure 1), thus placing a potential fossil Big Lost River channel underneath Craters of the Moon.

The shallow gravels in well 1 are likely from the Little Wood River. This location marks the western edge for the stratigraphic survey. To the east of well 1 is an area where two to three clay layers are interbedded with basalts between elevations of 1220 to 1310 m MSL. This area occurs in townships 5S and 6S and ranges 21E to 28E, between Dietrich butte and the Wapi Flow (Figure 1) making a elongate east-west strip just north of the Axial Volcanic High. The clay layers in well 7 are representative of this stratigraphy of interbedded clay layers in basalt.

DETRITAL ZIRCON

In figure 5, we compare the ages of detrital zircons in the Big Lost River system (five samples) with those in the Big Wood River system (three samples). For clarity, we show grains of age 0 to 150 Ma and grains 150 to 3500 Ma in separate plots. The data show the presence of 70 to 100 Ma grains in the Wood River system and their absence in the Big Lost River system. The reason for this difference is the presence of the Cretaceous Idaho batholith only in areas drained by the Wood River. Also, the Big Lost River system has a large component of 52 to 45 Ma Challis magmatic grains and a well-defined population of Neoproterozoic grains (600 to 750 Ma). This population is smaller and more diffuse in the Wood River samples. These respective patterns distinguish the two provenance areas from other drainages and from one another.

DISCUSSION AND CONCLUSION

Link et al. (2002) used the detrital-zircon data included here to demonstrate that the Wood River system was the primary sediment source

Table 2. Well information

No	Name or Type	Elevation	Township-Range	Section/Quarter-section
1	Stockwell	4290 ft MSL	5S20E	sec 7 SWSE
2	Stockwell	4707 ft MSL	3S21E	sec 13 NENESE
3	Stockwell	5030 ft MSL	1S23E	sec 26 SWSW
4	Stockwell	5440 ft MSL	3N25E	sec 22 NESE
5	Site 1 well	5362 ft MSL	2N26E	sec 22 NESE
6	Crossroad well	5120 ft MSL	1S28E	sec 2 NESE
7	Stockwell	4583 ft MSL	6S25E	sec 21 SENE

of the 2.5 to 4 Ma fluvial deposits of the lower Glenns Ferry Formation at Hagerman Fossil Beds National Monument. The Big Lost River is missing from the regional stratigraphic record between 4 Ma and the time it was captured by the Big Lost Trough, after 2.5 Ma (Link et al., 2005).

Pre-Holocene age dates for the Craters of the Moon National Monument (Kuntz et al., 2004) have greatly advanced our understanding

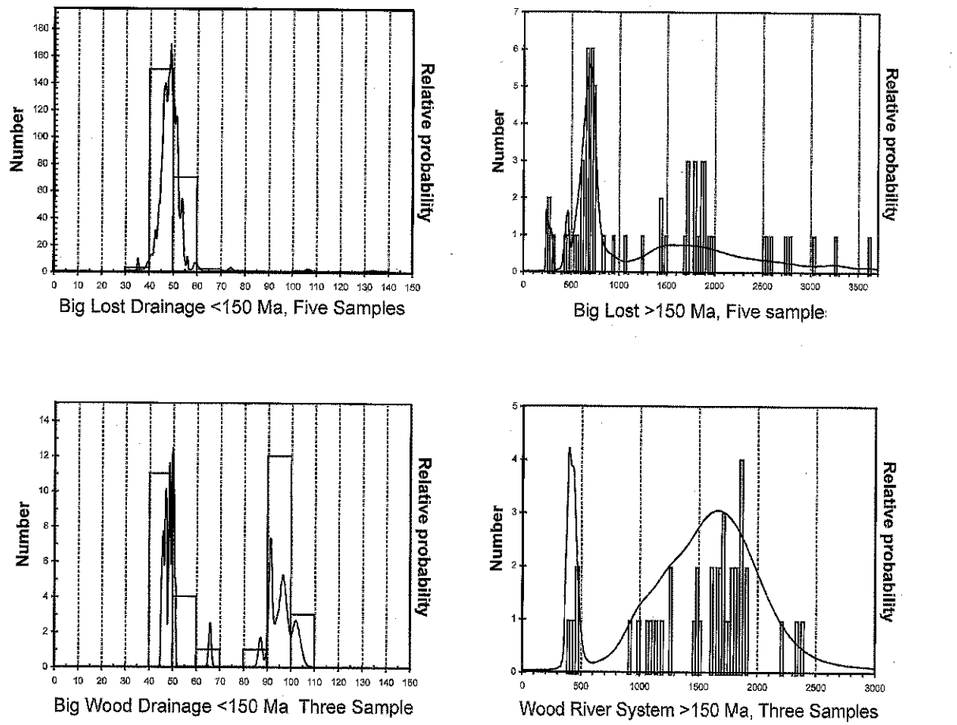


Figure 5. Zircon track age date distributions for the Big Wood and Big Lost Rivers. Sample locations and full data are presented in Link et al. (2005). Samples for the Big Lost River include the Big Lost River near Chilly, Idaho; Antelope Creek near its mouth; the Big Lost River at Hwy 26 Rest area; Big Lost River Pleistocene sand about 2 miles upstream from Hwy 26, and Holocene sand of Big Lost River about 2 miles upstream from Hwy 26. The Wood River samples include Trail Creek above Corral Creek, the Big Wood River south of Belleview and the Little Wood River south of Carey.

of uplift patterns for active volcanic areas on the Snake River Plain. However, these patterns can not be traced prior to ~0.5 Ma due to the lack of age dates south and west of the monument and the relative poverty of wells and well logs. There are no known dates in the subsurface west and south of well C1A at the southern edge of the Big Lost Trough. It is not currently possible to even estimate a date for the Axial Volcanic High west of the Great Rift. The mixed gravel sediments at elevation 1325 m MSL in the Crossroads Well (well 6, figure 4) indicate that sometime in the Plio-Pleistocene there were river waters at flood at this location on the flanks of the Quaking Aspen Butte swell – but that is all we can say until more data become available. Gravel-bearing sediments in this well are still remarkable when we consider that elevated rift zones accumulate little to no sediment (Anderson et al., 1997, Helm-Clark et al., 2005).

The age of the mixed gravel unit in wells 2, 3 and 5 is also uncertain. Applying a basalt accumulation rate of 33 m/100 ka averaged from data in Champion et al. (2002) and assuming the surface basalts at well 5 date from ~0.5 Ma, then the mixed gravel layer in this well is ~1.2 Ma or older. Given the variability of calculated recurrence intervals, however, it is possible that the accumulation rate is half this, which would date the mixed gravel unit at ~2.4 Ma instead.

There is no evidence for Big Lost River detrital zircon populations in the Glenns Ferry Formation at Hagerman below the uppermost units at about 2.5 Ma.. If the gravel sediments in the several wells do date from 2 to 4 Ma, the channels they represent may have been captured in playa sinks north of an ancestral Axial Volcanic High. These playa sediments may be represented by multiple clay layers interbedded with subsurface basalts in the area between Wapi and Dietrich (figure 1). This is the most likely explanation that fits both the lack of Big Lost River sediment in the Glenns Ferry Formation and the presence of the undated paleo-river channels and sinks in the subsurface south and west of the Arco and Great Rifts.

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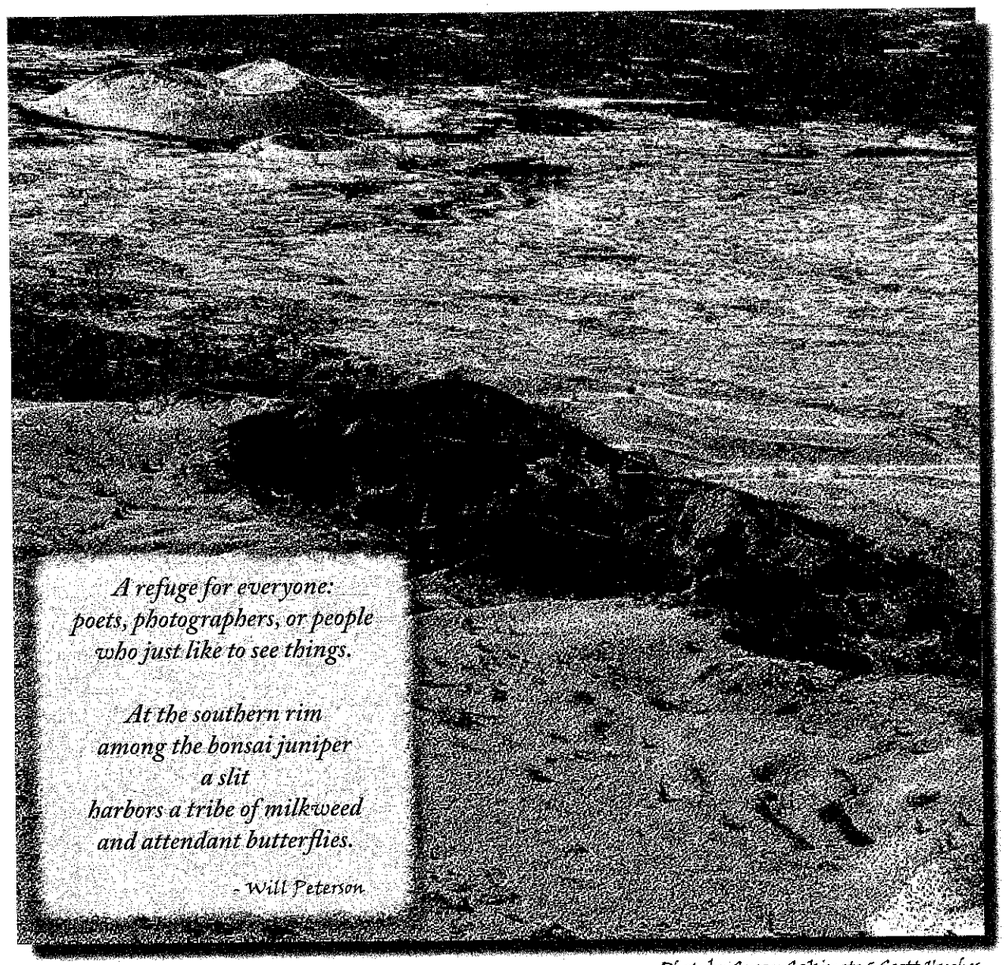


Photo by Susan Sakimoto & Scott Hughes

Reconstructing a Breached Cinder Cone at Craters of the Moon National Monument and Preserve: A Geographic Information Systems Approach

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ABSTRACT

North Crater is a breached basaltic cinder cone in the Pleistocene to Holocene Craters of the Moon lava field located within Craters of the Moon National Monument on the eastern Snake River Plain of southern Idaho. Large portions of the cone were rafted away by lava flows issuing from its base between about 2,222 ± 100 and 2,400 ± 300 years ago. The volume of cone material rafted from North Crater was documented utilizing a Geographic Information Systems (GIS) approach and far exceeds the volume which the breach in North Crater can contain. The breach in the northwest side of North Crater has a volume of only 1.23 x 10^6 m^3. Putting the 46 x 10^6 m^3 of rafted material back onto the current North Crater edifice would create a paleo-North Crater with a volume of 88 x 10^6 m^3, requiring a footprint area of 1.52 x 10^6 m^2, a radius of 700 m, and a height of 175 m. It is possible, however, that one large, monogenetic paleo-North Crater that size never existed. An alternative model is that a series of smaller paleo-North Craters were built at this location and destroyed by eruptions causing block rafting, the last of these being the existing, breached North Crater.

INTRODUCTION

Geologic Setting

Craters of the Moon National Monument and Preserve (CMNMP) is situated along the Great Rift, an 85 km-long, 2 to 8 km-wide volcanic rift zone in the eastern Snake River Plain of southern Idaho (Kuntz and others, 1986; Pierce and Morgan, 1992). The Great Rift has produced the Kings Bowl, Wapi, and Craters of the Moon lava fields (Kuntz and others, 1986). The latest Pleistocene to Holocene Craters of the Moon (COM) lava field comprises 8 eruptive fissure systems, 25 cinder cones, and more than 60 lava flows covering ~1,600 km^2 (Kuntz and others, 1986).

North Crater is a breached basaltic cinder cone in the northern portion of Craters of the Moon lava field (Kuntz and others, 1986). Five lava flows, the Highway, Devils Orchard, Serrate, Big Craters Northeast (2,400 ± 300 yrs B.P.), and North Crater flows (< 2,205 ± 25 yrs B.P.), erupted from vents within, or nearby, North Crater (Figure 1) (Kuntz and others, 1989). Three of these flows, the Highway,

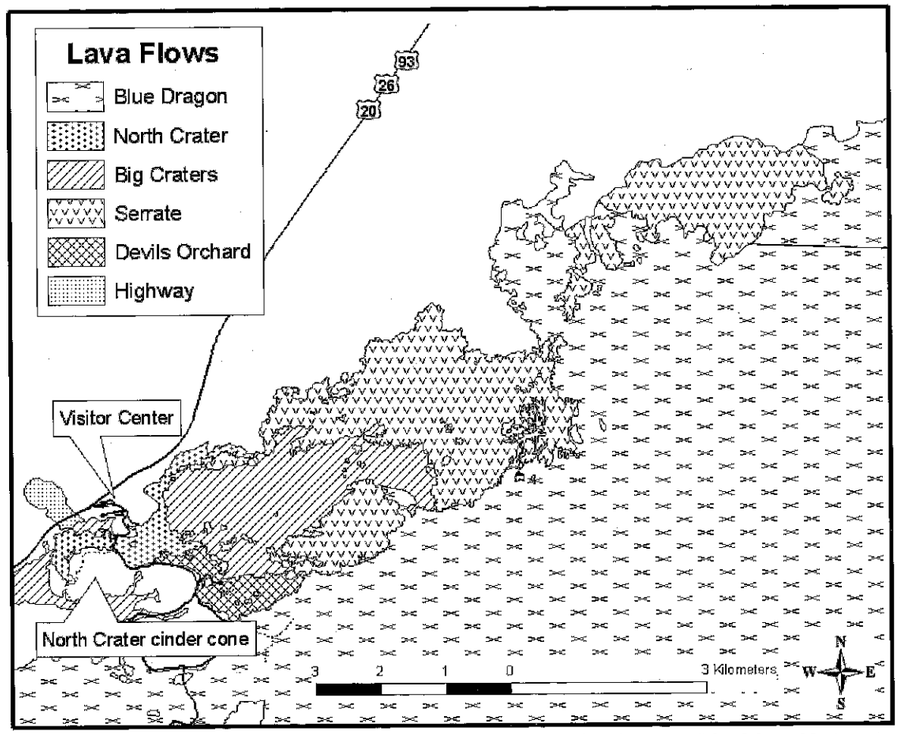


Figure 1. Map showing the location of North Crater in relation to the Craters of the Moon National Monument visitor center, Highway 20/26/93, and related lava flows.

Devils Orchard, and Serrate flows, are particularly high in silica (54–64 wt%), and are properly classified as basaltic-trachyandesite to trachyandesite (for a complete discussion of the chemistry of COM lava flows see Kuntz and others, 1986). They erupted violently as viscous block/a'a flows that damaged the northwest side of the cinder cone. These flows carried rafted blocks, pieces of bedded and oxidized spatter, agglutinated cinders, and ash from North Crater, as far as 13 km to the northeast.

Rafted blocks are often tens of meters in width and length and up to ~17 m high. As rafted blocks were carried by lava flows, they broke up into smaller pieces and became incorporated into the transporting flow. The results are lava flows with large patches of agglomerated cinders, jagged chunks of spatter, and rarely small patches of ash and cinders. In some locations, as much as 100% of the surface of the lava flow is blanketed by a layer of disaggregated rafted blocks. More commonly, the transporting lava flow contains domains where 30-50% of the lava flow is covered with disaggregated rafted blocks from North Crater. Later, younger pahoehoe flows buried many of the domains of disaggregated rafted blocks. Only the largest and most coherent blocks, which poke through the younger lava flows, are easily seen.

The volume of the material rafted from North Crater can be approximated by summing the volumes of exposed rafted blocks. The depth below the surface that partially buried blocks extend can only be estimated. Where the rafted blocks maintained a discrete form as they rafted, generating a volume calculation is relatively simple. Also, an unknown number of blocks have been partially or fully buried by as many as four later flows, depending on location. Since there is no way to estimate the volume

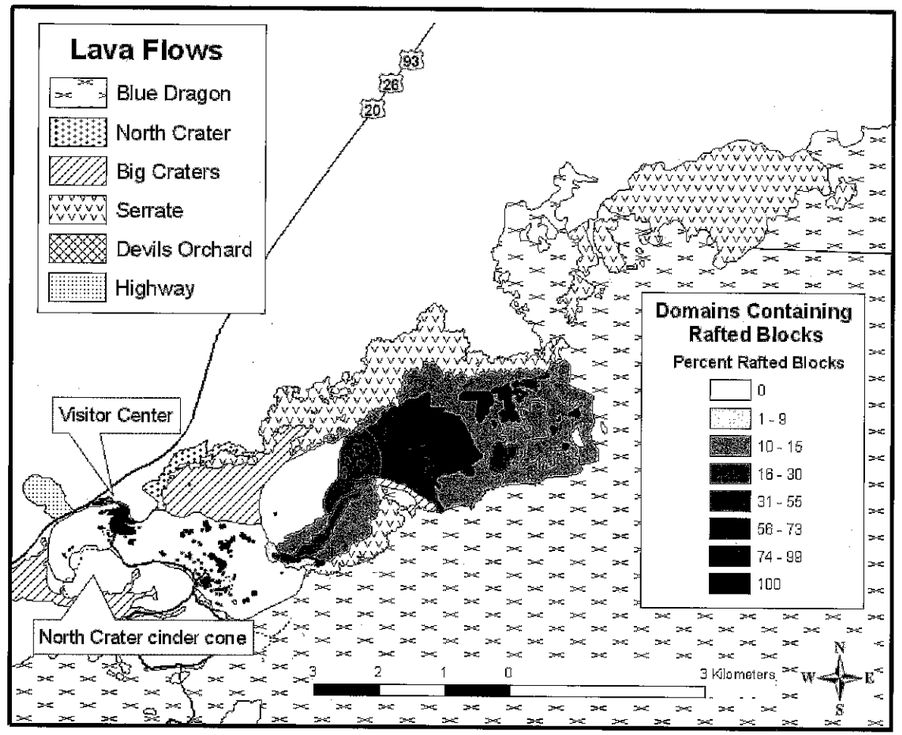


Figure 2. Map showing location of domains containing rafted blocks, disaggregated rafted material and related lava flows.

of rafted blocks that are buried by lava flows, any calculation of the volume of material rafted from North Crater is a minimum estimate.

Previous Studies

Other than the geologic maps produced by Kuntz and others (1989), little work has been done to describe the block rafting events at COMNMP. Rafted volcanic blocks have been described in detail in only a few other locations (Foshag and Gonzalez, 1956; Simons and others, 1966). Harwood (1989) and Riggs et al. (2004) conducted the most detailed studies to date on breached cinder cones in the San Francisco volcanic field of north central Arizona.

METHODS

Sub-Aerial Volumes of Discrete Blocks

By combining data on the block dimensions collected in the field with a 2002 National Park Service inventory of rafted blocks and digitized USGS geologic maps viewed in ArcView 3.2a (ESRI, 1999), we calculated the volume of discrete, coherent rafted blocks greater than 30 m^2 in area. The maximum height, typical width, and typical length of each block were multiplied together and the sub-aerial volumes of all the blocks were then summed.

Sub-Aerial Volumes of Disaggregated Blocks: The Domain Approach

The volumes of disaggregated blocks were also determined using ArcView 3.2a (ESRI, 1999). Domains of varying percentages of rafted material were identified by examining stereo air photos and delineated on digitized air photos in ArcView 3.2a (Figure 2). The percent rafted material in each domain was estimated after careful examination of stereo air photos and review of field notes. Domains covered by younger flows were assigned percentages of rafted material from the most appropriate

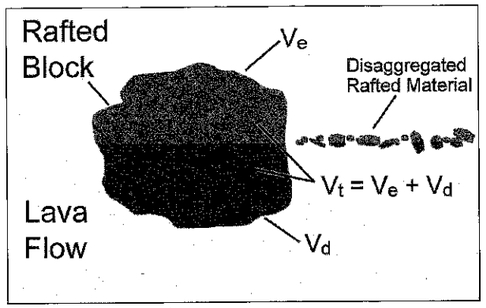


Figure 3. Schematic showing the above and below ground volumes of a rafted block. The total volume of the rafted block is the volume exposed (V_e) plus the volume of lava displaced by the block root (V_d).

nearby domain.

We developed a method to add up all the disaggregated cone material, creating an equivalent area that the disaggregated cone material would occupy if it were all put back into a coherent block. By multiplying the area of a domain, the percent of rafted material within it, and the maximum height of blocks in the domain together, the total above surface volume can be estimated. The sub-surface volume is accounted for by multiplying by a correction factor for the coherent block roots determined in the density analysis discussed below.

Sub-surface Volumes: Correction Factor for Sub-surface Roots of Blocks

We adopted a model where the transporting block/a'a lava flow was viscous enough to retard the isostatic rebound forces generated by the reduction in the block mass from disaggregation. This leaves a block root buried at some depth beneath the surface of the flow (Figure 3). By comparing the specific gravities of the transporting trachyandesite a'a lava and the rafted block material, the depth to which the blocks sink in the transporting flow (like the isostasy of icebergs floating in the ocean) can be determined and a complete volume can be calculated. The total volume of rafted material (V_t) can be determined from the volume of exposed rafted material (V_e) and the densities of the transporting lava (ρ_{lava}) and rafted blocks (ρ_{block}) (Figure 3) based on the following equation:

$$V_t = \frac{\rho_{lava} \times V_e}{\rho_{lava} - \rho_{block}} \qquad (1)$$

The densities of the Devil's Orchard and Serrate transporting flows were calculated by using major-element analysis data from Kuntz and others (1985) in MAGMA software (Wohletz, 2002). Densities of the rafted blocks were determined from samples collected in the field.

Volume, Area, and Height Relationships

In order to relate the calculated volume of paleo-North Crater to its footprint area and height, we examined the relationships between these parameters for eight relatively symmetrical cinder cones in the COM lava field. Ten meter USGS digital elevation models were used for this analysis in ArcView 3.2a with the Mila Grid Utilities and Xtools extensions.

RESULTS

Based on the methods described above, the volume of rafted material above the surface was calculated to be 21 x 10^6 m^3. We calculated the average specific gravity of the rafted blocks to be 1.42 g/cm^3 and estimated, from major element analysis of the lava flows (Kuntz and others, 1985) and MAGMA software, that the density of the Serrate and Devil's Orchard lava flows ranges between 2.59 and 2.82 g/cm^3. Plugging these numbers into equation 1 shows the ratio of total volume of rafted material to volume of rafted material exposed at the surface ranges between 2.01 and 2.21. Multiplying by the correction factor of 2.11 (the average of the two end-members) recovers the subsurface rafted material and gives the total rafted material: 46 x 10^6 m^3. Using the relation between cone footprint area and cone volume, as well as the current volume of North Crater, we determined that the breach in the northwest side of North Crater is only 1.23 x 10^6 m^3. Our calculations show there is over 38 times more rafted material than fits back into the hole in North Crater. Putting the 46 x 10^6 m^3 of rafted material back onto the current North Crater would create a paleo-North Crater with a volume of 88 x 10^6 m^3, a footprint area of 1.52 x 10^6 m^2, a radius of 697 m, and a height of 175 m.

Uncertainty

Despite any errors which may have resulted in overestimation of the amount of rafted material (in particular rafted block densities too high and percent rafted material in domains too great), the total volume of rafted material calculated is probably still a minimum. Perhaps as much as half the area which could contain rafted blocks is covered by younger lava flows that obscure any rafted blocks which may be there. Due to inadequate air photo coverage, almost a third of the area which could contain rafted blocks remains unanalyzed.

DISCUSSION

The reconstruction of North Crater presented above results in a paleo-North Crater that is substantially bigger than the current North Crater, ~60 m higher with a radius nearly 200 m larger. The large size of this paleo-North Crater is reasonable based on several observations. First, cinder cones of this size exist today in the lava field. Paleo-North Crater would have been approximately the size of modern Big Cinder Butte, 4 km to the south of North Crater. Second, there are pyroclastics which may be insitu lower flanks of a paleo-North Crater near the highway to the north, and near the campground to the northeast of North Crater (D. Owen and M. Kuntz, personal communication). If these represent the northern-most extent of a paleo-North Crater's footprint, and the current North Crater marks the southern extent, then the calculated paleo-North Crater with a radius of ~700 m fits quite well.

An alternative explanation to the large, monogenetic cone model is the possible presence of other, smaller monogenetic cinder cones that were completely rafted away (Caress and Owen, 2005). The apparent insitu cone deposits near the highway and campground may be remnants of possible neighbors to North Crater. These cones may have been parasitic or flank cones, having the same or different magma chamber and plumbing system as North Crater. Confirmation of these cones' existence is difficult because lava flows from North Crater or other younger vents may have rafted them away and buried any evidence. However, recent paleomagnetic studies of the northeast side of North Crater may support the existence of now absent neighboring cinder cones. Paleomagnetic data shows that a flat bench previously considered to be either a slumped section of North Crater or a large rafted block has the same orientation as the rest of North Crater and has not rotated to the west or east at all as a slump or rafted block might. That is, the bench could be the insitu margin of a former neighbor of North Crater that formed at nearly same time as North Crater.

Another explanation is provided by Foshag and Gonzalez (1956). They observed the development, destruction, and subsequent reconstruction of cinder cones throughout the early eruptive phases of the Parícutin volcano in Mexico. This repeated breaching and repair of cinder cone walls could generate substantially more material than would fit in the existing hole in North Crater. The presence of rafted blocks within two distinct lava flows (the Devil's Orchard and Serrate flows) suggests that at least two distinct periods of block rafting, and probably cone breaching and repair, took place. Instead of paleo-North Crater being one large, monogenetic cone, several smaller paleo-North Craters, perhaps similar in size to the present one, may have formed in the same location and been nearly completely destroyed.

Suggestions for Future Work

Close inspection of the contact relations between the lava flows issuing from North Crater might offer more clues as to the timing

of the rafting events. Further investigation of how deep disaggregated material lies under the surface of transporting flows would be helpful in refining the certainty of volume calculations. Inquiry into the composition of transporting flows in locations where they contain rafted blocks would help assign the lavas more accurate densities and methods to determine the yield stress the blocks needed to overcome to sink into the transporting flow would further improve the analysis.

ACKNOWLEDGEMENTS

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An Overview of the Idaho National Laboratory Site Wide Groundwater Model

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ABSTRACT

The purpose of the Idaho National Laboratory (INL) Site Wide Ground Water Model (SWGM) is to provide a comprehensive evaluation of environmental impacts from operations at the INL to the underlying Snake River Plain Aquifer. The SWGM is a schedule-driven, product-oriented project performed for the Department of Energy to evaluate the cumulative impacts from the co-mingling of residual contaminant plumes left behind after facility closures. Exposure risk will be evaluated during the remedial investigation/feasibility study process using the SWGM. The model will support environmental decisions and serve as a tool for managing, compiling, and synthesizing data. It is structured to integrate with and complement existing groundwater flow and contaminant transport models developed by other INL clean-up projects. The model development strategy is a departure from the strategies for other models that have sought a single, unique solution to ground water flow and transport. The SWGM strategy recognizes the likelihood of varied interpretations arising from a relatively sparse data set for the complicated INL subsurface and allows flexibility to incorporate these interpretations. Flexibility in the modeling approach will allow evaluation and testing of competing interpretations and will help to define the bounds of flow and transport in the aquifer at the scale of the INL. The SWGM consists of two major components, the conceptual and numerical models. To ensure technical quality, enhance credibility and maintain consensus with the regulating government agencies, the SWGM is subject to an annual external peer review and agency modeling summit meeting.

INTRODUCTION

The purpose of the Idaho National Laboratory (INL) Site Wide Groundwater Model (SWGM) is to provide a comprehensive tool for evaluation of environmental impacts to the underlying Snake River Plain Aquifer (SRPA) of past and present operations at the INL. The SWGM is being developed as part of the Operable Unit (OU) 10-08 remedial investigation /feasibility study (RI/FS) in support of the Federal Facility Agreement and Consent Order (FFA/CO) of 1991. The FFA/CO details the broad superfund objectives and schedules for decisions on remediation actions for environmental cleanup of legacy waste and contamination at the INL.

All major sources of contamination that may have an impact on the SRPA are identified in the FFA/CO and remediation is being accomplished in localized contamination

areas, or Waste Area Groups (WAGs). The OU 10-08 RI/FS addresses areas outside the boundaries of other WAGs (believed to be minor or negligible sources) and considers the potential for risk created by commingling of residual contamination left by individual WAGs. Cumulative impacts on the SRPA of all known contaminant sources will be evaluated during the OU 10-RI/FS.

A key component of the RI/FS effort (DOE-ID 2002) and a management tool for long-term stewardship of the groundwater resources at the INL will be the OU 10-08 SWGM, which is a groundwater-flow and contaminant-transport model. The model will support informed regulatory decisions and serve as a tool for managing, compiling, and synthesizing data regarding the SRPA beneath the INL. Currently, several different aquifer models are used at the INL to satisfy specific program needs. These models in some cases produce divergent predictive results based on the regimes they represent. The SWGM will combine and attempt to resolve technical inconsistencies of these models by using the best available information now available on the SRPA and incorporating additional technical data collected during the RI/FS. The SWGM will be used to satisfy requirements for preparation of the OU 10-08 record of decision (ROD) and will supplement and support existing aquifer models.

The need to produce the OU 10-08 SWGM is driven by advancements in the understanding of the INL subsurface. During the past decade, INL contractors, the United States Geological Survey (USGS), and numerous academic institutions have obtained information that significantly changes the conceptual model of the subsurface beneath the Eastern Snake River Plain (ESRP). These new data have not been reviewed and incorporated into a single comprehensive understanding of aquifer flow and transport. In order to use these new data in determining the risk posed by contaminants from the INL, the data must be compiled and used to update conceptual and numerical models.

GOAL, SCOPE AND PRODUCTS

The goals, scope and products for the OU 10-08 RI/FS have been developed and refined during meetings and monthly conference calls with U.S. Department of Energy (DOE), State of Idaho, Environmental Protection Agency (EPA), and INL site contractors. As a part of the RI/FS process, the direction and progress of the OU 10-08 SWGM has been and will continue to be tracked during these interactions. In addition, an annual two-day Groundwater Modeling Summit Meeting is held with the agencies, DOE and other project members to focus specifically on all aspects of the OU 10-08 SWGM.

This process has lead to the following overall goal for the SWGM:

Develop a site wide flow and transport model of the active flow portion of the Snake River Plain Aquifer that can be used to evaluate OU 10-08 remedial action alternatives and to ensure all remedies remain protective of the aquifer. The model will provide credible estimates of contaminant concentrations from sources at the INL over relevant future time frames.

The scope of the OU 10-08 SWGM is to evaluate the cumulative impact from individual INL groundwater contaminant sources to potential receptors within or near the boundary of the INL. As a consequence, the SWGM boundaries, referred to as the OU 10-08 model domain, extend some distance beyond the INL boundary. The scale of investigation for the SWGM is defined as "subregional" and is large enough to establish reasonable boundary conditions.

The primary products of the OU 10-08 SWGM effort will be as follows:

- An updated conceptual model of flow in the SRPA, capturing the current understanding of the aquifer system in a form that can be used in a numerical simulator to predict groundwater flow and contaminant transport

- A numerical modeling tool that can be used to predict the aquifer flow directions, water mass flux rates, and contaminant transport at the scale of the INL.
- A tool that can be used to ensure that remedies are protective of human health and the environment at the scale of the INL.

MODELING STRATEGY

To the extent possible, the SWGM will be structured to integrate with and complement existing groundwater flow and contaminant transport models developed by individual WAGs, the USGS, and the State of Idaho. This approach will enhance consistency across the INL and help resolve differences raised by different interpretations of subsurface data. Communication, staff integration, and data sharing are the foremost components in the strategy for integrating the SWGM with existing models. Meetings are held at regular intervals for technical and management staff involved with the active development or application of numerical simulations of the subsurface at the INL. Senior technical staff personnel have been recruited from the major facility-scale groundwater projects to act as technical consultants on the design and construction of the SWGM.

The SWGM development strategy is a departure from the strategies used for other models that have sought a single, unique solution to groundwater flow and transport. The SWGM strategy assumes that different and sometimes competing interpretations of groundwater flow and transport will develop because of the relatively sparse subsurface data set for the complicated INL subsurface and the many programs utilizing these data for varied purposes. Consensus on a single conceptual model will be difficult to achieve and will evolve as more data become available. The SWGM strategy for integration includes the capability to test interpretations generated by various projects (solving specific problems). Cross comparison between interpretations will define the bounds of flow and transport in the aquifer at the scale of the INL. Thus, unique solutions derived by individual projects can be included in the SWGM as long as the solutions are consistent within a range that is reasonable for possible interpretations described by the subregional understanding of aquifer flow and transport.

The task-based approach to implementing the modeling strategy is:

- Update and document the OU 10-08 subregional conceptual model of groundwater flow.
- Identify data gaps and make recommendations for filling them.
- Prepare a new OU 10-08 numerical model of subregional groundwater flow based on the updated conceptual model. This modeling effort will consist of a set of two subregional groundwater flow models (i.e., two-dimensional for design and three-dimensional for implementation).
- Coordinate with other WAG projects to provide a subregional numerical tool that is consistent with the intermediate-scale numerical models used for individual WAGs. To the extent practical, the OU 10 08 numerical model will integrate directly with the intermediate-scale models.
- Develop a numerical model of contaminant transport for INL site wide groundwater risk assessment. In particular, the objective is to identify areas where plumes might commingle, resulting in an unacceptable cumulative risk to groundwater users.

IMPLEMENTATION

Administratively, the OU 10-08 SWGM Project Team is organized into two teams as depicted in Figure 1. The Conceptual Model Team deals primarily with the physical and chemical processes that affect aquifer flow and transport, while the Numerical Model Team deals with how to represent the salient aspects of the conceptual model in a numerical

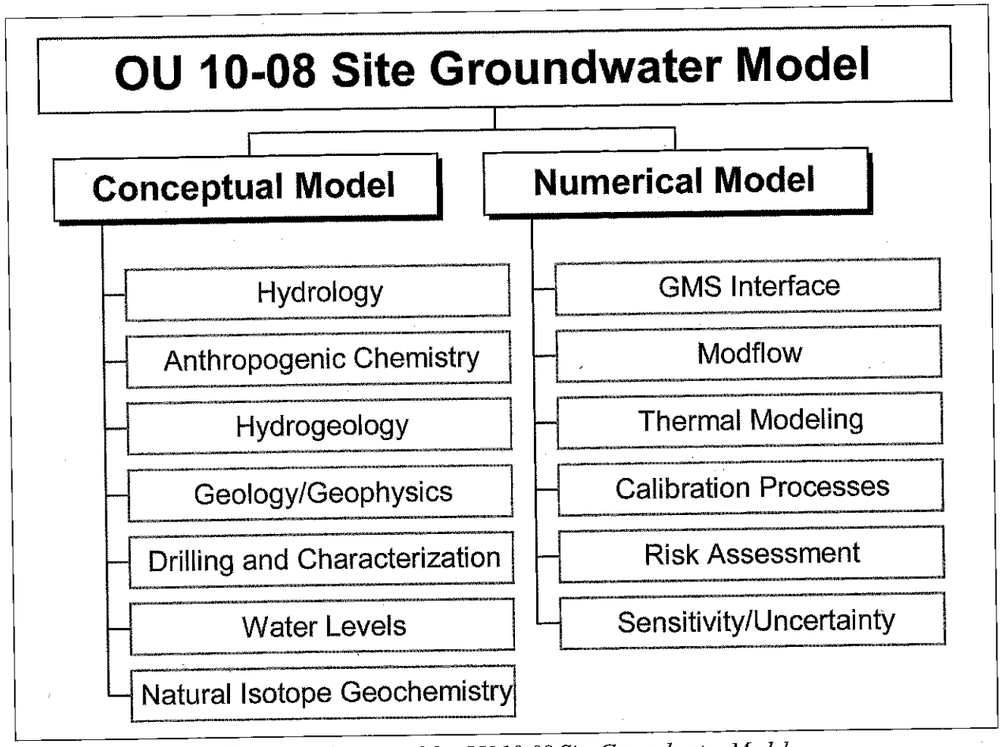


Figure 1. Elements of the OU 10-08 Site Groundwater Model.

simulator. There is considerable interaction and communication between the two teams in scheduled group meetings held twice monthly and informal weekly team meetings. Communication at the individual contributor level occurs daily. Project management has made a concerted effort to bring computer modelers and earth scientists together so that there is a mutual understanding and appreciation of how the various disciplines analyze and use data to make interpretations that influence contaminant flow and transport. Earth scientists are asked to make decisions on how complex data sets can be reduced or simplified for use in the SWGM. Numerical Modelers are asked to stretch the limits of standard numerical simulating approaches to incorporate important aspects of a complicated subsurface environment. Our interdisciplinary approach has lead to an improvement in both the conceptual and the numerical models.

External peer reviews of the OU 10-08 SWGM have proven to be very beneficial for enhancing communication and strengthening the technical rigor of the project. A team of four reviewers with national or regional expertise is selected for the review process and a two-day meeting is devoted to reviewing all aspects of the SWGM. The peer review team then prepares a summary report documenting their findings and making recommendations for potential improvements for the modeling approach. To date, two peer review meetings have been conducted.

SCHEDULE

The WAG 10 OU 10 08 RI/FS work plan (DOE 2002) describes the enforceable milestone schedule for OU 10-08, and the reader is referred to that work plan for a detailed summary of the events controlling the final deliverable date for the OU 10-08 ROD. The

OU 10-08 ROD is expected to be the last ROD completed at the INL, and the deliverable date depends on when the other WAG RODs are signed. The draft OU 10-08 RI/FS is currently scheduled to be submitted to the agencies in November of 2008.

This schedule is subject to change depending on the completion of other INL RODs. Groundwater modeling activities are scheduled to support the aquifer flow and transport portions of both the OU 3-13 and OU 7-13/14 RODs. The two-dimensional SWGM will be finished in time to support the OU 3-13 ROD, and the three-dimensional SWGM will be finished in time to support the OU 7-13/14 ROD.

It is critical that the OU 10-08 RI/FS activities overlap and are tied to remedial decisions across the INL site. All the other WAGs will eventually be managed under WAG 10 as activities close after individual WAG RODs are signed and remedial actions are completed. This will ensure a smooth and cost-effective transfer into the long-term stewardship role of WAG 10. Also, consolidation and communication of SRPA-wide concerns are needed as soon as possible because of the crucial importance of the SRPA to the population of eastern Idaho and the fact that predicted contaminant levels in the SRPA drive most selected remedies for individual WAGs. With this end in mind, the INL management has taken a proactive, technically acceptable approach to developing the SWGM.

SUMMARY

The approach described for development of the OU 10-08 SWGM has the following benefits:

- Reduces costs through use of data and resources from other WAGs and subsurface research at the INL by the USGS, Universities and DOE Research projects.
- Shortens implementation schedule with the effort in parallel with other individual WAG RI/FS's.
- Creates a high level of technical quality and defensibility.
- Develops a long-term tool for analysis of monitoring data and effectiveness of cleanup remedies.
- Creates a defensibly conservative model for risk assessment.
- Achieves a balance between technical credibility and cost.
- Iterations and rapid hypothesis testing builds consensus with stakeholders.

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Photo by Scott Hughes

When you go out there
you'll have a plan, I know:
somewhere to be, say
Pillar Butte, two hours.

It looms like the Sphynx.

The first wave crests
with strange ropy designs
stitched with paintbrush
and penstemon
but turns quickly to crevasse.

You edge north
Skirt another: realize
you're not going anywhere.

But it's alright.
You'll go where it takes you
stay out late
hope for a moon

- Will Peterson

Multi-objective and Multi-scale Modeling Approach for the Idaho National Laboratory Operable Unit 10-08 Sitewide Groundwater Model

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ABSTRACT

Numerical models are being constructed to simulate groundwater flow and chemical transport at the scale of the Idaho National Laboratory (INL). An integrated multi-objective and multi-scale modeling approach has been implemented to provide a robust and technically defensible numerical tool that adequately represents groundwater flow and solute transport at various scales. This approach permits model calibration to multiple data sets (water levels, natural and anthropogenic solutes, and water temperatures) and integrates conceptual models derived from each of these data sources. The approach also integrates numerical modeling results derived from facility-specific and regional scale studies.

INTRODUCTION

The objective of Waste Area Group (WAG) 10, Operable Unit (OU) 10-08 groundwater modeling study is to provide a comprehensive evaluation of environmental impacts from operations at the Idaho National Laboratory (INL) to the underlying Snake River Plain aquifer (SRPA). The subject modeling activity falls under the sitewide clean-up and long-term monitoring efforts of the Idaho Cleanup Project's WAG 10 program. Cumulative impacts from INL operations on

the SRPA will be evaluated during the OU 10-08 remedial investigation/feasibility study (RI/FS).

A key component of the WAG 10 RI/FS effort (DOE-ID 2002a) and long-term stewardship of the groundwater resources of the INL is the development of a sitewide groundwater-flow and contaminant-transport numerical model. This model will support regulatory requirements and decisions and will serve as a tool for management, compilation, and synthesis of groundwater data at the INL. This model will promote consistency and eliminate redundancies in WAG-specific models that previously had resulted in potentially conflicting directions and rates of groundwater flow and contaminant transport. The model will integrate modeling results of facility-scale and larger-scale studies. Facility-scale numerical modeling studies include WAG 1 studies (INEEL 1997, DOE-ID 2002b), WAG 3 studies (DOE-ID 2006), and WAG 7 studies (Magnuson and Sondrup, 2006). Larger-scale studies include the USGS Regional Aquifer-System Analysis Program (Garabedian 1992); State of Idaho regional water resource model (Cosgrove et al 1999, IWRRI web page), and USGS subregional models (Robertson 1974; Spinazola 1994; USGS subregional flow and transport model currently in preparation). The OU 10-08 model also will incorporate recent geohydrologic information and an evolving conceptual model of groundwater flow and contaminant transport.

This article describes the numerical modeling approach being implemented in the construction of the OU 10-08 Sitewide Groundwater Model within the domain representing the 2,500 mi² area of the Eastern Snake River Plain around the INL (Figure 1). The article also defines the utility of this multi-objective and multi-scale model of groundwater flow and contaminant transport in the integration of hydrologic data and concepts derived from multiple conceptual models at different scales into a consistent, flexible interpretation tool. A major benefit of

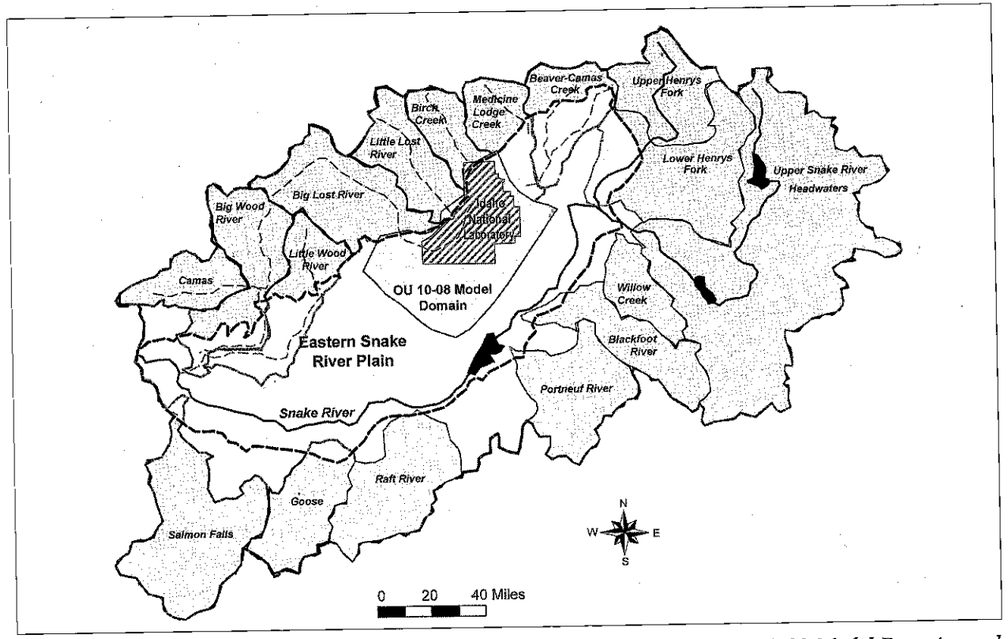


Figure 1. Eastern Snake River Plain, tributary drainage basins, Operable Unit 10-08 Model Domain, and the Idaho National Laboratory.

this approach is that it communicates complex hydrologic, geochemical, and geological concepts to a wide range of audiences.

OU 10-08 SITEWIDE GROUNDWATER MODEL WORK PLAN

The strategy for this modeling effort is established in the OU 10-08 Sitewide Groundwater Model Work Plan (DOE-ID 2004). The work plan established the path for model development to support the OU 10-08 Remedial Investigation Baseline Risk Assessment. This path was determined in a consensus process conducted with the U.S. Environmental Protection Agency and the State of Idaho. The work plan identified and justified data gaps and developed strategies to address those data gaps. The work plan also outlined integrated modeling activities and defined the schedule for completion of those activities.

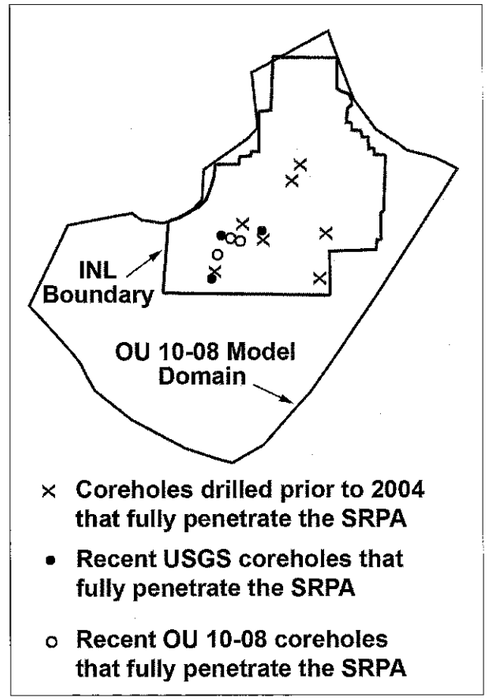


Figure 2. Location of recent deep coreholes penetrating the SRPA at the INL.

DATA GAPS

The OU 10-08 Sitewide Groundwater Model Work Plan (DOE-ID 2004) identified significant data gaps with respect to the geologic framework, variability of hydraulic parameters, distribution of data, and sparseness of chemical data. Many of these data gaps are being filled through core-drilling and monitoring-well operations and through data collection programs as identified in the work plan.

In recent years, five deep coreholes (including three coreholes drilled by the U.S. Geological Survey) have been drilled through the base of active flow in the SRPA beneath the INL (Figure 2). These new coreholes were drilled to supplement limited deep corehole data and are being completed as multi-level monitoring wells to provide information about the thickness of the SRPA, hydrostratigraphy, and vertical distribution of head, solutes and temperature. In addition, a water-chemistry sampling program was designed to collect samples from existing wells to improve coverage for spatial and vertical characterization of natural and anthropogenic chemistry, contaminant plumes, and temperature data. New information derived from these data-gap activities is being incorporated into the OU 10-08 conceptual and numerical models.

INTEGRATED MODELING ACTIVITIES

The OU 10-08 Sitewide Groundwater Model Work Plan (DOE-ID 2004) defined the numerical modeling approach. This approach employs specific state-of-the-art simulators and utilizes a phased modeling strategy, beginning with a two-dimensional flow and transport model, followed by a three-dimensional model

NUMERICAL MODELING TOOLS

The multi-objective, multi-scale numerical modeling work utilizes the computer codes MODFLOW-2000 (Harbaugh et al. 2000) and MT3DMS (Zheng and Wang, 1999) within the Groundwater Modeling System (GMS) (U.S. Army Corps of Engineers, 2005) environment.

MODFLOW-2000 simulates the two- and three-dimensional groundwater flow fields throughout the OU 10-08 model domain and MT3DMS simulates two- and three-dimensional transport of solutes. The computer code HST3D (Kipp 1987) is being used to generate thermal boundary conditions for the model domain as derived from a regional thermal transport model. MT3DMS will then be used to develop the spatial and vertical thermal distribution within the model domain.

Calibration of flow and transport models is automated by linking MODFLOW-2000 and MT3DMS with PEST (Doherty 2005), a parameter estimation tool. This automated calibration technique assists in efficient testing of hypotheses and expedites model revision as new information becomes available.

PHASED MODELING STRATEGY

A phased approach is being employed to first solve the simpler two dimensional case and identify issues and data gaps that need to be addressed in the final comprehensive three-dimensional case. This strategy includes development of several integral components: (1) a 2-D model relying primarily on published data; (2) two-dimensional flow and transport models, (3) a 3-D conceptual model that incorporates recently acquired geohydrologic information, (4) three-dimensional flow and transport models; and (5) a Response Surface Model. Work on the numerical models in this phased approach is both sequential and concurrent, with preliminary three-dimensional activities being initiated as two-dimensional models are being completed.

The two-dimensional groundwater flow model using MODFLOW-2000 was constructed to represent variable aquifer thickness (Smith 2002) in a single layer, incorporating, where possible, individual WAG model hydraulic characteristics. The purpose of this model was to finalize the extent of the model domain, boundary conditions, and general distribution of permeability fields without adding the complexities of the fully three-dimensional system. This model was calibrated to measured water-level data.

The two-dimensional transport model using MT3DMS was based on the two-dimensional flow model results. The purpose of this model was to work out the transport simulation process and to integrate source terms derived from individual WAG models. Simulated contaminant plumes were compared to known plumes but the two-dimensional model was not calibrated because it cannot represent the three-dimensional character of contaminant transport that is known to occur in the aquifer.

The three-dimensional flow model using MODFLOW-2000 will build upon the two-dimensional model output. This model will incorporate vertical anisotropy and will be used to refine the permeability field. Calibration objectives will consist of available sets of three-dimensional measured water-level data.

The three-dimensional transport model using MT3DMS will be linked to the three-dimensional flow model results. This integrated model will be used as the cumulative risk evaluation tool for OU 10-08. Multiple calibration objectives will include velocities estimated from natural chemical tracers, concentration time histories resulting from anthropogenic tracers and contaminants, and temperature data.

The Response Surface Model (RSM) is presently under development and is a numerical tool that can rapidly emulate the results of the three-dimensional transport model. The RSM utilizes output from the three-dimensional transport model in a convolution integral approach to create a numerical response surface to emulate the more detailed model. The RSM provides a tool that has the capability to perform rapid assessment of cumulative risk from multiple contaminant sources at the INL that includes all the information garnered from the three-dimensional transport model but in a more computationally efficient manner.

INTEGRATED MULTI-OBJECTIVE AND MULTI-SCALE MODELING APPROACH

The multi-objective approach is defined as the utilization of more than one type of data in model calibration. The multi-scale approach is defined as the approach that integrates and permits consistency between INL facility-scale numerical models and regional-scale numerical models.

The multi-objective and multi-scale approach is intended to more accurately describe flow and transport at scales necessary to provide resolution near INL facilities while honoring the sub-regional aquifer system. The benefit of this approach is that it ties together areas around facilities with more wells and water chemistry data within the context of a sub-regional flow field, maintaining a balance between conservative modeling for risk assessment and technical credibility.

MULTIPLE OBJECTIVES

The numerical modeling approach being utilized for the OU 10-08 Sitewide Groundwater Model incorporates multiple data sets for calibration. This approach was initiated because of the limited data sets (spatial and vertical distribution of water levels, for example) available for model calibration. The use of multiple and some non-traditional, data sets will result in a model that considers all data to yield interpretations that reasonably represent local and sub-regional scale phenomena. The model may be capable of resolving uncertainties derived from numerous, conflicting conceptual models of flow and transport. Multiple objectives have been determined from conceptual model development and consist of data sets of measured water levels, natural chemical data, contaminant concentrations in groundwater, and groundwater temperature data.

WATER LEVELS

Water levels measured in wells provide a data set that is indirectly usable in calibration of both steady-state and transient flow models. However, because of the extremely permeable, fractured, and anisotropic character of the aquifer, the exact direction and gradient of flow is difficult to ascertain using only this data set, in part because of measurement uncertainties and paucity of data in places

NATURAL CHEMICAL DATA

Natural chemical data, including stable and radioactive isotope data, have been used to evaluate flow velocity and to identify preferential flow zones within the SRPA. These data are available from wells located throughout much of the model domain, represent large areas with long travel times, and have the advantage in that they are not tied to facilities. The apparent direction of flow within these preferential zones, derived from chemical data alone, is not consistent in all cases with local flow directions derived from water-level data. Use of these natural chemical data in calibration of the three-dimensional transport model will supplement the use of water-level data in calibration of the flow model.

ANTHROPOGENIC CONTAMINANT DATA

Anthropogenic contaminant data sets are available from wells located within contaminant plume areas. These data provide flow velocity and solute transport property information and additional calibration targets to better constrain the flow field in the vicinity of contaminant sources.

GROUNDWATER TEMPERATURE DATA

Groundwater temperature data are readily available from most sites within the model domain. This data set easily provides for calibration of the linked flow and transport model because heat behaves in a manner that is similar to that of conservative solutes. Temperature as a tracer will be evaluated within the transport model, utilizing thermal boundary conditions derived from regional thermal models.

MULTIPLE SCALES

The numerical model will integrate results from WAG-specific models and -regional scale models and will permit integration of contaminant source terms derived from individual WAGs into the OU 10-08 model domain.

INTEGRATION BETWEEN WAG AND REGIONAL SCALES

Domains of WAG-specific numerical models are spatially limited to optimally represent water levels within areas of known contaminant plumes. The model domains and boundary conditions do not permit direct integration with regional-scale models that ensures consistent water fluxes within the aquifer. The OU 10-08 Sitewide Groundwater Model will provide the capability to integrate results from WAG-specific numerical models with regional groundwater flow and thereby demonstrate consistency with independent estimates of the flux of water through various portions of the aquifer. The OU 10-08 model has the capability of incorporating detailed local-scale conceptual model information derived from individual WAG models as well as regional conceptual model information. This information includes stratigraphic/lithologic data, hydraulic properties, and boundary conditions.

INTEGRATION OF WAG-SPECIFIC CONTAMINANT SOURCE TERMS

Multiple contaminant source terms at the INL are derived from individual facilities. Mass loading from these source terms to the SRPA has occurred through injection wells, vadose zone transport to the top of the aquifer from infiltrating wastewater in disposal ponds, leaching of contaminants from landfills, and gas-phase transport.

Evaluation of the contaminant mass loading term to the aquifer is the responsibility of individual WAGs. This evaluation is being accomplished through development of WAG-specific vadose-zone transport models. Model development at the different WAGs ranges from under construction to complete, and, in several cases, is expected to continue to evolve as new information is collected through the RI process.

The OU 10-08 transport model will integrate contaminant mass loading from multiple source terms at the INL. Transport model representation of mass contaminant loading to the SRPA from to the OU 10-08 transport model will be derived from individual WAG numerical model results. This approach provides consistency with the numerical modeling tools used in CERCLA Records of Decision (RODs) and provides the best estimates of source volumes and release rates that have been reviewed and negotiated with federal and state agencies.

Although this mass loading approach will rely explicitly on output from individual WAGs, it is recognized that the contaminant loading to the aquifer is the key input affecting the predicted future groundwater concentrations. As such, the appropriateness of the individual WAG vadose zone models and the underlying assumptions included in their development will be reviewed in the process of integrating the simulated fluxes from those models.

The OU 10-08 transport model is designed to adapt to changes in contaminant input. The model also will be archived with the capability to be rerun, permitting future analysis of an evolving understanding of contaminant mass loading to the SRPA. The model will be a critically important tool for evaluating groundwater monitoring data in light of model predictions used to make regulatory decisions. These reviews are mandated every five-years under the CERCLA process.

SUMMARY

The OU 10-08 Sitewide Groundwater model is being developed using a multi-objective multi-scale modeling strategy as a tool to assess cumulative groundwater risk from INL contaminant sources. This model simulates groundwater flow and contaminant transport within the 2,500 mi^2 area represented by the OU 10-08 model domain and provides

a robust and technically defensible numerical tool that adequately represents groundwater flow and solute transport at various scales.

The multi-objective approach utilizes multiple data sets (water levels, natural and anthropogenic solutes, and water temperatures) in model calibration. This use of multiple calibration targets reduces uncertainties that exist with each independent data set and offers the capability to integrate conceptual models that have been derived from each of these data sources.

Facility-specific and regional scale numerical modeling results previously resulted in potentially conflicting directions and rates of groundwater flow and contaminant transport. The multi-objective multi-scale approach has the potential to integrate and incorporate results from studies at these different scales.

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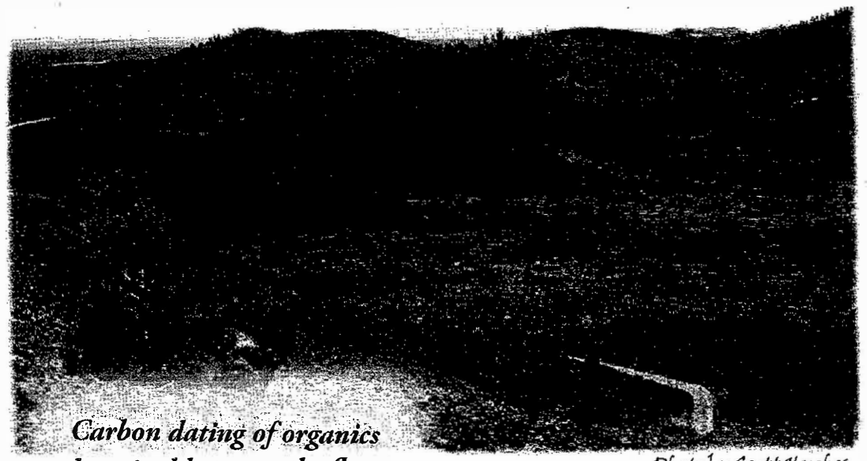


Photo by Scott Hughes

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deposited between the flows
shows they occur
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another estrus cycle
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The last was around
the birth of Christ,
which means we're due for another:
maybe tonight
a comet crossing the sky.

- Will Peterson

Overview of the Conceptual Model of Groundwater Flow within the Snake River Plain Aquifer at the Idaho National Laboratory, Idaho

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ABSTRACT

A three-dimensional numerical model is being constructed to simulate groundwater flow at the Idaho National Laboratory. This model is part of a phased modeling study designed to evaluate sitewide groundwater remedial-action alternatives under the Operable Unit (OU) 10-08 project. The numerical model is based upon a technically defensible conceptual model of groundwater flow. This paper presents an overview of the elements of the conceptual model, including stratigraphy, geohydrologic features, and groundwater flow into and out of the area.

INTRODUCTION

A comprehensive evaluation of environmental impacts from operations at the Idaho National Laboratory (INL) is needed to evaluate Operable Unit (OU) 10-08 remedial action alternatives and to ensure that all remedies remain protective of the Snake River Plain aquifer (SRPA). This evaluation will be accomplished through development of a technically defensible conceptual model to support numerical modeling of groundwater flow and contaminant transport as described in the OU 10-08 sitewide groundwater model work plan (DOE/ID 2004). This paper presents an overview of the conceptual model of flow within the SRPA at the INL supporting development of a preliminary two-dimensional numerical model for the OU 10-08 study area.

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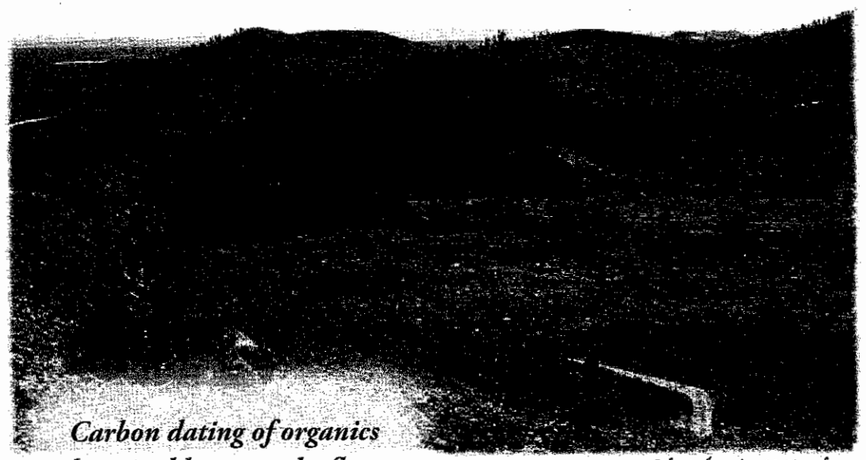


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control flow and transport. A description of the physical system includes additions (inflows) and subtractions (outflows) of water.

The conceptual model evolves with improved understanding of the geohydrologic features controlling flow and transport. Each conceptual model aspect includes definition of competing hypotheses about those geohydrologic features. As competing hypotheses are identified, they can be tested to further refine the conceptual model.

REGIONAL SETTING

The conceptual model of flow at the INL is described within the context of the regional geohydrologic systems of the Eastern Snake River Plain (ESRP). The SRPA, one of the most productive aquifers in the United States, underlies the plain (Figure 1) and has been estimated to contain from 80 million to as much as 1 billion acre-ft of water. The aquifer provides a drinking-water source to more than 200,000 people and supplies water to a large, regional agricultural and aquacultural economy.

Recharge is derived from irrigation and river seepage, infiltration of areal precipitation, and tributary-basin underflow. Groundwater flow is to the southwest (Figure 1), with travel time from recharge areas in the northeast to discharge areas along the Snake River in the southwest part estimated to exceed 300 years (Ackerman, 1995).

Discharge predominantly occurs from large springs in the Thousand Springs area along the Snake River between Twin Falls and King Hill (Figure 1). Aquifer discharge also occurs from pumpage for irrigation, municipal, and domestic supply.

BACKGROUND FOR CONCEPTUAL MODEL DEVELOPMENT

Numerical flow models have been utilized

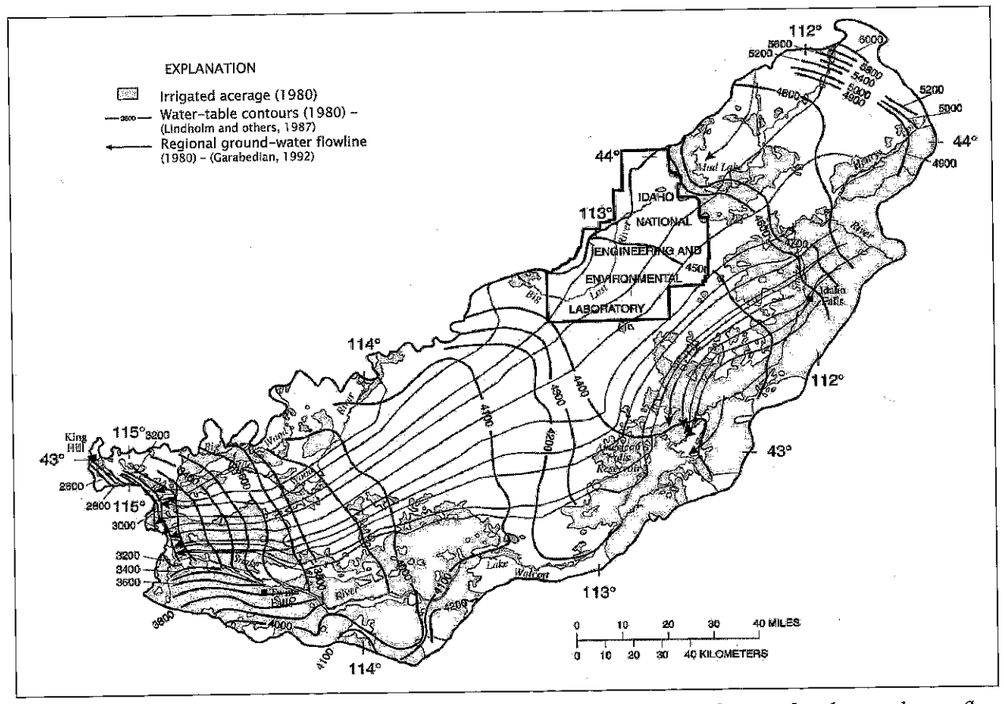


Figure 1. Extent of the Snake River Plain aquifer, potentiometric surface, and generalized groundwater flow paths. Map shows irrigated acreage and important regional surface-water features.

for many years, both at the scale of the INL and for much larger areas of interest. Several studies resulted in development of regional, INL-scale, and facility-scale flow models and provided input to development of this conceptual model of groundwater flow. These studies are summarized in the following sections to acknowledge their contributions to the development of the current conceptual model.

1992 USGS Garabedian Regional RASA Study

Garabedian's (1992) quasi-three-dimensional flow model of the ESRP was prepared as part of the USGS regional aquifer systems analysis (RASA). The model summarized regional data, provided estimates of regional properties, and contributed useful background information for the INL conceptual model.

1994 INL Waste Area Group-10 Regional Study

This regional flow model (McCarthy et al., 1995) was developed to support WAG 10 objectives, including modeling contaminant transport and defining flow at facility scales. This model's domain, layering, and quasi-three-dimensional approach was the same as that of the Garabedian model, but the grid was further subdivided to provide better resolution. The model improved representation of the permeability distribution at the INL by integrating Garabedian's and subregional hydraulic conductivity zones. However, grid spacing was too coarse to adequately define facility-scale boundary conditions.

State of Idaho IWRRI Regional Study

This two-dimensional regional groundwater model supports water resource management and adjudication of groundwater and surface-water rights on the ESRP. This model provides improved detail of the aquifer extent and thickness in areas of intensive groundwater use and groundwater/surface water interaction, and improves understanding of water-table dynamics over the past 20 years. The central focus is on interaction of the groundwater flow system with the Snake River and on seasonally varying tributary valley underflow (Wiley 2003).

1974 USGS Robertson Subregional Study

Robertson (1974) calibrated a two-dimensional flow and transport model with data from the early 1940s through 1972 to predict solute transport to the year 2000. Robertson's model domain represented an area of 2,548 mi^2 around the INL and was used to predict concentrations in groundwater of INL-derived tritium, chloride, and strontium-90. The match of predicted to observed chloride concentrations required an unexpectedly large ratio (1.5) of transverse to longitudinal dispersivity.

1990 INEEL Spent Nuclear Fuel Environmental Impact Statement

A flow and transport model (Arnett and Springer, 1993) was developed for the INEEL Spent Nuclear Fuel Program's environmental impact statement. The two-dimensional steady-state model simulated an area larger than the INL to utilize natural boundary conditions. This model could not satisfactorily simulate the observed contaminant distribution. Assumption of two-dimensional flow was considered reasonable for regional groundwater flow, but a transient simulation was determined to be necessary to better represent the highly dispersed contaminant plumes.

1994 USGS Spinazola Mud Lake Study

This numerical model evaluated changing water-management practices near Mud Lake (Spinazola, 1994). This five-layer model represented an area of 2,200 mi^2 and utilized a uniformly sized grid with each cell 1 mi on a side. The model provided regional underflow estimates into the OU 10-08 study area.

Current USGS Subregional Study

The USGS conceptual model, supporting next-generation INL flow and transport models, encompasses 1,940 mi^2, including most of the INL. The aquifer is treated as an equivalent porous media with nonuniform properties. Three hydrogeologic units represent the thick basaltic aquifer, including fractured basalts and permeable sediments; underlying, dense basalt and less-permeable sediments; and older, much-less-permeable, altered basalts and interbedded sediments. This conceptual model differs from the OU 10-08 model in estimates of maximum thickness, distribution of the active aquifer, and potential for downward flow and deep contaminant circulation.

Facility Scale Studies

Modeling studies have been conducted at Test Area North, Idaho Nuclear Technology and Engineering Center, and the Radioactive Waste Management Complex. These studies have provided invaluable local conceptual model information.

OVERVIEW OF THE INL SUBREGIONAL CONCEPTUAL MODEL

The complex stratigraphy, specific geohydrologic features, and inflows and outflows control flow in the SRPA. Integration of these conceptual model elements determines the configuration of the field of groundwater flow.

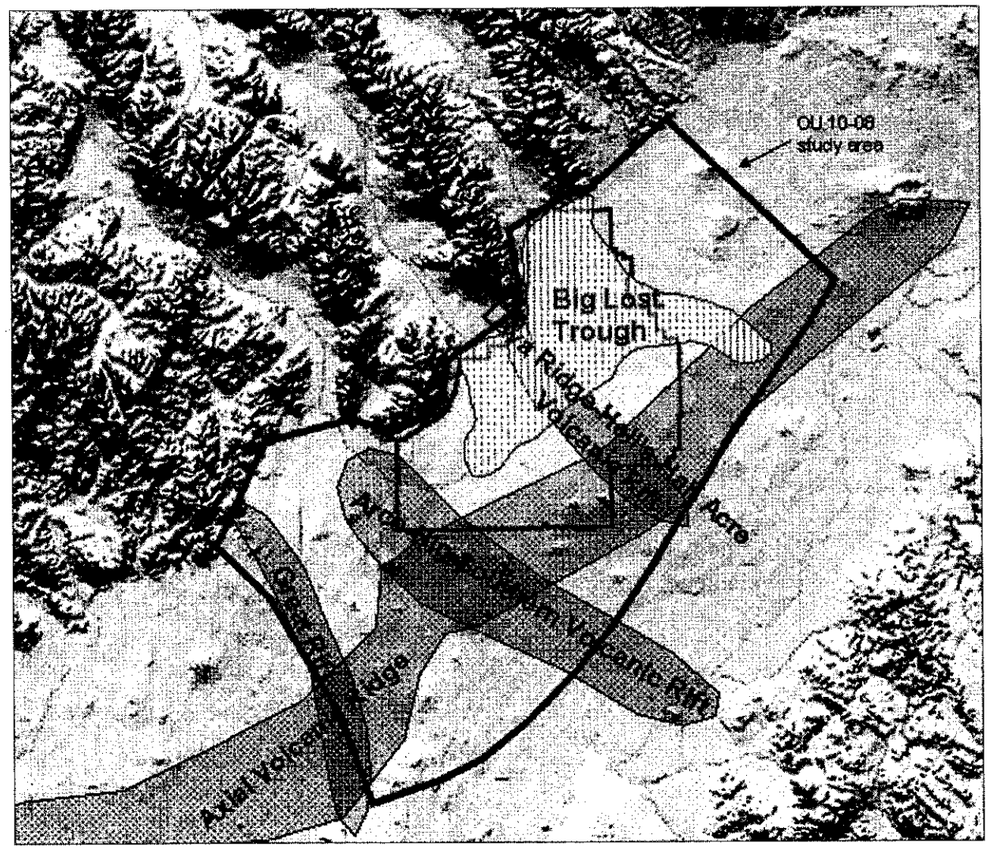


Figure 2. Volcanic rift and sedimentary features controlling groundwater flow in the SRPA, OU 10-08 study area.

Stratigraphy

The SRPA is predominantly composed of thin tube-fed pahoehoe basalt flows (typically less than 30 ft thick) occupying medial and distal parts of lava fields. Basalts underlying this complex sequence are altered and mineralized.

The active thickness of the SRPA is defined as that thickness through which most groundwater flow occurs. The active thickness, estimated from borehole, electrical-resistivity, and water-temperature data, likely ranges from about 300 to more than 1,200 ft. Altered and mineralized basalts beneath the section of active groundwater flow are characterized by greatly reduced permeability.

Geohydrologic Features

Geohydrologic features control groundwater flow and contaminant transport through the SRPA. These features include the basalt-flow architecture, deposition of sedimentary units, and volcanic rift zones.

Basalt-Flow Architecture

Contacts between basalt flows commonly form rubbly interflow zones capable of transmitting large quantities of groundwater. In contrast, flow interiors are massive, with diminished transmissivity. Heterogeneity is attributed to the areal and vertical distribution of basalt-flow features, including interflow zones, fissures, deflation areas, and massive, unjointed flow interiors. Interflow zones may extend over several tens of square miles and are hydraulically connected to other interflow zones through vertical cooling fractures and by direct contact.

Hydraulic properties are controlled by flow thickness and number of interflow zones. Hydraulic conductivity is increased where basalt flows are thin and interflow zones are numerous. Conversely, hydraulic conductivity is decreased where basalt flows are thick and interflow zones are limited. Flow through this integrated system is anisotropic and heterogeneous, with maximum groundwater flows occurring horizontally.

Sedimentary Interbeds

Sedimentary deposits accumulating on the ESRP between volcanic eruptions formed interbeds with thicknesses that can exceed 50 ft in places and consist of clay, silt, sand, and gravel. Historically, extensive volcanic activity to the south diverted the Big Lost River to the north, accumulating sedimentary interbeds in the area identified as the Big Lost Trough (Figure 2). Numerous interbeds occur beneath the current channel but decrease in thickness and number away from the channel. Within the northern part of the OU 10-08 study area, extensive lacustrine sediments were deposited within ancestral Lake Terreton.

Sedimentary interbeds within the SRPA affect groundwater flow because they occupy interflow zones and typically reduce the permeability of those zones. The hydraulic effect of these interbeds is correlated to their vertical and areal distribution.

Volcanic Rift Zones

On the ESRP, southeast-trending rift zones have provided avenues for repeated basaltic eruptions (Kuntz et al., 1992). Within the study area, these include the Arco-Big Southern Butte, Great Rift, and Lava Ridge-Hells Half Acre rift zones (Figure 1).

Associated volcanic features affect the distribution of hydraulic properties (Anderson et al., 1999). Areas near volcanic vents may provide localized, preferential pathways for groundwater flow or may impede flow (Hughes et al., 1997). Hydraulic gradient changes in the vicinity of the Arco-Big Southern Butte rift zone may be associated with these features (Anderson and Liszewski, 1997). Arnett and Smith (2001) observed that these rift zones are perpendicular to the ESRP axis and may locally influence groundwater flow directions.

Inflows/Outflows

Study area inflows include regional underflow across the northeast boundary, tributary-basin inflows, and areal precipitation. Outflow occurs across the southwest boundary.

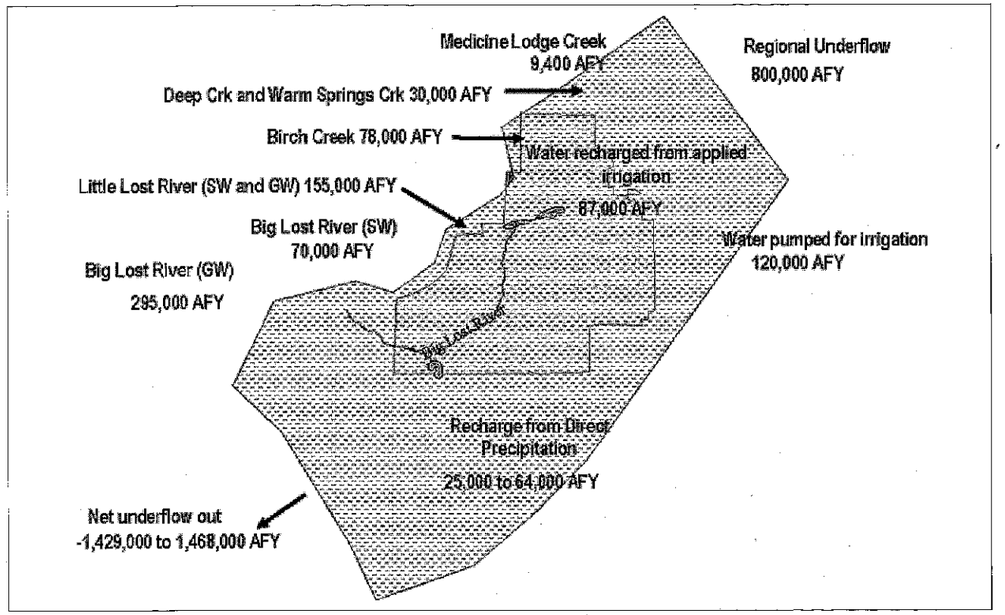


Figure 3. Groundwater (GW) and surface-water (SW) inflows to and outflows in acre-feet per year (AFW) from the OU 10-08 study area.

Regional Inflow

Groundwater moves into the study area as regional underflow from the northeast. This inflow, derived from streamflow and underflow from the Yellowstone Plateau and tributary basins to the north, is estimated to be approximately 800,000 acre-feet per year.

Tributary Basin Inflows

Basins contributing recharge as underflow and streamflow to the study area include the Medicine Lodge, Deep Creek, Warm Springs, Birch Creek, Little Lost River, and Big Lost River basins. Underflow from tributary basin aquifers is estimated to be approximately 640,000 acre-feet per year, with recharge to the SRPA occurring in transitional zones at basin mouths. Infiltrating streamflows in the Big Lost River provide episodic recharge averaging 70,000 acre-feet per year.

Areal Precipitation

Precipitation over the study area averages 8 inches per year, for an annual total of 1.3 million acre-ft, most lost to evapotranspiration. Actual recharge is estimated to range from 25,000 to 64,000 acre-feet per year (2 to 5 percent of total precipitation).

Regional Outflow

Groundwater moving across the southwest boundary represents the sum of regional and tributary underflow, infiltrating streamflow, and precipitation recharge. Outflow, estimated to be 1.43 to 1.47 million acre-feet per year, eventually discharges to the Snake River in the Thousand Springs area, 80 miles to the southwest.

Field of Flow

A potentiometric surface map constructed from a dense 2004 water-level data snapshot (see Figure 4) indicates that groundwater flow is to the southwest, with a steepening hydraulic gradient in the southwestern part of the study area. This surface integrates conceptual model

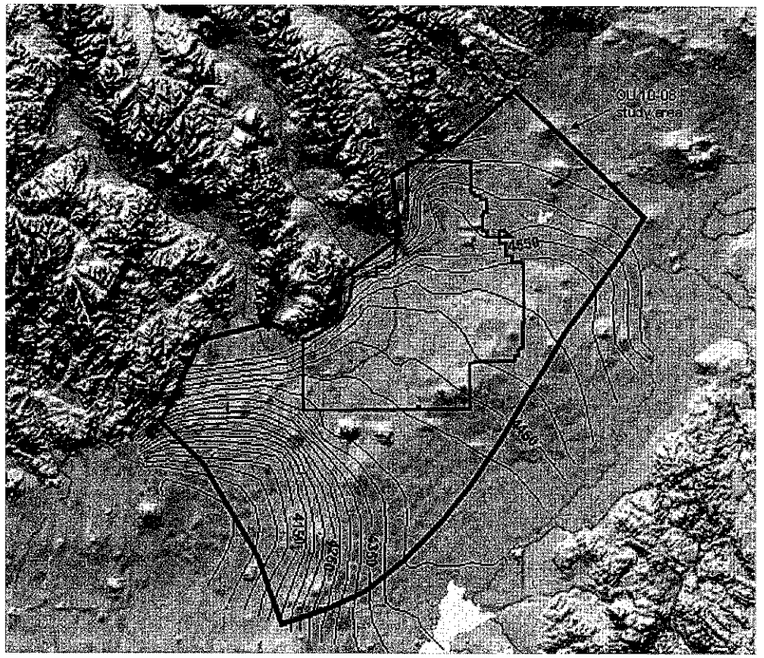


Figure 4. Potentiometric Surface for the Snake River Plain aquifer, OU 10-08 Study Area. Contours are drawn from 2004 water level data from 235 wells. Potentiometric contours interval 25 ft.

elements, including those features that control permeability (basalt-flow architecture, volcanic rift zones, and areas of increased sedimentary deposition), and inflows/outflows.

SUMMARY

Groundwater flow at the INL occurs within a complex network of connected, highly transmissive, interflow rubble zones. Heterogeneity in hydraulic properties is attributed to the large range of basalt-flow thickness, number of interflow zones, and presence of sedimentary interbeds. Extreme anisotropy is attributed to the layered character of the basalt-flow architecture.

Volcanic rift zones generally are at right angles to regional groundwater flow and affect the flow direction and gradient. Sedimentary interbeds in areas of persistent fluvial and lacustrine deposition occupy otherwise highly permeable interflow zones and locally affect the movement of groundwater flow.

Inflows are from regional underflow, tributary basins, streamflow recharge, and areal precipitation. Episodic streamflow recharge occurs near INL facilities. Outflows across the southwestern boundary, representing the sum of inflows, total 1.43 to 1.47 million acre-feet per year. Groundwater flow is to the southwest and is locally modified by rift-zone and sedimentary features.

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Photo by Sheryl Boyack

A Conceptual Model of the Geology of the Snake River Plain Aquifer in the Environs of the Big Lost Trough

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INTRODUCTION

This paper briefly describes a geological conceptual model for the Eastern Snake River Plain basalt sequence which hosts the Snake River Plain Aquifer. The study area for this model stretches from Mud Lake in the northeast to the Great Rift of Idaho in the southwest (see Figure 1). This model was built for the Idaho National Laboratory Operating Unit 10-08 sitewide aquifer model. The geological conceptual model must explain how groundwater and subsurface rocks interact. The geological information for the model is best presented at two scales: a lava flow scale and a subregional scale. Due to length constraints, not all of the model specifics and few of the construction methodologies used to assemble the conceptual model can be included. The methodology and detailed data used to construct the model are described at length elsewhere and the reader will be directed to these other publications where appropriate. Overviews of the conceptual model details dealing with flow conditions, inflows, outflows, and hydraulic conductivity are presented in papers by Podgorney et al. and Orr, which are both included in this volume.

LAVA FLOW SCALE

On the Eastern Snake River Plain, over 95% of the volcanic rocks are basalts erupted as pahoehoe flows (Kuntz et al., 1992). These basalts host most of the aquifer. Eastern Snake River Plain pahoehoes flows tend to build small low-angle (less than 2°) shield volcanoes (Greeley, 1982) with medial to distal thicknesses typically 7m or less (Knutson et al., 1992; Welhan et al., 2002). Due to low eruptive volumes, flows do not travel far from their vents, typically between 0.5 and 50 km with an average length of 8 km (Hackett and Smith, 1994). These small shields and flows are eventually buried by younger basalts to form a stratigraphic sequence resembling a randomly-stacked pile of pancakes.

The top of a pahoehoe flow is glass-rich, vesicular and prone to fracture from thermal contraction, often resulting in rubble that can be up to 2 m thick. Vesicularity decreases from the top of a flow into its interior, which will be massive with occasional columnar fractures in thicker flows. The massive interior of a pahoehoe flow usually acts like an aquiclude. At the base of a massive flow interior, the bottom of a pahoehoe flow is vesicular, fractured and often oxidized. Flow bottoms tend to be thinner than flow tops, often 0.5 m or less (Knutson et al., 1992).

Most groundwater flow occurs within interflow zones which are sandwiched between massive basalt flow interiors. These interflow zones are formed by the juxtaposition of one flow's fractured top with the fractured base of the flow immediately above it. The jointed, fractured and sometimes rubbly vesicular basalt in an interflow zone creates a permeable pathway for groundwater due to the void spaces in fractures and joints and rubble (Figure 2),

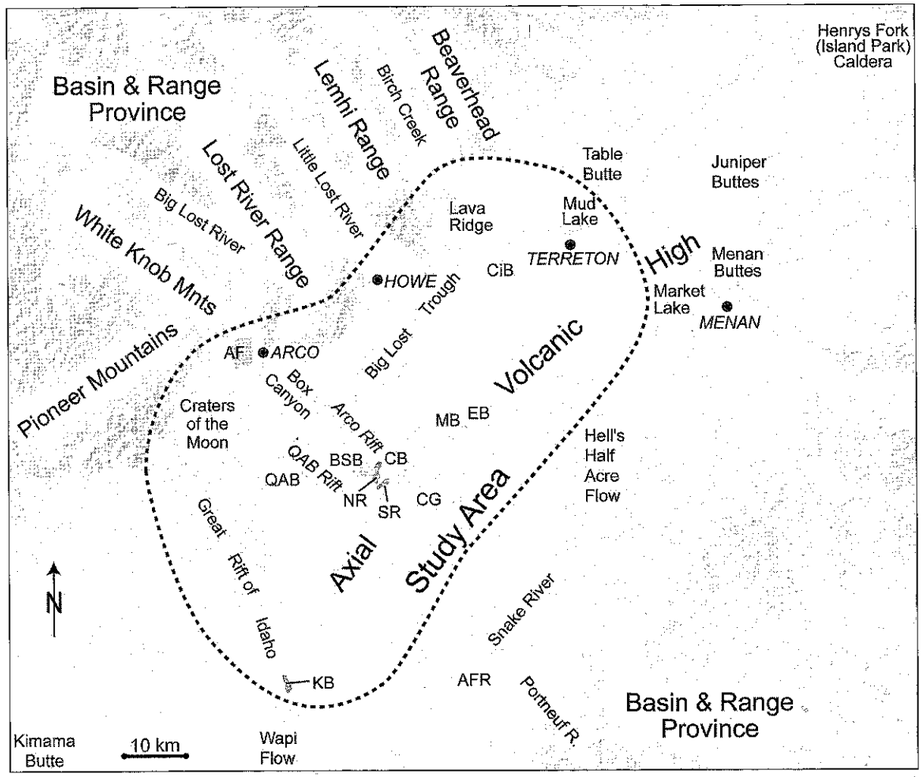


Figure 1. Location map of the conceptual model study area on the Eastern Snake River Plain. The area within the black dotted line is the study area, approximately a third of the plain. White circles with italic text represent towns mentioned in the text. White dotted lines are approximate locations of volcanic rift zones. Names of features used in this paper may be different than those used in other studies. Some names have been shortened for convenience or due to space restraints on the figure, e.g. QAB Rift instead of Quaking Aspen Butte volcanic rift zone. Map abbreviations are: AF – Arco flow; AFR – American Falls Reservoir; BSB – Big Southern Butte; CB – Cedar Butte; CG – Cerro Grande Flow; CiB – Circular Butte; EB – East Butte; KB – Kings Bowl Flow; MB - Middle Butte; NR – North Robbers Flow; QAB – Quaking Aspen Butte; SR – South Robbers Flow.

a characteristic of the aquifer basalts noted as early as Nace et al (1951). In contrast, flow is greatly impeded in the dense and massive flow interiors. Since flows are thin with respect to their horizontal extent and since flows and their interflow zones are randomly stacked, there is both horizontal and vertical heterogeneity in the groundwater flow, though in general, hydraulic conductivity is greater in the horizontal direction than in the vertical (Orr et al., this volume).

At the same scale as the interflow zones, interbeds may be deposited between flows before they are buried. Where accumulation time is long or where deposition is very fast, discrete and distinct sedimentary beds, usually of finer-grained eolian, fluvial or lacustrine sediments in the study area, can form. Sometimes these beds have thicknesses sufficient to separate flows. Where the flow top of a basalt under an interbed is fractured or rubbly, the sediments will usually penetrate partially or wholly into these spaces, clogging them and choking off the effective porosity (Nace et al., 1951; c.f. Welhan et al., 2002).

When deposition time is short, deposition rate is slow, or deposited sediments are eroded or scoured by eolian or flood processes, then there will be less infiltration of sediments into flow top rubble and fractures, and more open void spaces will be preserved. In the Big Lost Trough and its environs, interbedded sediments tend to be fine-grained with many silt-sized particles (e.g., Bestland et al., 2002; Blair, 2002). Compared to the rubble, fractures, joints and abundant vesicles through which groundwater travels in sediment-free interflow zones, groundwater flow through sedimentary interbeds and sediment-infiltrated interflow zones will be slower. Since most of the groundwater flow occurs in the interflow zones, it is really the sediments in the interflow zones that control any flow variability in the aquifer.

Distinct from the interbedded sediments between flows, sediments can infiltrate, in some cases aggressively, into voids in pahoehoe basalt as observed by several researchers over the last six decades (e.g., Jones et al., 1951; Barraclough et al., 1966; R. P. Smith, B. Orr, L. Knobel, M. Rohe, pers. comm.). In terms of the conceptual model, the infiltration into of fine-grained sediments into fissures may act to impede groundwater flow on a local scale. Sediment infiltration has been observed at several fissures, including at depth both in the drained fissure vent of Kings Bowl Lava field (R. P. Smith, E. Scott, pers. comm.; Stone, 2006) and the non-eruptive Dick's Fissure/Tea Kettle Butte scarp in the Arco Rift (R. P. Smith, C. Schaefer, pers. comm.; Helm-Clark, unpubl. data, 2001-2005). Observations at these and other features suggests that large but not-yet quantified volumes of eolian silts and clays infiltrate into the subsurface through fissures. Since fine-grained sediments in fractures and other large (>0.5 m, Welhan et al., 2002) voids will impede groundwater flow by clogging porosity, large scale sediment infiltration through fissures may in part account for localized lowered transmissivity in volcanic rift zones.

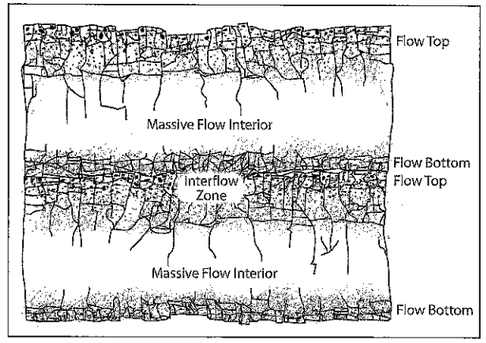


Figure 2. Sketch diagram of basalt flow and interflow zone architecture. Seldom-fractured non-vesicular flow interiors act as aquitards. Interflow zones form permeable pathways to groundwater flow. The boundary between the flow top of the bottom flow and the flow bottom of the top flow is difficult to discern and this is often the case when looking at Eastern Snake River Plain basalt in outcrop or as core. Introducing sedimentary interbeds or infiltrating sediments into fractures of the interflow zones (not shown here) reduces interflow zone hydraulic conductivity. This figure was modified from Schraeder and Kattenhorn (2003).

SUBREGIONAL SCALE

Because of the difficulty of making subsurface observations and the uneven distribution of subsurface datasets available for the study area, the geological conceptual model relies on the observation of surface processes and features. The model is built upon the simple premise that the key to the subsurface is the surface. By categorizing surface deposition patterns, we were able to recognize their buried counterparts in the subsurface. It is worth noting that the wide variety of processes and features seen on the surface of the Eastern Snake River Plain are seldom identified at the same level of detail in the interpretation of subsurface data. The tendency to oversimplify the subsurface in favor of the most common observed phenomenon sometimes leads to the misidentification of certain features, such as labeling infiltrated sediment in void spaces as interbedded sediment (e.g., Anderson and Lewis, 1989; Helm-Clark et al., 2004). This

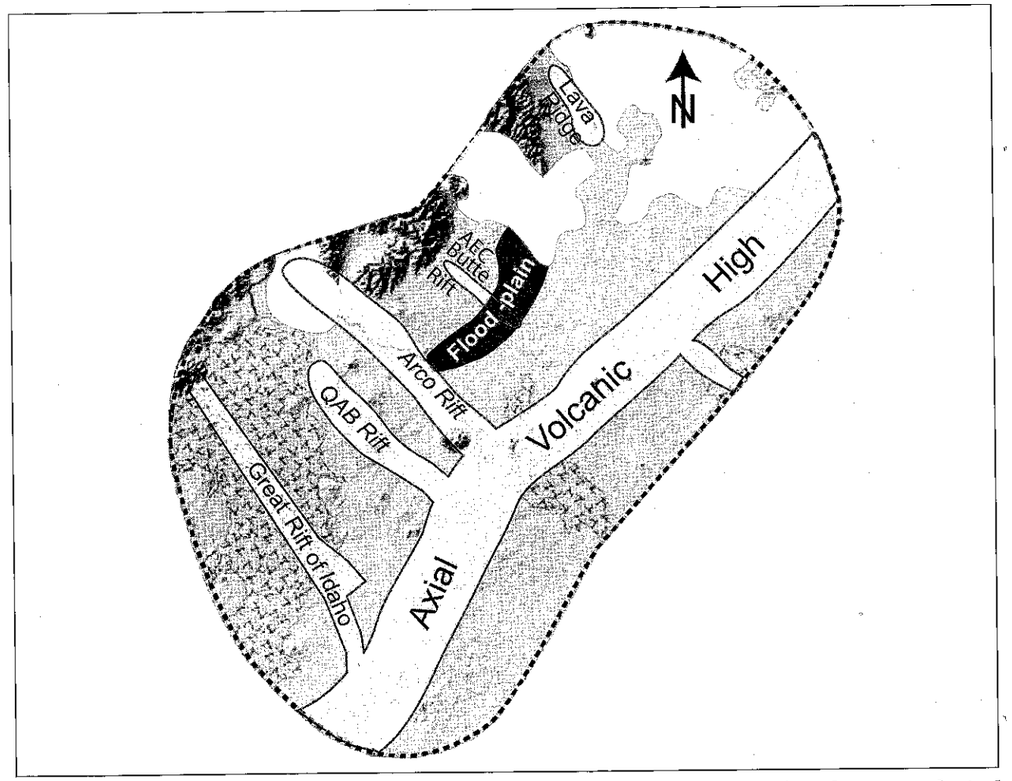


Figure 3. Plan view of the conceptual model study area on the Eastern Snake River Plain showing geological subdomains. White unbordered areas contain thick pluvial or ponded outwash sediments. The floodplain of the Big Lost River is shown by dark grey shading. Outlined light-grey areas are volcanic rift zones. Areas with no shading are volcanic tablelands. All geologic subdomain boundaries are approximate and subject to revision as more surface and subsurface data becomes available. Buried three dimensional subdomain units like the Olduvai lakebed which have no surface exposures are not shown.

tendency is due to the extreme difficulty of interpreting subsurface geophysical data in basalt, a material with extremely poor geophysical contrast for multiple geophysical methods.

The conceptual geological model is based on the observation that lavas, sediments and water all flow from higher elevations to lower ones. Lavas erupt from volcanic vents in volcanic source areas and flow downhill toward topographic lows. In the study area, topographic lows are river channels, flood plains and sinks. Likewise, sediments travel from uplands like the axial ridge of the ESRP or the surrounding Pioneer, Lost River, Lemhi and Beaverhead Ranges, and are transported downgradient as mainly fluvium and slope wash alluvium. In parts of the study area, these water-borne sediments and lava flows are mantled, mixed with or infiltrated by wind-borne sediments.

The geology above the aquifer is no different than the top of the aquifer. It needs to be said, however, that the vadose zone in the study area is ~100 to ~300 meters thick, where that thickness increases from northeast to southwest. The base of the aquifer is defined in the conceptual model as a basalt alteration horizon (Morse and McCurry, 2002) where porosity is completely clogged off by a combination of basalt alteration, authengenic

mineral growth and diagenesis. This depth of this alteration horizon is controlled by the interaction between the high subaquifer regional heat flux (~110 mW/m2), gradual heating of aquifer flow, and influx of colder recharge water (Brott et al., 1981; Plummer, this volume; Smith, 2002). The base of the aquifer is shallower over areas of high heat flow and deepest where cold groundwater recharge enters and mixes in the aquifer. While basalt flows and sedimentary layers in the study area dip to the southwest, the hydraulic head drop across the study area is much gentler in slope than the gradually dipping beds indicating that the top of the aquifer is unconfined.

The recognition and categorization of different volcanic and sedimentary environments led to the identification of general geological subdomain types, each with a distinct set of hydrogeological behaviors. The general subdomain types can be categorized as elevated volcanic source areas, depressed downgradient depositional areas and volcanic tableland areas between the first two. These are divided further into subdomain units which form the framework for the conceptual model and their description is the subject of the rest of this paper.

VOLCANIC SOURCE AREAS

Volcanic vents can occur in isolated areas but they more commonly occur closely spaced together as part of a trend of associated vent features (e.g. the northern third of the Great Rift; Fig. 3). When several vent features occur together along a linear trend along with aligned grabens, non-eruptive fissures, and/or general elevated topography, these are indications that the linear trend is a volcanic rift zone. The terminology for rift zones in general and volcanic rift zones in particular can be confusing (Neuendorf et al., 2005) and usage for the Eastern Snake River Plain is no exception with assorted researchers using terms like vent corridor, volcanic rift zone, volcanic zone and volcanic source area (e.g.: Christiansen, 1979; Kuntz et al., 1992; Anderson et al., 1999; Mark and Thackray, 2002; Kuntz et al., 2002).

There is no consensus on volcanic rift zone terminology, names or distribution. For the conceptual model, we used a modified definition of volcanic rift zones on the Eastern Snake River Plain as formulated by Kuntz et al. (1992): "linear arrays of volcanic landforms and structures," which "include eruptive fissures, spatter ramparts, tephra cones, lava cones, shield volcanoes and dikes at depth." For the conceptual model we amended this definition to include present or past topographic elevation of the features defining a volcanic rift zone.

Unlike some previous models of volcanic rift zones (e.g., Kuntz et al., 1992), the conceptual model does not consider volcanic rifts zones as persistent throughout the Quaternary, but of shorter duration, based on both stratigraphic and geophysical evidence (e.g. Helm-Clark and Link, this volume, and Wood et al., 2007). Accordingly, we have divided volcanic rift zones into younger active and older inactive types. The term *volcanically active* usually implies that a volcanic source area is of Holocene age. For the Snake River Plain, however, it is customary to also include volcanic rocks up to 15 ka as evidence of active volcanism. The Great Rift and features like the nearby North and South Robbers Lava Fields are included in the active volcanic source areas of the Eastern Snake River Plain. This split allows the conceptually model to distinguish distinctly older volcanic rift zone features like Lava Ridge and the linear vent trend that runs through AEC Butte, where such features are clearly inactive volcanically and are now partially buried by younger strata. Implicit in this division is the assumption that active and/or very young volcanic rift zones are thermally elevated with respect to their local surroundings, which is the case for the Craters of the Moon, the Wapi Lava Field, the Hells Half Acre Lava field, and much of the Arco Rift, among others.

The axial ridge of the Eastern Snake River Plain, here called the Axial Volcanic High, is included with the active volcanic rift zones - not because it satisfies our modified definition

of a volcanic rift zone *per se*, but because it is a volcanic source area with many volcanic rift zone-like features. The Axial Volcanic High is a continuous elevated topographic bulge and ridge line made up of numerous small volcanic shield volcanoes, tephra cones, fissure flows, crater and other ventforms; plus occasional rhyolitic domes, and intermediate to silicic cones, flows and sills (Hughes et al., 1999; Wood et al., 2005; Wood et al., 2007). Topographic profiling of the Eastern Snake River Plain shows that this feature runs down the long axis of the plain, stretching from Juniper Buttes, 50 km northeast of the study area, to west Dietrich Butte, 70 km southwest of the study area. We believe that this feature *has* been a persistent feature on the plain, perhaps the only one besides the Snake River itself, for at least the last 2 million years based on sedimentary, stratigraphic and geochronological evidence (e.g., Bestland et al., 2002; Blair, 2002; Helm-Clark and Link, this volume).

The Axial Volcanic High is included in the volcanically active features of the study area, in part due to the several Late Pleistocene and Holocene lava flows that have erupted along its flanks and the positive geothermal anomaly centered under it between East and Middle Buttes (Smith, 2002; Plummer, this volume).

The view of volcanic rifts used for the conceptual model is evolved compared to previous studies (e.g., Kuntz et al., 2002). Relatively recent research on volcanic source areas by the conceptual model team (e.g., Wood et al., 2005; Helm-Clark, 2005; Wood et al., 2007) is too lengthy to include here. An extensive discussion of volcanic rift zones in the conceptual model is summarized in the appendices of Wood et al. (2007). The conceptual model associates volcanic rift zones with certain hydrogeological properties. The relative elevation of volcanic rift zones while active means that they are less likely to build up accumulations of sediments compared to other areas on the plain. The lowered amount of sediments in interflow zones plus the increased likelihood of voids like collapsed lava tubes suggests that volcanic rift zones may be zones of unimpeded groundwater flow. Alternatively, sediment infiltration into deep fissures, palagonitic alteration and congealed dike swarms (but *not* isolated dikes, see Wood et al, 2007) may all act to create localized impediments to groundwater flow.

While there are several linear trends of volcanic features on the Eastern Snake River Plain that could be volcanic rift zones, we limited the conceptual model to examining only those volcanic rift zones and rift zone-like features, included the Axial Volcanic High, that appeared to have an effect on hydraulic head at the beginning of the site-wide groundwater modeling project using the hydraulic head data compiled by the modeling team in June 2004. Since the submission and revision of this paper, our conception of which volcanic rift zones to include in the model has narrowed and we refer the reader to Wood et al. (2007) for further details.

Other than the volcanic rift-like Axial Volcanic High, the active volcanic rift zones considered in the conceptual model include the Arco Rift from Arco to Cedar Butte, the elongated fissure, cone and crater vent system of the Hells Half Acre Lava Field, and the Great Rift of Idaho, particularly its northern end where it forms the dike swarm and vent system which has fed the 2 to 15 ka Craters of the Moon Lava Field. For the limited extents shown on Figure 3, all three of these have had volcanic activity from the latest Pleistocene or younger, and whose local elevation and aeromagnetic signature terminate at the Axial Volcanic High (Mankinen et al., 2004; Wood et al., 2007).

Inactive volcanic rift zone features included in the conceptual model include the ~0.8 to 1.2 Ma Lava Ridge, ~0.3 to ~0.6 Ma AEC Butte volcanic rift zone and ~40 to 64 ka Quaking Aspen Butte volcanic rift zone (see Fig. 1). The Middle Pleistocene Lava Ridge feature forms a distinct aeromagnetic residual signature (Mankinen et al., 2004) whose southern termination coincides with a zone of

impeded groundwater flow at Test Area North at the Idaho Nation Laboratory. The AEC Butte volcanic rift is a linear the trend of volcanic vent and fissure features now wholly or partly buried by younger basalts and the sediments of the modern Big Lost River flood plain. It is a good example for demonstrating the tendency of older buried volcanic rift systems to form stratigraphic divides between sediments and basalts from different source areas, in this case dividing sources to the northeast from sources to the southwest (see Fig. 4).

The inactive volcanic source that we call the Quaking Aspen Butte volcanic rift zone has sometimes been included as the western half of the Arco or Arco-Big Southern Butte Volcanic Rift Zone (Smith and Hackett, 1994; Kuntz et al., 2002). We consider it to be a distinct feature in the conceptual model for several reasons (Wood et al., 2007) including its potential association with a ground water head inflection just southwest of the Idaho National Laboratory; the clustering of later Pleistocene age dates along this linear trend of vents; and the distinct and separate ridge line and drainage divide which it forms between the Arco Rift and the northern end of the Great Rift.

VOLCANIC TABLELANDS

Between volcanic source areas and topographically depressed river courses and sinks are the volcanic tablelands (Neuendorf et al., 2005) that form most of the volcanic plateau of the Eastern Snake River Plain. This subdomain type is characterized by the near-flat horizontally-extensive medial and distal portions of basalt flows. Approximately 5 to 15% of the vertical stratigraphic column of the volcanic tablelands (R. Smith, unpubl. data) is made up of thin sedimentary interbeds and sediment-rich interflow zones. While it is certain that sediments in interflow zones and fine-grained interbeds can lower hydraulic conductivity, volcanic tablelands in the conceptual model have high hydraulic conductivity *on an average basis* compared to areas of concentrated sedimentary deposition. An example of a typical volcanic tableland in the conceptual model study domain is what we named the *west axial slope* which is between the

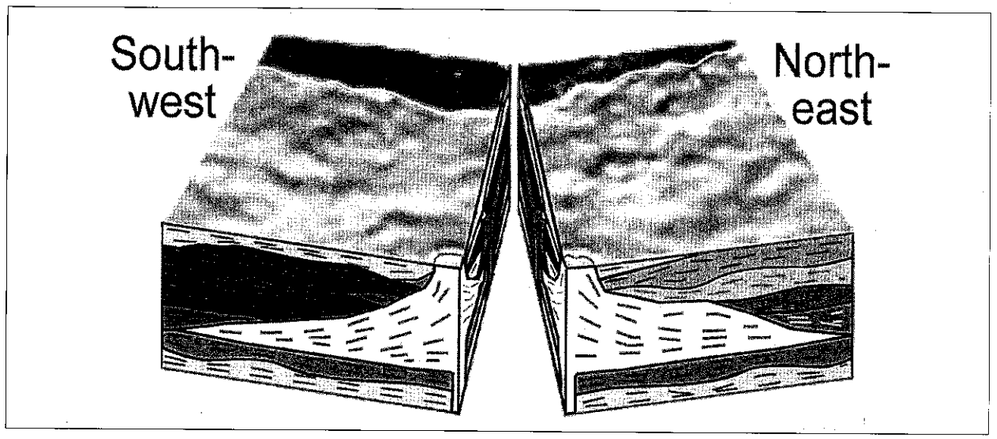


Figure 4. Conceptual cartoon sketch diagram through one of the buried shield volcanoes (white) along the AEC Butte Rift. View is approximately 5 km wide, looking to the northwest toward the Lost River Range from the floodplain of the Big Lost River. The vent shown is in a kipuka. Younger lava flows (grey layers) lap on the sides of the vent's buried shield volcano which acts as a divide between basalt flow originating from the northeast from those originated to the southwest (Helm-Clark et al., 2005). The flows on the left originated from sources along the Arco Rift whereas the flows on the right originated from vents to the north and northeast.

elevated Axial Volcanic High where is crosses the southeast corner of the Idaho National Laboratory and the flood plain of the Big Lost River (Wood et al., 2005).

Groundwater flow through the stratigraphic column of the volcanic tablelands can display both horizontal and vertical heterogeneity because of the random-stack-of-pankcake stratigraphy and the horizontal orientation of platy finer-grained sediments in interflow zone and interbedded sediments (Orr et al., this volume). The hydraulic conductivity through the aquifer commonly decreases with depth.

AREAS OF SEDIMENTARY DEPOSITION

In general, relatively depressed areas such as sinks and river courses can become sites of increased deposition of sediments compared to the more elevated volcanic source areas and volcanic tablelands. Within the study area, sedimentation areas include the floodplain of the Big Lost River; the sinks of the Big and Little Lost Rivers and Birch Creek; and the buried analogs of these features. One pattern that occurs on the Eastern Snake River Plain for which there is subsurface evidence in the conceptual model study area (Wood et al., 2007) is for lava flows, singly or in groups along volcanic rift zones, to dam rivers for hundreds to thousands of years, creating occasionally extensive lake or playa beds with subsequently become buried (e.g., Houser, 1992) depending on climatic conditions which have been variable throughout the Plio-Pleistocene.

The geologic conceptual model includes four sedimentary sequence-type subdomains which are as follows. The first consists of relatively shallow lake and playa sediments associated with late Pleistocene and Holocene deposition in the sinks areas of the Big Lost Trough and the adjacent basin areas of Mud and Market Lakes (see Fig. 1). The modern Mud and Market lakes are the remnants of a glacial-period pluvial lake known as Lake Terreton (Stearns et al., 1938). Pluvial lakebed sediments are also present in the subsurface in the sinks of Birch Creek, the Big Lost River and Little Lost River, stretching from Howe in the southwest to Mud Lake and beyond in the northeast. At a low point on the Axial Volcanic High during the last glacial period at the end of the Pleistocene, high stands of Pluvial Lake Terreton crossed this central divide in the middle of the plain, connecting for a short time waters fed by the Big and Little Lost Rivers with those fed by the Snake River. Older pluvial lakes from prior glacial episodes of the Pleistocene could also have similarly breached low points of the Axial Volcanic High, briefly connecting Big Lost Trough and Snake River waters during high water conditions; this scenario is conjectural with the exception of some very new evidence consisting of mitochondrial DNA fish data (B. Gamett, pers. comm.).

The second sedimentary subdomain is a thick lacustrine sequence named the Olduvai Lakebed (Bestland et al., 2002) because its age corresponds to the paleomagnetic Olduvai Subchron dated between 1.77 and 1.95 Ma (Cande and Kent, 1995). Like most strata in the study area, these beds dip gradually south. Under Circular Butte, the Olduvai beds intersect the upper half of the aquifer. To the south, underneath the Big Lost floodplain, these beds have dipped beneath the aquifer and no longer intersect it. Since the beginning of this groundwater and contaminant modeling project at the Idaho National Laboratory, we have identified some additional thick sequences of lacustrine deposits not previously recognized within the study, ~300 m deep under the US Route 20 north of Middle Butte (Wood et al., 2007). We have iteratively updated the conceptual and numerical portions of this project continuously such that newly discovered features like these previously unidentified units lake beds are already accounted for in our modeling runs.

The third sedimentary subdomain consists of lacustrine sediments from the damming of rivers trapped in the Big Lost Trough. The Big Lost River has been trapped at the mouth of the Basin-and-Range valley near Arco two and possibly three times by the rise of volcanic

rift zones, most recently by the flows of the Arco Rift and Quaking Aspen Butte volcanic rift zone (Wood et al., 2005; Helm-Clark and Link, this volume). Each entrapment caused sediments to pond at the river's egress onto the Eastern Snake River Plain by the town of Arco. The Little Lost River has been similarly trapped south of the town of Howe (Wood et al., 2007.) Hence the third sedimentary subdomain consists of fine-grained sequences of these ponded sediments interbedded with river channel deposits and Eastern Snake River Plain basalts. The recognition of this trapping and damming pattern has underscored a very useful insight into the behavior of the Big Lost River in the study throughout the Pleistocene and that is the fact that this river has had many channels that have traveled significantly to both the east and west of the river's modern flood plain.

The fourth sedimentation subdomain is the floodplain of the Big Lost River, easily the most complex portion of the study area, where alluvium and fluvium interfinger with pahoehoe basalts originating from several different volcanic rift zones surrounding the Big Lost Trough (Helm-Clark et al., 2005). The sediments and basalts deposited on the floodplain come from three different directions, making a very complex stratigraphic column in the subsurface. Since erupted flows will not cross the river to flow up hill on the opposite bank, the river and its floodplain act as a stratigraphic divide and the locus of interfingering between tableland (Helm-Clark et al., 2005). Up to 50% of the subsurface can be sediment. Finer-grained sediments dominate the interbeds of the floodplain. Interfingered basalts will have more sediment infiltration into fractured flow tops. Groundwater flow will be reduced compared to volcanic tablelands and volcanic source areas because of the more abundant sediments clogging the interflow zones.

There are some uncommon coarse-grained fluvial sand and gravel beds in the study area subsurface. These units have much higher hydraulic conductivity compared to finer-grained sediments. Since the hydraulic conductivity of these sediments is often indistinguishable from interflow zones, they are included with tableland basalt flows without differentiation in the numerical model.

SUMMARY

We have identified geologic subdomain types for the Eastern Snake River Plain to use as guides to construct the geological conceptual model of aquifer stratigraphy. This model is three-dimensional because the subdomains units and their arrangement are three-dimensional. For example, in the north half of the study area, the Olduvai lakebed is overlain by volcanic tableland basalts which are themselves overlain by the Lake Terreton lakebed. Another example is the floodplain of the Big Lost River which has widened and migrated to the northwest over time.

The next step is to use this geologic conceptual model to define hydrostratigraphic units for the numeric aquifer model. Hydrostratigraphic units are mapped-out regions that share hydrologic properties based on the details of the geologic conceptual model, which in comparison is based on the known stratigraphy of the Eastern Snake River Plain subsurface. It was recognized early-on that a traditional stratigraphy based on basalt flows and interbeds would not adequately account for all the features that affect groundwater flow, namely: unconfined groundwater flow, high regional geothermal heat flux, interflow zones, lack of long distance continuity in the random pancake-stack stratigraphy, southward dipping sedimentary and volcanic beds, fine-grained interbeds and sediment infiltration, stratigraphic divides at rifts and rivers, and localized aquitards along volcanic rifts. The salient feature of this geologic model is that it incorporates for the first time knowledge of *all* these features, thus providing a more apt and germane basis to construct hydrostratigraphic units than that provided by a more traditional flow-and-interbed stratigraphy of the Eastern Snake River Plain.

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Glossy purples, greens
blacks, pinks:
the work of iron, manganese
and titanium-fixing bacteria:

desert varnish, they call it.
Here it's brand new
with a silvery sheen:
a glossy lacquer
she used to preserve her designs;
enhance the colors of the grain;
present the most startling effects...
-Will Peterson

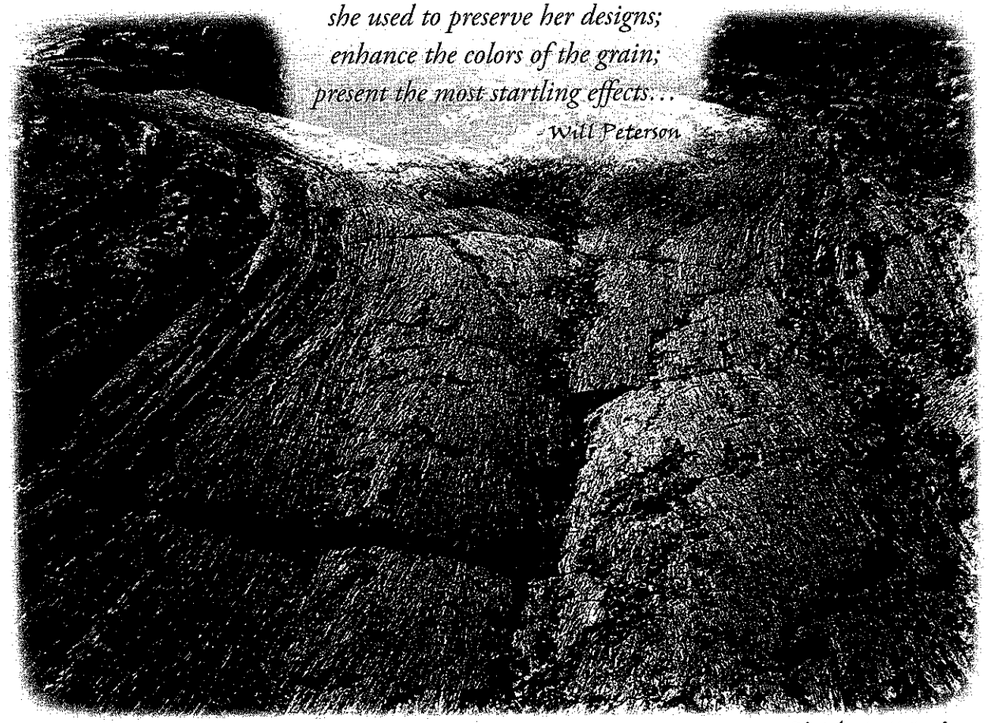


Photo by Scott Hughes

Methodology for Determination of Large-Scale Effective Hydrogeologic Units in the Vicinity of the Idaho National Laboratory

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ABSTRACT

This article outlines the three methods used to define the vertical and horizontal extent of hydrogeologic units at the INL. These units are represented as vertically discrete layers in support of three-dimensional numerical models under development to evaluate cumulative contaminant risk in groundwater. The first method discretizes the active thickness of the SRPA into uniform hydrogeologic units. This discretization permits simplistic representation of the strongly anisotropic ratio of horizontal to vertical flow but does not represent vertically discrete hydraulic and contaminant concentration data. The second method utilizes a numerical model to determine vertical distribution of hydraulic properties through calibration to vertically discrete hydrologic datasets assigned to the uniformly distributed hydrogeologic units. The third method utilizes hydrogeologic data to identify discrete hydrogeologic units within selected wells that deeply penetrate the aquifer. Hydrogeologic units are extrapolated to hydrogeologic unit sections. These sections will be used to build a series of hydrogeologic unit solids to which ranges of hydraulic properties can be assigned based on aquifer test data in wells. Solids in turn will be represented in subsequent numerical models of groundwater flow and contaminant transport.

INTRODUCTION

Conceptual and numerical models of groundwater flow and contaminant transport within the Snake River Plain aquifer (SRPA) at the Idaho National Laboratory (INL) require identification of large-scale effective hydrogeologic units. A hydrogeologic unit is defined here as a body of geologic material that can be characterized by similar hydraulic properties and that constitutes a distinct hydrologic subsystem within the SRPA. Identification of these units is a challenging task because of the complex nature of the basaltic aquifer, which is comprised of an intercalated sequence of basalt flows, interflow zones, and sedimentary interbeds, all of which exhibit a high degree of variability in their hydraulic properties and distribution both

spatially and vertically. The architecture of basalt flow sequences, presence or absence of sediments, and local structural features exert significant control over groundwater flow. This paper discusses the strategy for identification of large-scale effective hydrogeologic units in the development of a three-dimensional sub-regional numerical model representing groundwater flow and contaminant transport in the SRPA. This numerical model is being developed to define cumulative risk from those contaminants in the Snake River Plain Aquifer (SRPA) in the vicinity of the INL.

Numerical models of groundwater flow beneath the INL have been utilized since the mid-1970s. The USGS Robertson model (1974) was constructed at the scale of tens of kilometers to evaluate transport of radioactive and chemical contaminants at the INL. The USGS Garabedian model (1992) was constructed at the regional scale of hundreds of kilometers to evaluate SRPA flow systems. The USGS Spinazola model (1994) was constructedat a scale of tens of kilometers to characterize groundwater flow in the subregion northeast of the INL. Additionally, numerical models have been constructed to focus on modeling contaminant fate and transport for INL cleanup activities. McCarthy et al. (1995) constructed a regional numerical model at the scale of hundreds of kilometers to support facility-scale modeling activities. These facility-scale models, constructed at scales ranging from hundreds of meters to kilometers, included models developed as part of remediation activities at Test Area North (DOE 2003), ICPP (1997), and RWMC (INEEL 2002). Recent numerical models have included the State of Idaho regional water resource model (Wylie 2003) and the USGS subregional model, at a scale of tens of kilometers (Ackerman et al. 2001, written communication). The conceptual basis for these models has evolved with our understanding of groundwater flow and contaminant transport.

As part of the current INL SRPA modeling effort, two-dimensional flow and transport models have been constructed and calibrated as a preliminary step in construction of a fully three-dimensional transport model (Huang this issue; Wood et al., 2005). These models serve as tools to further refine our conceptual model of the aquifer and to focus our efforts to identify and collect information for development of the three-dimensional model. While the two-dimensional models reasonably represent the head field in the aquifer, the three-dimensional nature of groundwater flow and contaminant transport within the SRPA cannot be adequately reproduced in two dimensions, as evidenced by data collected from two INL wells using the recently installed Westbay© system (Whitmore this issue) and from several nested piezoemeters. The modeling approach being used in these current SRPA simulations consists of inverse modeling techniques utilizing the PEST parameter estimation code (Doherty 2005) coupled with MODFLOW (Harbaugh et al., 2000; BYU 2002).

A numerical modeling strategy has been developed to vertically subdivide the model domain for the purpose of developing a three-dimensional numerical simulation. The strategy utilizes a graded approach beginning with a very simplified vertical subdivision followed by numerical representation of more rigorous characterization of hydrogeologic units. This strategy will permit evaluation of the improvement in the simulation gained by adding hydrogeologic information and conceptual model understanding to the definition of the subsurface. Comparison of the modeling results will be made by examining the goodness of fit of the simulation results to the three-dimensional head field and to contaminant plume distributions. This paper describes the methodology used to determine large-scale effective hydrogeologic units within the SRPA in the area of the INL.

VERTICAL DISCRETIZATION METHODOLOGY

Three vertical discretization methods were selected for the preliminary evaluation of three-dimensional flow and transport. Simple discretization methods are utilized first, and complexity is increased as the evaluation proceeds. This approach provides a definite way of assessing improvements gained by adding more rigor to the definition of the subsurface in the model. An initial baseline simulation (Simple Vertical Discretization) is first established by simply dividing the vertical dimension of the model domain into uniform layers and by assuming heads are uniform with depth. In the second method (Calibrated Simple Vertical Discretization), additional detail is added to the baseline discretization based on vertically discrete head and contaminant data from monitoring wells. The last and most rigorous method (Geologic Modeling Discretization) builds upon the geologic framework defined by Helm-Clark (as reported in Wood et al., 2005) for the two-dimensional analysis. These three methods are described in more detail in the following subsections.

Simple Vertical Discretization

The estimated thickness of active flow within the SRPA within the study area represented by the OU 10-08 model domain is estimated from temperature, geophysical, and borehole data to range from less than 100 to more than 400 meters. Throughout most of this area, the aquifer thickness consists of numerous layered basalt flows with an average basalt-flow thickness of 7 meters. It is impractical to identify each basalt flow as a discrete hydrogeologic unit, in part because these flows are areally limited, because information about their extent and thickness is not well known, and because of the limitations of the numerical tool to represent these units. A simple vertical discretization is being used that will capture the vertical to horizontal anisotropy of the aquifer.

This vertical discretization provides a starting point for three-dimensional identification of hydrogeologic units across the study area. The method consists of dividing the vertical dimension of the aquifer into as many as 7 hydrogeologic units, each comprised of multiple basalt flows and sedimentary interbeds. A uniform thickness of 30 meters is used for each of the upper six units. The bottom unit is assumed to have variable thickness to represent deeper, less characterized parts of the aquifer. In areas where the aquifer is thin, deeper hydrogeologic units are truncated, and all units are present in the thickest parts of the aquifer.

The capability of this simple vertical distribution of hydrogeologic units to adequately represent aquifer anisotropy will be evaluated using the three-dimensional numerical model. This simple scenario will serve as the initial baseline against which subsequent conceptual models will be compared. Because of the assumptions used in the development of this scenario, no new insights are expected to be gained regarding the head distribution in the aquifer. The primary objective of this scenario will be the simple representation of vertical to horizontal anisotropy with respect to three-dimensional contaminant transport.

Calibrated Simple Vertical Discretization

This method is an extension of the simple vertical discretization method, but with addition of vertically discrete hydrologic data to further refine the three-dimensional characterization of hydrogeologic units. In this method, hydraulic conductivity of individual hydrogeologic units is derived using vertically discrete water-level and time-series solute concentration data from available monitoring wells.

Geologic Discretization

The geologic discretization approach consists of identifying specific hydrogeologic units that are based on a vertical extension of the geologic subdomains determined as part of the two-dimensional modeling effort. Four general types of geologic subdomains have been identified at land surface within the study area (Wood et al., 2005; Helm-Clark, this volume). These subdomains, shown on figure 1a, consist of 1) volcanic rift zones and axial volcanic high, 2) volcanic tablelands, 3) Big Lost River floodplain, and 4) sedimentation areas.

Wells are located within each geologic subdomain that represent the vertical character of the aquifer within that subdomain. A total of 30 wells (figure 1a) penetrate at least 100 meters or more into the aquifer and have a reasonably complete set of lithologic and geophysical logs. These logs are used to identify discrete hydrogeologic units penetrated by the well bore.

The distribution of these wells indicates that hydrogeologic units in parts of the study area are poorly characterized. For example, no deeply penetrating wells are located within the southern part of the study area, generally outside the southern boundary of the INL. In this and other areas, a "characteristic" geologic column derived from representative wells within the subdomain is used in conjunction with data from shallower wells to aid in the evaluation of hydrogeologic units. Figure 1b shows the location of all the wells with data available to aid in the analysis, grouped by depth of penetration below the water table.

The hydrogeologic unit discretization is based upon changes with depth in geophysical logs and core lithologic data collected throughout the active portion of the aquifer from numerous wells in and around the INL. The types of geophysical logs that provide the most valuable information for differentiating these units are natural gamma logs (to identify areas with high amounts of sediments), gamma-gamma and neutron logs (to identify interflow zones and dense basalts), and temperature logs (to identify alteration in the basalt and changes in groundwater flow velocities).

Analysis of geophysical logs from well INEL-1 provides an example of the delineation process, Figure 3 shows selected geophysical logs collected in INEL-1 over the active thickness of the aquifer. At this location, four hydrogeologic units are identified. An Upper Aquifer Unit (UAU) extends from the water table to a depth of approximately 170 meters below land surface (BLS). The contact between the UAU and the underlying hydrogeologic unit (Mid-Aquifer Unit or MAU) is identified by the pronounced deflection in the density log and an inflection in the temperature log (and resulting charge in the temperature gradient). A Sediment Rich Unit (SRU) is identified in well INEL-1 underlying the MAU by readily identified peaks in the natural gamma logs. A Basal Aquifer Unit is identified between the SRU and the base of the active aquifer from an inflection in the temperature log. The base is at a depth of approximately 223 m BLS at this location. The rationale for identification

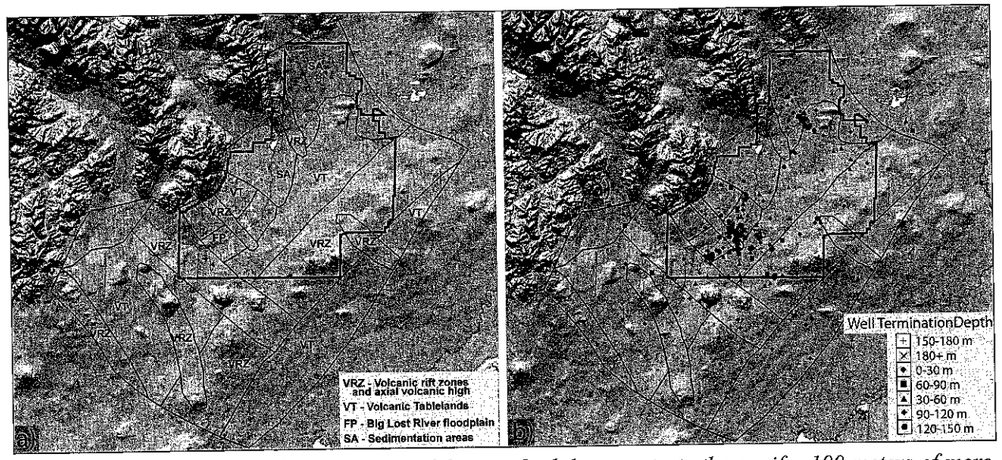


Figure 1. a) Wells used for the geologic modeling method that penetrate the aquifer 100 meters of more, and b) Other wells in the model domain and the depth range they penetrate the aquifer. Also shown in light gray outlines are the geologic subdomains.

of these hydrogeologic units differs from well to well because of differences in available data, but each boundary is identified by at least two of the geophysical logs mentioned above, and is supported by other data such as core, video logs, other geophysical logs, or driller/ geologist logs.

Hydrogeologic unit delineations within the 30 deeply penetrating wells are then projected across the study area on a series of hydrogeologic sections (figure 2). Eight sections are identified that traverse the entire study area. Several of the sections intersect only a few wells or no wells at all (Lines 2 and 3) because of the limited well coverage in those areas. "Characteristic" geologic columns are used to extrapolate hydrogeologic units on those sections where little or no well control exists. These extrapolated "characteristic" column locations are shown on figure 2.

The hydrogeologic sections as constructed are being used to construct three-dimensional solids that will represent individual hydrogeologic units. Ranges in hydraulic properties will be assigned to each hydrogeologic unit based on aquifer pumping, slug, and straddle packer tests, with values distributed in light of such large-scale features as major rift zones, the Big Lost Trough, and ancestral lake beds and playas. These ranges in hydraulic properties will provide a reasonable starting point for the three-dimensional numerical simulations.

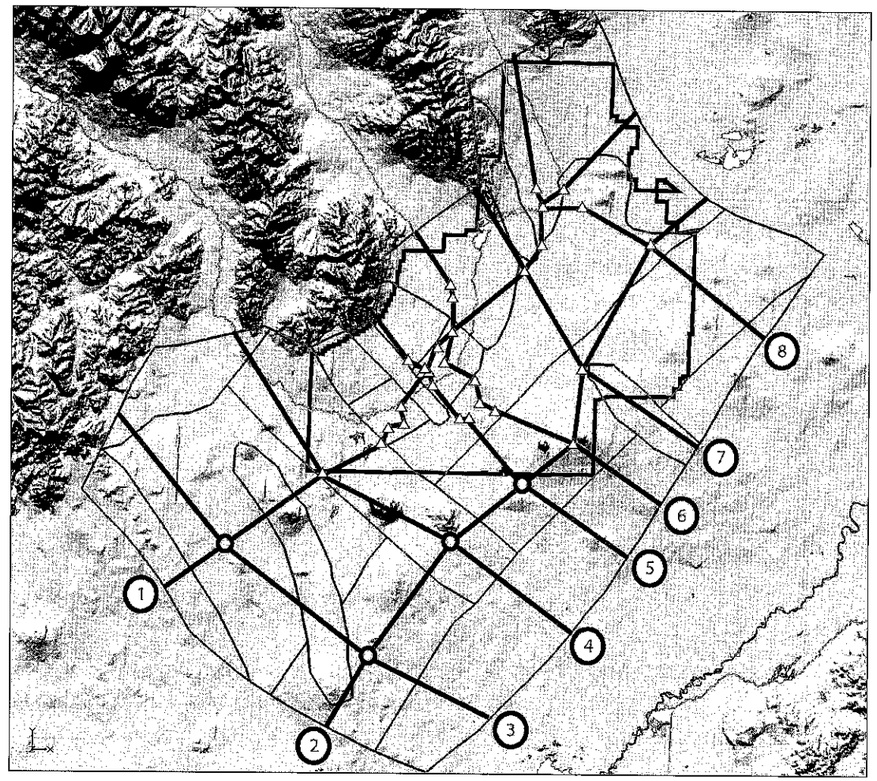


Figure 2. Cross-section lines (large circles with numbers) used to extrapolate the hydrogeologic units. Triangles represent deeply penetrating wells; circles at section interstices represent "characteristic" delineations. Also shown with the light gray outlines are the geologic subdomains.

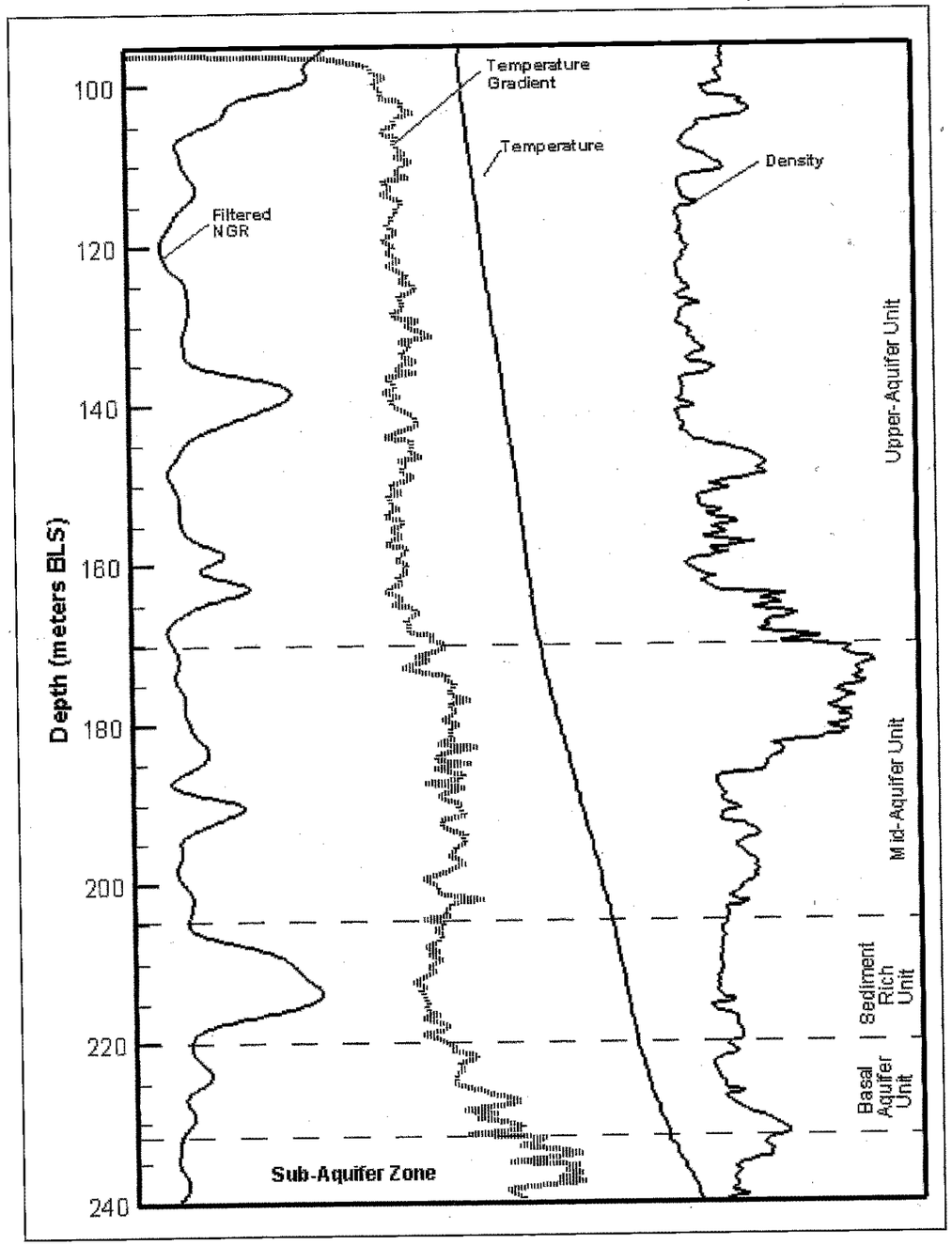


Figure 3. Selected geophysical well logs collected in well INEL-1 and the hydrogeologic unit delineations interpreted from the logs.

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Photo by Tim Frazier

Interpretation of Water-Level Data in Support of the OU 10-08 Groundwater Flow and Contaminant Transport Model

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ABSTRACT

The water-level dataset from selected Snake River Plain aquifer wells is a primary calibration target for the OU 10-08 numerical model of groundwater flow and contaminant transport at the Idaho National Laboratory. Assembly of an internally-consistent set of time-series water-level measurements from this primary data set commonly is problematic. Erroneous data resulting from problems inherent to field-data collection can affect interpretation and model calibration if the erroneous data are not screened out. A water-level data evaluation and validation process was developed for the OU 10-08 project to minimize this effect on the modeling process. This article describes the data screening process involving water-level time-series analyses to check for consistency with data from nearby wells and describes specific applications where errant data have been identified and removed. The article also describes the use of validated water-level data in construction of water-table maps, in determination of numerical model boundary conditions, and in model calibration.

INTRODUCTION

Water-level data consist of measured depths to water in wells. These data can be used to calculate the elevation of a water surface above a selected datum, which, in turn, can be used to determine the configuration of the water table and the direction and gradient of groundwater flow. These data are useful in numerical groundwater models to define the groundwater flow velocity field, identify appropriate boundary types, provide model calibration targets, and determine whether a steady-state or transient model is required.

Water-level data can be collected from wells more simply and quickly than other data (for example, water chemistry). Although water-level data are easily obtained, their application in modeling projects is subject to errors. Field measurements are often inexact. In addition, water levels in wells can change considerably over time in response to natural and anthropogenic influences. As a result, preparation and timing of measuring events is critical. Equally important is the need for an adequate validation process to ensure data are correct and meaningful.

DATA VALIDATION

A water level measured in a well must accurately represent true head in order to be

a used in a large-scale hydrologic evaluation. The usefulness of a measured water level may be affected by errors introduced during the measurement process and by local conditions. These errors and conditions commonly are noticed upon inspection only after completion of the water-level measurement campaign.

Errors that invalidate water-level data may be derived from a variety of sources, including inadequate equipment calibration, inconsistent measurement procedures, and errors in data transcription. During the OU 10-08 June 2004 water-level measurement campaign, the effects of these errors on the data set were minimized through establishment of administrative controls, including routine equipment calibration and standardized measurement and transcription procedures. Additionally, validation of the OU 10-08 June 2004 water-level data set included comparison of individual measurements to water-level trends. The previous year's measurements were evaluated for all wells to compare the apparent decline rate to the recent (last several years) annual water-level decline rate for the Snake River Plain aquifer (SRPA) of 2 to 3 feet. Sites where apparent declines greatly exceeded this rate were treated with suspicion and, if investigation warranted, were discarded. Summary statistics of well hydrographs, or time histories of water levels, yielded mean water levels and standard deviations; in cases where the June 2004 measurement differed from the mean value by more than twice the standard deviation, the measurement was further evaluated.

Local conditions, including changing barometric pressure, pumping from nearby wells, and other localized stresses, may affect water-level data and invalidate them as calibration targets. The OU 10-08 water-level data set required completion of a large-scale field effort during which water levels were measured in more than 200 wells in a short period of time to minimize water-level fluctuations from these sources. This effort consisted of an intensive water-level measurement campaign conducted in early June 2004 and involving eight teams of trained field personnel. To minimize spread of time between data, the majority of field measurements were collected over a three-day period.

Well completion characteristics can result in water-level measurements that are not entirely comparable to those from other wells, leading to an inaccurate representation of the true water table. The length and depth of a well's open interval within the aquifer may invalidate the water level measurement, particularly if a strong vertical head gradient exists with depth. Water-level measurement errors can be introduced if a well is not constructed plumb and straight. Incorrectly surveyed or confusing land-surface reference points add uncertainty to the accuracy and use of these data. Those data collected from wells with known borehole deviation were corrected using results of prior deviation logs. Confusing reference points were addressed through procedural implementation and recent resurveys resulted in corrected locations for wells that previously had been incorrectly surveyed.

Several of the wells considered for inclusion in the OU 10-08 water-level measurement campaign were constructed significantly deeper than the typical well's completion depth below the water table. For instance, well INEL-1, drilled to a depth 10,365 ft below land surface, is approximately 112 feet from a nearby shallower well. The shallower well extends 595 ft below land surface. Although the two wells were measured moments apart on the same day in June 2004, the water level in the deeper well was approximately 97 feet higher. The water level in the shallower well is more typical of the flow system monitored by other wells in the June 2004 set and, as a result, the INEL-1 measurement was not used in water table mapping or 2D flow model calibration. Figure 1 depicts the distribution of well completion depths relative to the measured water table surface.

Less obvious examples indicate the need to carefully examine completion intervals when comparing water levels for the purpose

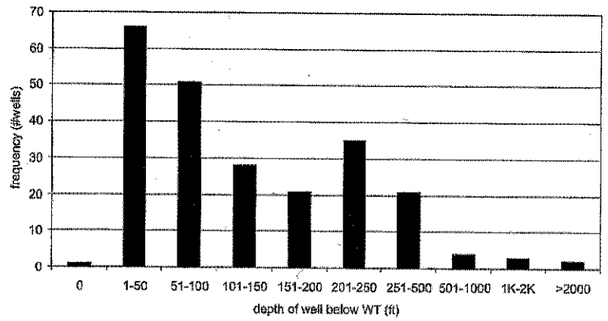


Figure 1. Histogram of well completion depths relative to measured water level for June 2004 data set.

of water table mapping. In one example, the measured water level in a well screened from 725-755 feet below land surface, extending about 270 ft into the aquifer, has consistently been nearly two feet lower than those in wells about 100 feet away that extend only ten feet into the aquifer. Based on these data, strong vertical hydraulic gradients exist within the aquifer. To reduce contouring errors derived from hydraulic gradient changes with depth, the OU 10-08 project utilized only those wells that are completed in the top 200 feet of the aquifer; however, in outlying study domain areas, limited well distributions did not always permit the opportunity to selectively rule out those measurements that may have been affected by vertical gradient changes.

The June 2004 water-level measurement campaign produced useful data after a thorough validation effort. 236 aquifer wells located within the model domain were measured in June 2004. Fifteen of these were determined to be from wells completed at significantly deeper depths than the mean completion depth of the aquifer well set and were not used in calibration of the two-dimensional flow model calibration or in construction of water table maps. Water-level measurements in seven of the remaining 214 wells were discarded because close examination of well hydrographs indicated that measurements were likely in error. These were replaced by measurements made by the USGS during the same month. Additionally, water levels from another 119 aquifer wells measured by the USGS were added for contour mapping purposes. These 119 are outside the model domain and were used to extend water-table contours but were not used in model calibration. The timing of measurements is not as critical for these wells outside the model domain. The dates of these outlier well measurements range from January to December 2004; nearly 40% of these measurements were made in either March or September 2004. Thirty-nine of the outlier wells were measured only once in 2004.

DATA APPLICATION

The water-level data collected in June 2004 supported development of the OU 10-08 groundwater flow model. These data were used to prepare maps of the water table, to define boundary conditions, and to identify calibration targets.

WATER TABLE MAPS

Water-level data collected during the 2004 OU 10-08 campaign were used to prepare an interpolated map of the water table. The interpolation was accomplished using ordinary kriging. This map defined the field of groundwater flow within the model domain. The results of the mapping exercise indicated that the general groundwater flow direction is from northeast to southwest. Subsequently, the orientation of the numerical model domain was rotated 44.2 degrees to align the principal axis

along the general flow direction.

A set of water-level data measured within a short time interval can be used as a starting-head input to the model. Water-table maps constructed from the 2004 water-level measurement campaign provided the initial distribution of heads in forward numerical modeling simulations. Additionally, a series of water-table contour maps was prepared to observe flow-field changes that occur with time. These maps were used during conceptual modeling efforts to determine the observed flow field and to evaluate whether the flow system is best represented using transient or steady-state conditions.

BOUNDARY CONDITIONS

Water-level data are useful in determining appropriate model boundary conditions. This includes determination of boundary types, boundary shapes, and the specification of head-dependent flux conditions or fixed head boundaries.

The southeast model domain boundary was determined to be best represented by a no flow boundary along a groundwater flow line; as such, this boundary is perpendicular to the contour lines of equipotential head. Water-level data from the 2004 measurement campaign were used to refine this flow path. Refinement resulted in modification of the extent of the model domain.

The 2004 water-table map (Figure 2) also was used to define the numerical model's top surface. The top portion of this figure shows the original model domain that was developed at the start of this project. Beneath this is the revised model domain that was developed after mapping water table contour lines from June 2004. Also shown in the lower portion of Figure 2 are the June 2004 water-table contours, wells identified for calibration, and supplemental wells used for controlling contours along the margins of the revised model domain.

Initially, the northeast and southwest model-domain boundaries were defined as specified head boundaries interpolated from mapped contour lines. However, comparison of two-dimensional simulated flux across the northeast boundary to flux from other subregional (Spinazola 1994) and regional (Garabedian 1992; Wylie 2003) models indicated that the specified head boundary resulted in significantly smaller regional inflows to the OU 10-08

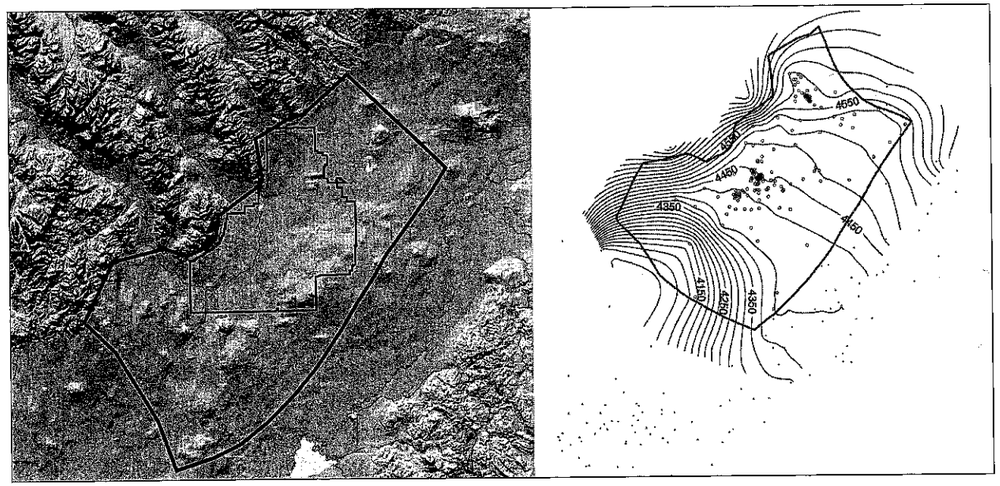


Figure 2. Comparison of original OU 10-08 model domain (above) with revised domain featuring water level contours (feet above mean sea level; 25-ft contour interval). Circles mark calibration targets for 2D flow model. Smaller triangles mark location of supplemental wells added for water table contour control.

model domain and increased the potential for underestimating the magnitude of transmissivity throughout the model domain. Subsequently, a specified flux boundary was established that utilized a reasonable and technically defensible inflow across the northeast boundary.

For this model, specified flux boundaries were also established to represent tributary drainages along the northwest boundary; these correspond to poorly understood recharge sources from groundwater underflow that occurs from these tributary drainages into the regional aquifer system.

CALIBRATION TARGETS

A numerical groundwater flow model typically is calibrated by adjusting the model properties until simulated heads closely resemble measured heads. During the development of the OU 10-08 flow model, an initial domain was used that encompassed water levels from 253 calibration wells measured in or near June 2004. After the model domain was reduced in size to eliminate simulation of the hydrologically complex agricultural area northeast of the INL, the original calibration well set was reduced to 214 wells.

FURTHER INVESTIGATION

Typically, contaminant transport models are based on a steady-state groundwater flow model. The steady-state flow model is inherently less complex than a transient one. To justify steady-state conditions, hydrographs of water elevation over time must be examined, water-table contour maps must be constructed for different time periods, and pumping and recharge sources must be investigated. Currently, the OU 10-08 model development includes investigation of potential transient flow-field effects.

Several time scales of cyclical variation are observable in INL wells. These variations include short-term annual fluctuations, intermediate-term cycles corresponding to flood/drought cycles, and long-term trends related to changing climate and reduced recharge as a result of more efficient agricultural irrigation methods. Extended periods of measured water-level changes in three wells (Figure 3) demonstrate these different time scales. Water-level hydrographs (also shown on Figure 3) were constructed from monthly water-level measurements. These hydrographs have been normalized but separated to show relative water-level changes.

The northernmost well, USGS-25, is located in proximity to the groundwater irrigation area to the northeast of the model domain and near the mouth of Birch Creek. The hydrograph for this well shows annual water-level fluctuations that occur in response to irrigation pumpage. The hydrograph for this well also shows intermediate-term fluctuations (10-15 years) likely derived from drought-cycle precipitation

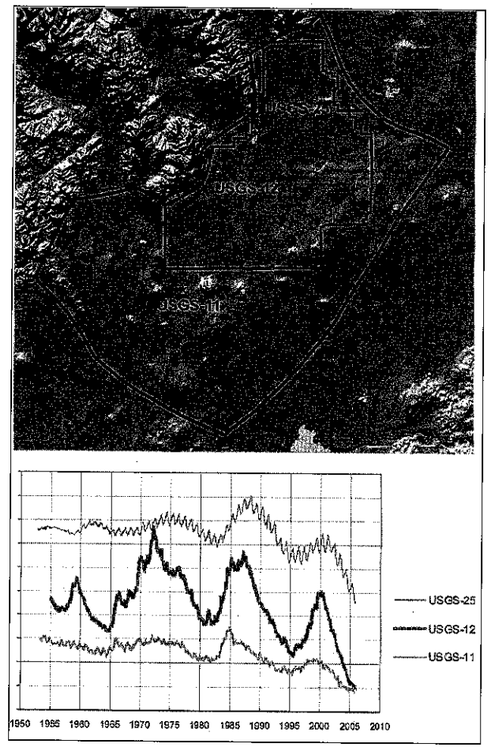
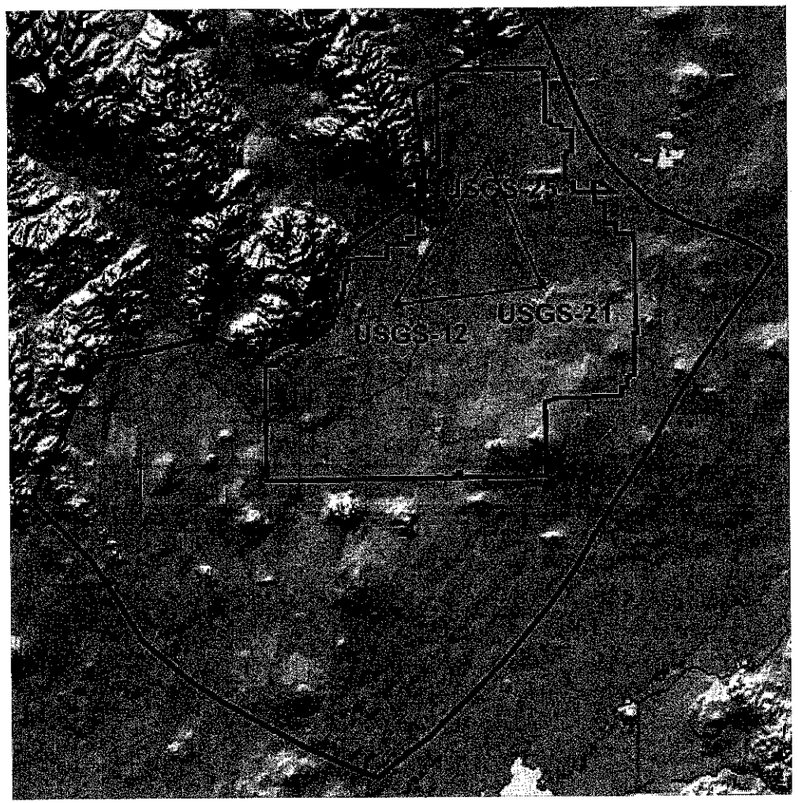


Figure 3. Comparison of water level hy drographs for three aquifer wells across OU 10-08 model domain.

changes and resultant tributary surface-water and groundwater inflows to the Snake River Plain. In particular, this well is close to the Birch Creek drainage and may reflect influx from that drainage. The hydrograph for this well also shows a generalized long-term decline in water levels, likely reflecting regional trends from changing irrigation practices on the ESRP.

Well USGS-12 is located in the middle of the OU 10-08 model domain and in proximity to the mouth of the Little Lost River (Figure 3). Water-level changes in this well do not show annual fluctuations in response to irrigation season pumpage. However, water levels in this well fluctuate strongly in the intermediate time scale in response to tributary inflows.



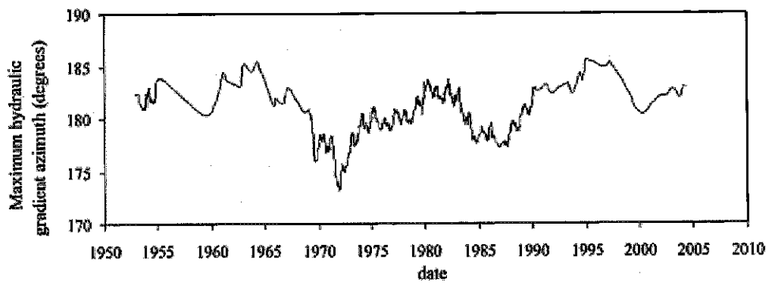


Figure 4. Location of three aquifer wells within OU 10-08 model domain used to calculate hydraulic gradient. Lower portion of this figure shows calculated hydraulic gradient as a function of time.

The hydrograph also shows general declining water levels in response to long-term regional trends.

The southernmost well, USGS-11, is located west of Big Southern Butte and approximately 20 miles southeast of the mouth of the Big Lost River valley. Water levels in this well vary annually but the annual fluctuations are not as pronounced as those in well USGS 25. Inspection of the annual cycle indicates that water levels in this well may be responding both to irrigation pumpage to the southeast and to the northwest and to localized recharge from infiltration of streamflow along the Big Lost River. Intermediate drought-cycle fluctuations occur but are also less pronounced than those in the other two wells. This damped intermediate cycle may be attributed to increased distance to tributary drainages. Again, the hydrograph shows a generally declining water level that reflects long-term regional trends.

Water-level data from these three wells demonstrates the lack of synchronicity among aquifer well hydrographs across the model domain. In particular, the peaks and low points related to the intermediate flood/drought-cycle occur at different times in different areas, and definable lags occur in response to short-term, intermediate-term, and long-term stresses.

Water levels from three wells (USGS-25, -12, and -21) were used to generate simple three-point surfaces throughout the period of water-level record. The dip azimuths of these surfaces, indicating the general direction of groundwater flow in the vicinity of the three wells, were determined and plotted against time (Figure 4). The azimuth fluctuated over time, ranging from about 173 to 185 degrees. Increasing azimuth values with time indicated that the general direction of groundwater flow, as approximated using these three wells, was more to the southwest. Decreasing azimuth values indicated a more southeasterly direction of flow. Time intervals of increasing azimuth corresponded to intervals shown on Figure 3 when water levels were declining; similarly, time intervals of decreasing azimuth corresponded to intervals when water levels were generally increasing. These fluctuations indicate that the general direction of groundwater flow was modified throughout an intermediate time-scale drought cycle characterized by increasing or decreasing recharge derived from tributary basins.

ADDITIONAL ISSUES

Several issues persist for users of water-level data collected for OU 10-08 modeling purposes. Along the western boundary of the plain, corresponding to the alluvial fans that enter the plain from tributary mountain valleys, water-level data indicate that subsurface water bodies appear to be stratified. Near the mouth of the Big Lost River valley, a layer of water several hundred feet above the regional aquifer is apparent in many shallower wells. Deeper wells in this vicinity appear to tap the regional aquifer. Potential inclusion of perched water levels could affect accurate portrayal of the water table in this area. The delineation of regional and perched water in the vicinity of the Big Lost River along the margin of the plain is still under investigation.

Perched water bodies have formed beneath several INL facilities in response to wastewater discharges to infiltration ponds. Wells monitoring these perched water bodies were clearly identified and water levels measured in these wells were omitted from the preparation of regional water table maps.

CONCLUSION

Water-level data provide an easily obtained insight into aquifer response to stresses. These data can be used to define groundwater flow fields, identify flow model boundaries, and provide flow model calibration targets. For the OU 10-08 model, a large set of water levels were collected from the field over a relatively short period of time; these were then analyzed for accuracy by comparing to previous measurements and discarding data with identifiable errors. Additionally, water levels measured in wells with screened or open

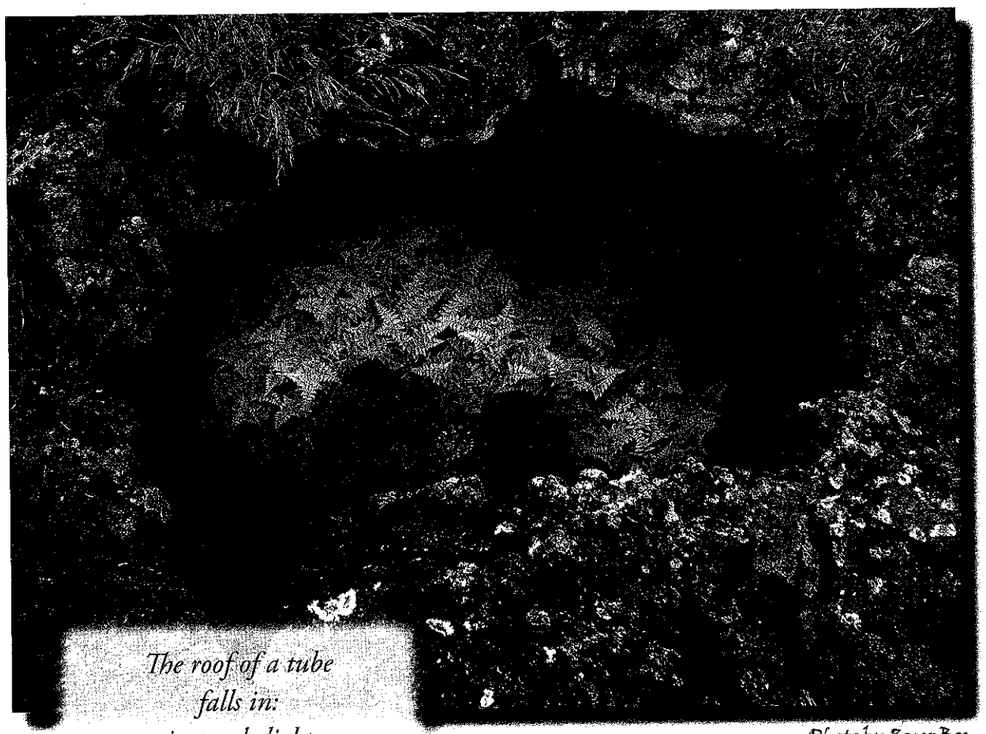
intervals that are significantly different from the majority of wells in the measured set were eliminated.

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The roof of a tube
falls in:
just a skylight
and at the bottom
two ferns
glow like starfish.

- Will Peterson

Photo by Roger Boe

Anthropogenic Contaminants as Groundwater Flow Tracers

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ABSTRACT

Although many facilities on the INL disposed similar contaminants to the subsurface, these sources are not identical and the differences can be used to "fingerprint" facility plumes. The unique combinations and ratios of multiple contaminants together provide a tool that can be used to distinguish the specific source of contamination, map groundwater flow paths, evaluate the potential for upgradient influences, and evaluate the potential for contaminant plumes to overlap. The constituents utilized as groundwater flow tracers include chloride, sulfate, nitrate, iodine-129, chlorine-36, tritium, and Tc-99. The radiological constituents and chloride are very soluble and can be tracked over great distances. Although sulfate and nitrate concentrations are susceptible to reduction/oxidation changes, conditions in the aquifer are oxidizing and concentrations and isotope signatures should be relatively conservative in the Snake River Plain aquifer. Some anthropogenic constituents, such as iodine-129 and chlorine-36, can be used to determine groundwater flow paths and potential receptors in areas much further downgradient because samples can be analyzed using accelerator mass spectrometry methods to achieve ultra-low detection limits. These data are being used to refine groundwater flow paths, to support development of the groundwater flow model, and to assess wells that may potentially be impacted by contaminants from INL facilities.

INTRODUCTION

A geochemical study using anthropogenic contaminants was conducted to resolve the source of tritium in the Snake River Plain aquifer (SRPA) beneath the Radioactive Waste management Complex (RWMC), to identify contaminant flow paths in the SRPA from sources derived from the Idaho Nuclear Technology & Engineering Center (INTEC) and the Reactor Technology Complex (RTC), to determine the source of elevated anion concentrations in groundwater south of the RWMC, and to identify SRPA flow paths and evaluate contaminant influence in groundwater south of the southern INL site boundary (Figure 1). Identification of groundwater flow paths is essential for development and calibration of the OU 10-08 Sitewide Groundwater Model. In addition, data from this geochemical study are being used to evaluate the potential for commingled plumes that may elevate the cumulative environmental risk above levels calculated for individual plumes. The wells used in this study ranged in completion from screened wells at the water table to deeper open boreholes. Because the purpose of this study was to trace or determine the source of contaminants drawn from a well, the three dimensional aspects of plumes were not examined.

The geochemical study used anthropogenic

constituents introduced into the SRPA from INL operations as tracers. These tracers included chlorine-36 (Cl-36), sulfur and oxygen isotope ratios in sulfate, and nitrogen and oxygen isotope ratios in nitrate. The extremely low detection limits for Cl-36 using the accelerator mass spectrometry (AMS) method enabled tracking of contaminant plumes and identification of groundwater flow paths south of the INL boundary.

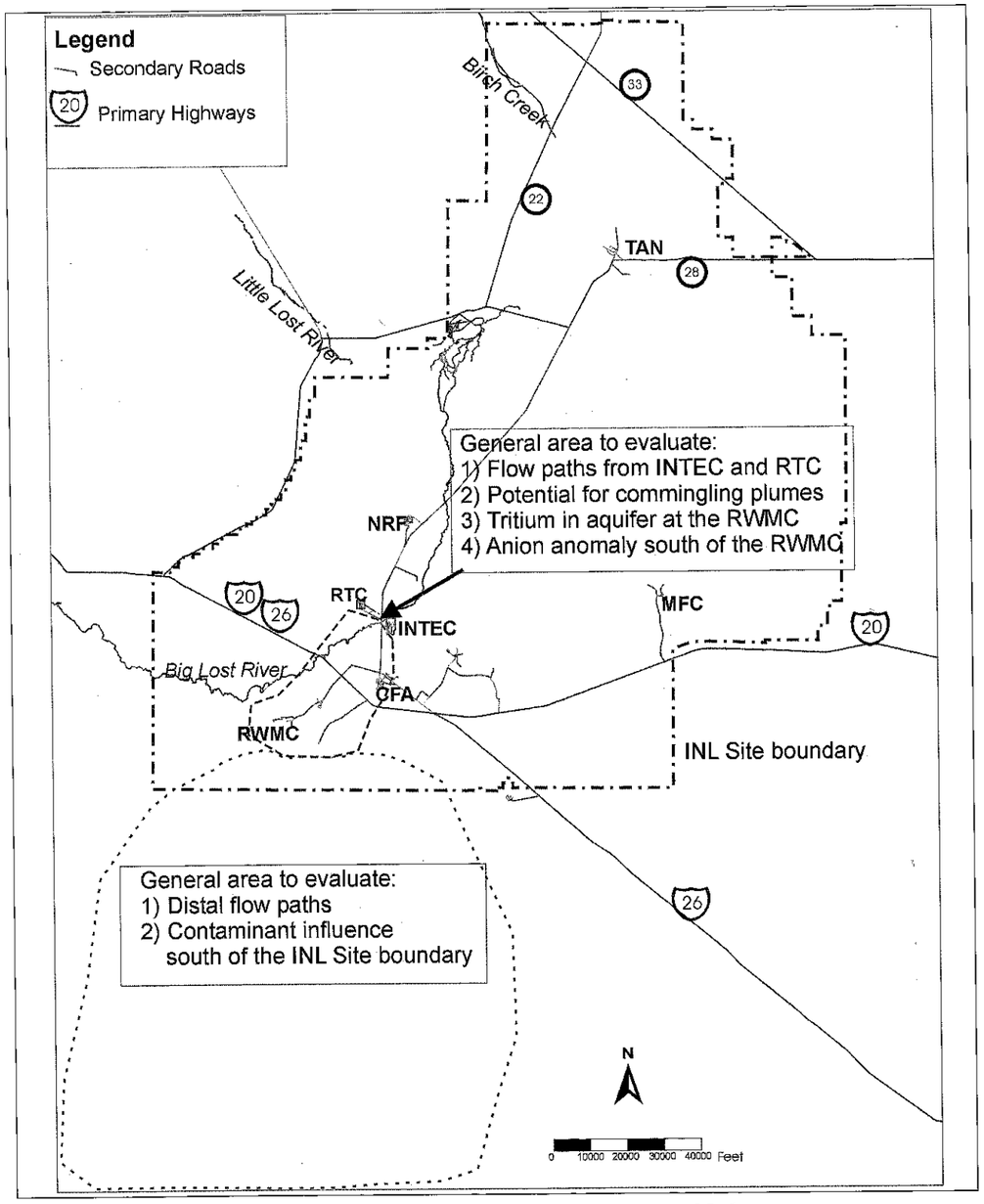


Figure 1. Geochemical study areas at the Idaho National Laboratory.

Tracers were selected based on their capability to assist in identification of sources and on their potential to be tracked over great distances. Cl-36 and nitrogen and oxygen isotope ratios in nitrate were used to evaluate plumes and downgradient flow paths from INTEC. Cl-36 and sulfur and oxygen isotope ratios in sulfate were used to track plumes and downgradient flowpaths from RTC. Sulfur and oxygen isotope ratios in sulfate, along with nitrogen and oxygen isotope ratios in nitrate, were used to evaluate the source of the elevated anion concentrations south of the RWMC. In addition to the above tracers, results of an iodine-129 (I-129) study presently in progress will be compared to the results of the study presented here.

ANALYTICAL METHODS

The Cl-36 analyses were performed by the Purdue Rare Isotope Measurement laboratory (PRIME) in Lafayette, Indiana. Samples were analyzed using the AMS method. In AMS, a particle accelerator is used in conjunction with negative ion sources, electric and magnetic analyzers, and nuclear detectors to separate interferences (S for ^{36}Cl) and measure the isotope abundance to the level of 10^{-15}.

The stable isotope results were performed by the USGS Water Quality Laboratory in Reston, VA. Sulfur isotope ratios were reported in parts per thousand (per mill) relative to Canyon Diablo Triolite (VCDT). The 2-sigma uncertainty of sulfur isotopic results and 2-sigma uncertainty of oxygen isotopic results both were 0.4 per mill, unless otherwise indicated. Nitrogen isotope ratios were reported in parts per thousand (per mill) relative to N^2 in air (Mariotti, 1983). Oxygen isotope ratios were reported in per mill relative to Vienna Standard Mean Ocean Water (VSMOW). The 2-sigma uncertainty of nitrogen isotopic results was 0.5 per mill and the 2-sigma uncertainty of oxygen isotopic results of nitrates was 1.0 per mill.

Cl-36 Results

The distribution of the ratio of Cl-36 to Cl at E-15 in groundwater was plotted (Figure 2) using data from the current study and some data points from Beasley (1995). Although data from Beasley (1995) are about 13 years older than the current data set, Cl-36/Cl ratios were within a factor of 2 to 4 for water from the wells sampled in both data sets. Given the many orders of magnitude that the data spans, this difference was within acceptable limits for showing the general distribution of Cl-36 in groundwater.

Water from wells near the RWMC was characterized by two different groups of Cl-36/Cl ratios. Water from wells on the northeastern side of the RWMC was characterized by much higher (262,000 to 400,000) Cl-36/Cl ratios than water from wells south of the RWMC (300 to 15,000). Water from wells containing the higher Cl-36/Cl ratios also was contaminated with tritium and was similar to water from wells M12S and USGS-106, located within the INTEC plume.

Cl-36/Cl rations in water from wells USGS-009, USGS-105, USGS-109, and USGS-108, all at the southern INL boundary, were above background. South of the INL boundary, water from the Houghland and Crossroads wells showed evidence of site-derived Cl-36 because ratios exceeded background values of 320 to 640 (Bentley et al 1986). The Houghland well is approximately 13 miles south of the INL boundary (Figure 2).

STABLE ISOTOPE RESULTS

The stable isotope data presented below are expressed in conventional delta (δ) notation in per mill (‰, parts per thousand) difference in the ratio of the less abundant isotope to the most abundant isotope in a sample relative to the same ratio in a known reference standard (Clark and Fritz 1997). The following equation is used:

$$\delta X_{sample} = [(R_{sample} - R_{standard})/ R_{standard}] \times 1000$$

where

δX = isotope of interest ($\delta^{18}O$, $\delta^{34}S$ or $\delta^{15}N$)

R = ratio of $^{18}O/^{16}O$, $^{15}N/^{14}N$ or $^{34}S/^{32}S$.

The purpose for using stable isotope ratios rather than nitrate or sulfate concentrations was to extend the discernable limits of the INTEC nitrate plume and the RTC sulfate plumes. Because of the oxidizing conditions and near neutral pH in the SRPA, stable isotope ratios in nitrate and sulfate should behave conservatively and the stable isotope values should indicate the sources.

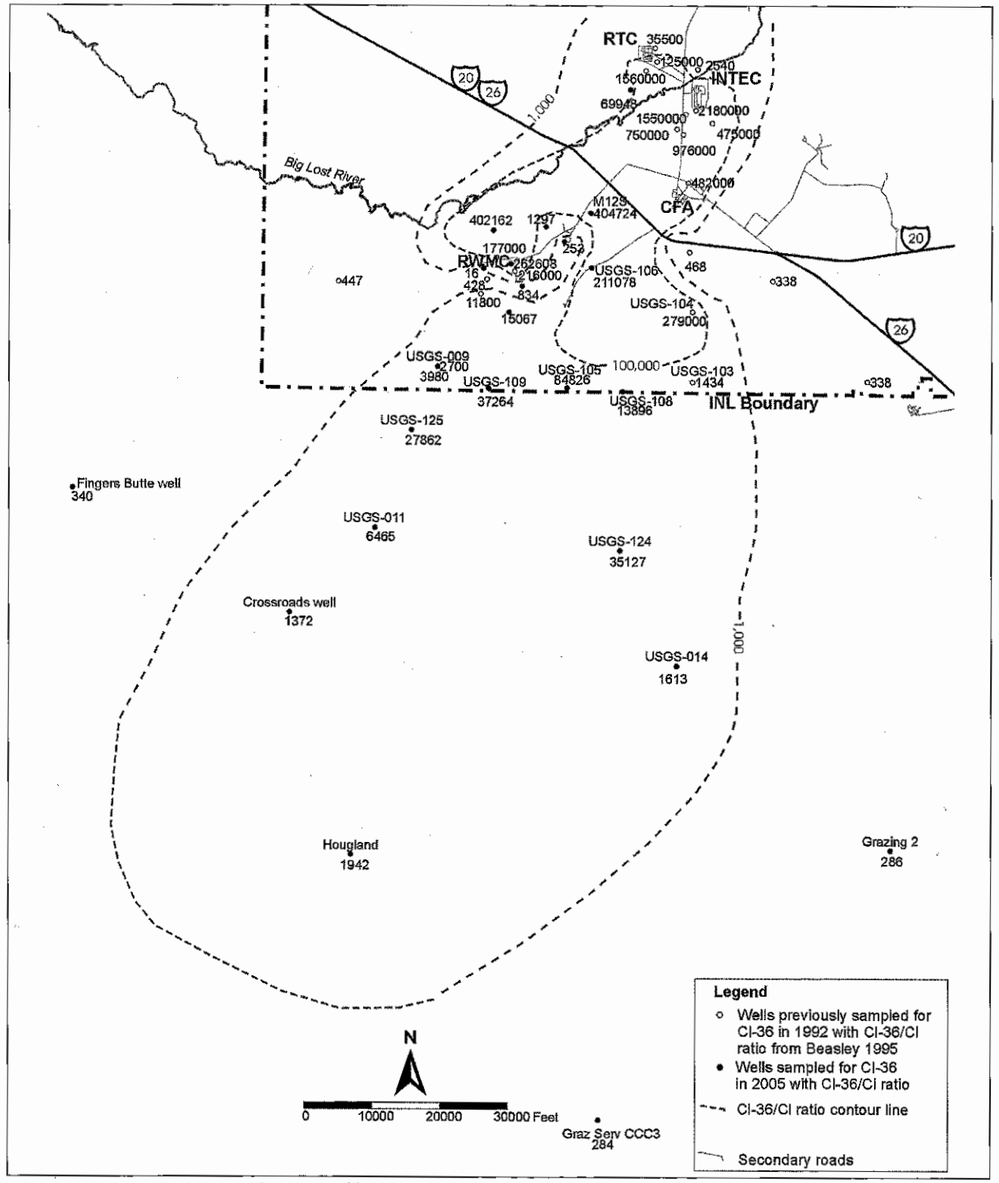


Figure 2. Distribution of $^{36}Cl/Cl$ values in water from the Snake River Plain Aquifer

NITROGEN AND OXYGEN ISOTOPE RESULTS

The $\delta^{15}N$ results for the samples collected for the WAG 10 geochemical study ranged from +6.1 to +7.37 ‰, while the $\delta^{18}O_{nitrate}$ results ranged from –3.19 to –6.52 ‰ (Figure 3). In order to examine the potential sources of nitrate contamination, the $\delta^{15}N$ values were plotted versus the $\delta^{18}O$ values for nitrate (Figure 3). The plot of $\delta^{15}N$ values versus the $\delta^{18}O_{nitrate}$ values showed that the samples collected for this study plotted in two groups with well Middle-1823 plotting as a separate point (Figure 3).

The first group, consisting of isotope ratios in water from wells M12S, USGS-106, M14S, M7S and the RWMC production well, was represented by a range of $\delta^{15}N$ values from +6 to +6.4 ‰ and a range of $\delta^{18}O_{nitrate}$ values from -3 to –4. This group of tritium contaminated wells plotted between background and water from production well CFA-2 and is consistent with INTEC disposals as dilution occurs south of CFA-2. Another explanation for the $\delta^{18}O_{nitrate}$ values in water from the M12S, USGS-106, M14S, M7S and the RWMC production wells is that the nitrate may have originated from wastes in the RWMC. Nitrate from nitric acid or nitrate salts in the RWMC could have $\delta^{15}N$ and $\delta^{18}O_{nitrate}$ values similar to the INTEC plume since they would originate from a manufactured source. On the basis of the $\delta^{15}N$ and $\delta^{18}O_{nitrate}$ values alone, a nitrate source from wastes in the RWMC could not be ruled out.

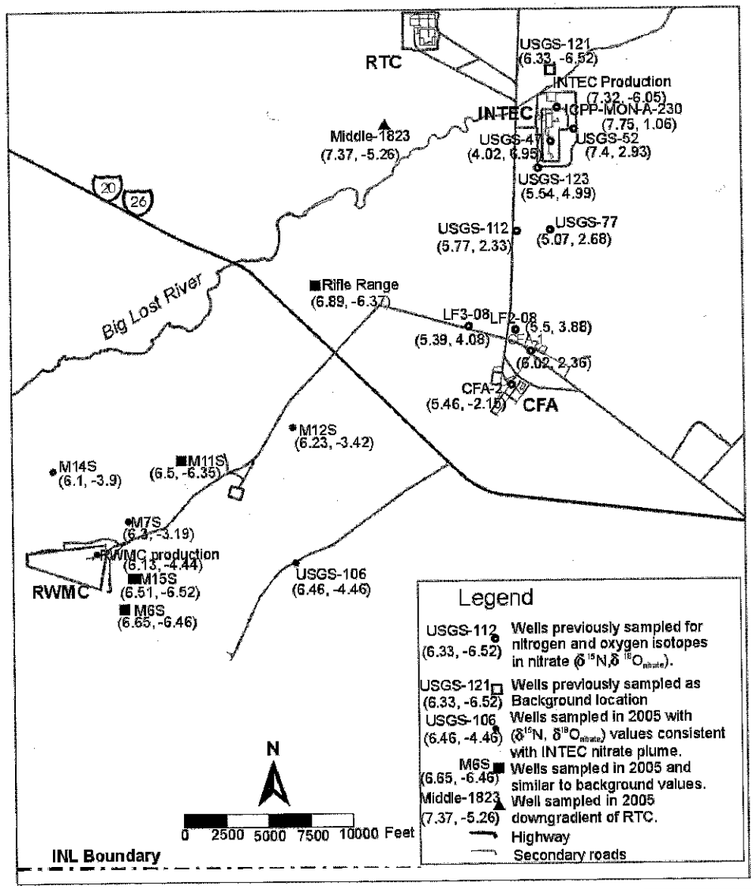
The second group of samples plotted similar to natural background values (nitrogen isotope ratios of 6 to 7 ‰ and $\delta^{18}O_{nitrate}$ of –6 to –7 ‰) as represented by well USGS-121 and the raw water supply for INTEC. The background group included water samples from wells M11S, M15S, M6S and the Rifle Range well.

Sulfur and Oxygen Isotope Results

The $\delta^{34}S$ results for the SRPA and perched water samples ranged from 5 to 7 ‰, while the $\delta^{18}O_{sulfate}$ results ranged from –6 to 6 ‰ (Figure 4). The aquifer samples showed a small range in $\delta^{34}S$ values of 4 to 7 ‰. In contrast, $\delta^{18}O_{sulfate}$ values for the aquifer samples showed more variability, ranging from -5.6 to 5.6 ‰. The three perched water/lysimeter samples had $\delta^{34}S$ values of 6 to 7 ‰ and $\delta^{18}O_{sulfate}$ values of -3.8 to -4.7 ‰.

A plot of $\delta^{34}S$ versus $\delta^{18}O_{sulfate}$ was used to distinguish sources of sulfate (Figure 4). At least three sources of sulfate were indicated based on the plot of $\delta^{34}S$ and the $\delta^{18}O_{sulfate}$. These sources included the RTC, the vadose zone at the RWMC, and natural sources. The sulfate plume from RTC was characterized by relatively higher $\delta^{18}O_{sulfate}$ values than those for other aquifer samples and for vadose-zone samples at the RWMC. Water from the Rifle Range well also had a higher $\delta^{18}O_{sulfate}$ value, indicating that the probable source of the tritium in this well was the RTC. The elevated sulfate concentration with background chloride concentrations prior to the operation of the new INTEC percolation ponds also supported RTC as the source of the tritium in water from this well (Roddy and Koeppen 2004). It can be argued that sulfate contained in water from well M4D, a deep well south of the RWMC, is derived from another source based on its $\delta^{34}S$ and the $\delta^{18}O_{sulfate}$ values. Water from this well also is considered to be isolated from the shallow ground water based on major ion chemistry (Roddy and Koeppen 2004).

Although $\delta^{34}S$ and the $\delta^{18}O_{sulfate}$ values in water upgradient of INTEC and RTC were not determined, water from wells M11S and M13S can be considered to be background since neither of these wells shows radiological contamination and M11S has a background nitrogen and oxygen isotope signature. Water from wells with tritium contamination in vicinity of the RWMC, including M14S, M7S and the RWMC production well, plotted the same as the background as represented by $\delta^{34}S$ and the $\delta^{18}O_{sulfate}$ values for M11S and M13S. In addition, plots of water samples from well M12S, located hydraulically upgradient of the RWMC, were similar to plots of samples from tritium-contaminated wells near the RWMC. This similarity indicated that water



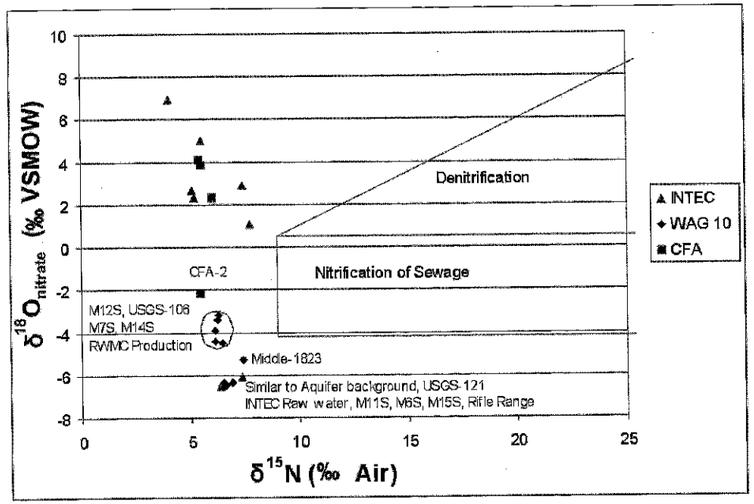
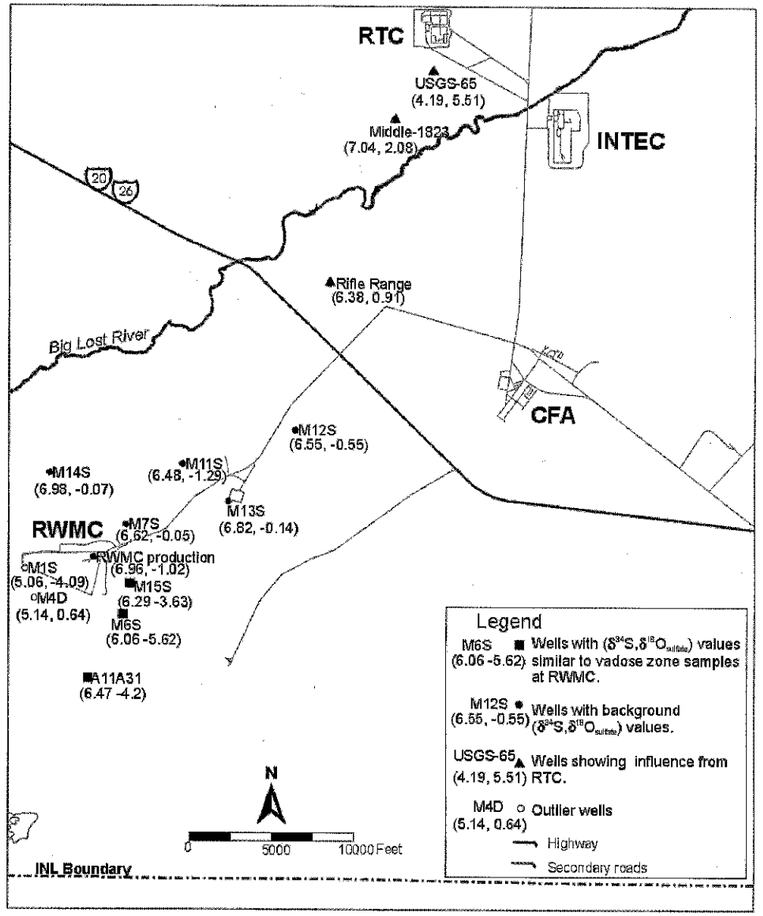


Figure 3 Distribution of $\delta^{15}N$ values and $\delta^{18}O_{nitrate}$ values in the Aquifer and plot of $\delta^{15}N$ versus $\delta^{18}O_{nitrate}$.



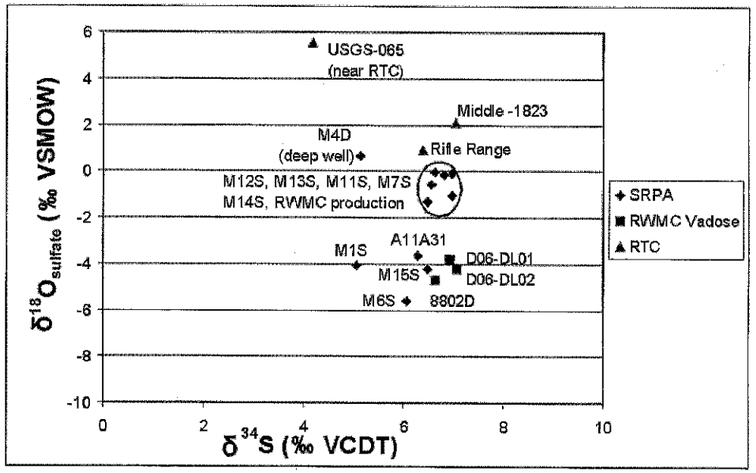


Figure 4. Distribution of $\delta^{34}S$ and the $\delta^{18}O_{sulfate}$ values in the Aquifer and plot of $\delta^{34}S$ versus $\delta^{18}O_{sulfate}$.

from M12S, M14S, M7S and the RWMC production well have the same sulfate source and is derived from the same groundwater flow path. These wells did not appear to be impacted by the vadose zone sources based on $\delta^{34}S$ and the $\delta^{18}O_{sulfate}$ values for the three vadose zone samples collected in the RWMC. Water from well M12S appeared to be impacted by INTEC disposals based on the Cl-36 and nitrogen and oxygen isotope data. Thus, the $\delta^{34}S$ and the $\delta^{18}O_{sulfate}$ data were consistent with groundwater flow from INTEC impacting water from wells M14S, M7S and the RWMC production well.

DISCUSSION OF GEOCHEMICAL DATA

This discussion integrates the results for Cl-36, $\delta^{34}S$, $\delta^{18}O_{sulfate}$, $\delta^{15}N$ and $\delta^{18}O_{nitrate}$ along with historical data to evaluate implications for groundwater flow paths.

Previous studies by the USGS indicated the possibility of upgradient influences for groundwater beneath the RWMC (Mann and Beasley 1994; Beasley et al. 1998; and Busenberg et al. 2001). In addition, water-level contour maps also indicated that the RWMC was downgradient from RTC and INTEC (DOE-ID 2004). Evidence supporting upgradient influences for the RWMC included low I-129 concentrations in water from a well located near the RWMC (Mann and Beasley 1994) and Tc-99 concentrations in water from the RWMC Production Well. The interpretation of upgradient influences was complicated because Tc-99 and I-129 were also present in the wastes emplaced in the RWMC. In addition to the radiological analytes discussed above, a plume of dichlorodifluoromethane (F-12) was identified by the USGS to originate from INTEC (Busenberg et al. 2001), with the F-12 plume matching the distribution of Cl-36 in groundwater (Beasley 1995) resulting from INTEC and the RTC operations.

The present data for Cl-36, $\delta^{34}S$, $\delta^{18}O_{sulfate}$, $\delta^{15}N$ and $\delta^{18}O_{nitrate}$ and the historical data consistently identified INTEC as the source of tritium and other contaminants in groundwater beneath the northern and eastern sides of the RWMC. These data implied that preferential groundwater flow pathways in the aquifer bypass screened intervals in wells M11S and M13S. These two wells are located on the direct flow path from INTEC to the RWMC as defined by water-level contours (DOE-ID 2004). Previously, the absence of tritium in M11S, M13S, and EBR-I was interpreted as indicating that the INTEC plume was a separate from the RWMC plume (Holdren et al 2002). Although many contaminants derived from the RWMC and from the upgradient facilities were similar, the unique combination and ratios of multiple contaminants favored INTEC and cast doubt on the alternative interpretation of the RWMC as the source of radiological contaminants.

Groundwater flow paths and the extent of contaminant influence south of the INL boundary were examined using Cl-36 data. A Cl-36 plume extending south of the INL site boundary had been previously identified (Beasley et al. 1993; Beasley 1995; Cecil et al. 2000). Cl-36 concentrations decreased rapidly south of the INL boundary with concentrations more than five orders of magnitude below MCLs, detectable only using the AMS method. Based on present and historical results, the Cl-36 plume was traceable as far as 13 miles south of the INL boundary. In general, the shape of the Cl-36 plume appeared to agree with the ground-water level contour map.

The stable isotope data were used to evaluate the source of the elevated anion concentrations in groundwater south of the RWMC. Possible sources for the elevated anion concentrations are leachate from the wastes within the RWMC, magnesium chloride brine applied to the roads at the RWMC, or the sulfate plume from the RTC. The brine dust suppressant was used between 1984 and 1993 and was determined to have migrated in the vadose zone to a depth of at least 240 ft below the RWMC (Hull and Bishop, 2003). The $\delta^{34}S$ and the $\delta^{18}O_{sulfate}$ values in water from the wells in the anion anomaly, M6S, M15S, and A11A31, were similar to those in perched water well 8802D and two samples from lysimeters D06-DL01 and –DL02, known

to be affected by the magnesium chloride brine (Figure 4). The $\delta^{15}N$ and the $\delta^{18}O_{nitrate}$ values for wells M15S and M6S were similar to background values. The background values also indicated that the nitrate in these wells did not originate from wastes buried in the RWMC because nitrate from that source is expected to have a $\delta^{15}N$ and the $\delta^{18}O_{nitrate}$ signature similar to that of a manufactured source of nitrate as derived from INTEC operations. The $\delta^{15}N$ and the $\delta^{18}O_{nitrate}$ values also indicated that leakage from the sewage evaporation ponds at the RWMC was not the source of the elevated anion concentrations as sewage samples would be expected to plot in the nitrification or denitrification fields shown on Figure 3, as based on a literature review and data from the INTEC sewage lagoons (EDF-5778).

SUMMARY AND CONCLUSIONS

Previously collected data and data collected for this study supported the hypothesis that tritium in groundwater on the northeastern side of the RWMC was attributed to migration of contaminants from INTEC. However, I-129 data will be required to fully support this conclusion. Contaminant data from individual wells were not conclusive regarding the extent of contamination. It is recommended that multiple conservative tracers be employed along with contaminant data to more fully evaluate groundwater flow paths.

Stable isotope ratios in sulfate and the lack of other contaminants in groundwater beneath the south side of the RWMC indicated that anion anomaly in this area probably is derived from migration of the Mg-Cl brine applied to the roads in the RWMC. However, the stable isotope data in this area were not definitive.

Analysis of Cl-36 ratios indicated that Cl-36 concentrations are diluted rapidly south of the INL boundary. Using the AMS method, it was possible to trace groundwater flow paths to a well 13 miles south of the INL boundary. At this well, the Cl-36 concentration was about three times background, but more than five orders of magnitude below the Cl-36 MCL. The large dilution in Cl-36 concentrations that occurs south of the INL boundary indicated that contaminants from the INL will not have an impact on wells further south in the Magic Valley area.

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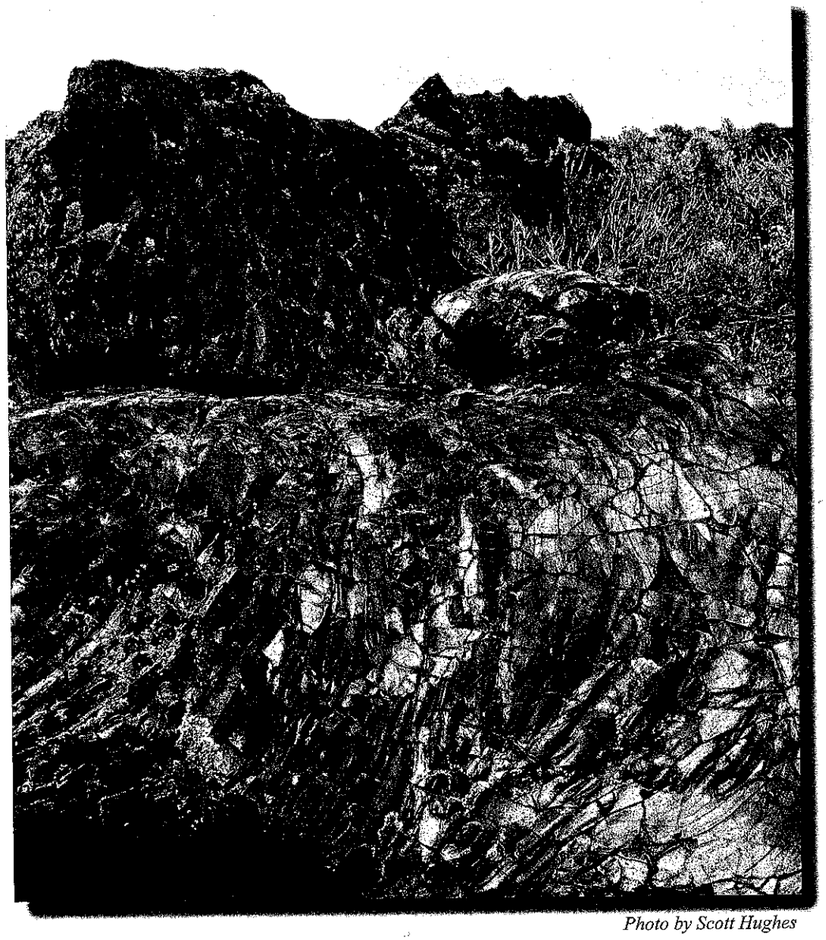


Photo by Scott Hughes

Use of Aquifer Temperature Distribution and Chemical/Isotopic Characteristics to Define Groundwater Flow Paths at the Idaho National Laboratory

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ABSTRACT

Natural groundwater parameters (i.e. temperature, chemistry, and isotopic composition) were used to advance the current understanding of groundwater flow systems in the Snake River Plain aquifer in the vicinity of the Idaho National Laboratory. The use of these diverse natural parameters has provided valuable insight into the long-term hydraulic structure of the aquifer. In this region, aquifer recharge areas contain significantly different rock types compared to those of the plain itself. The differences in aquifer geology impart unique hydrochemical signatures to waters originating in the different recharge zones that can be tracked across the aquifer. In a similar manner, groundwater temperatures display regional differences that reflect differences in the recharge temperatures and the regional flow patterns. Lateral differences in groundwater temperature are interpreted to show the intrusion of cool plumes of recharge water into warm aquifer zones, the aerially abrupt warming of cool recharge plumes, and the threading of cold recharge plumes through warm areas of the aquifer along the northwest margin of the Eastern Snake River Plain. The combined use of groundwater temperature distribution and chemical/isotopic characteristics defines groundwater flowpaths at a level of detail not possible by other means.

INTRODUCTION

Since the earliest studies of the Snake River Plain aquifer (SRPA), researchers have recognized that the temperature and the chemical signature of groundwater are useful tools in characterizing the aquifer flow system (Olmsted 1965, Robertson et al 1974). A significant body of groundwater temperature, natural isotope, and chemistry data has been derived from several key geochemical studies conducted during the past decade (Johnson et al 2000, Luo et al 2000, Roback et al. 2001, McLing et al. 2002) These data provide an insight into the complex groundwater flow patterns within the SRPA at the Idaho National Laboratory (INL).

Because of the INL's proximity to the northern boundary of the Eastern Snake River Plain (ESRP), the flow and chemistry of groundwater at the INL are affected by several distinct sources contributing recharge to the system. These sources include irrigation, tributary basins for the Big Lost River, Little Lost River, and Birch Creek , the Mud Lake basin, and the largest contributor, the Yellowstone Plateau. Another source of water to the aquifer system is upwelling of thermal water emanating from deep within the ESRP

(McLing et al. 2002; Mann 1986). Because of the distinct chemical and thermal signatures of recharge waters from each of these sources, they provide natural tracers to elucidate patterns of regional groundwater flow that impact contaminant transport at the INL. These signatures also provide calibration targets for flow and transport models under development to ascertain cumulative groundwater risk from INL derived contaminants. Distributions of groundwater temperature, natural isotopes, and chemistry reveal coherent patterns that are derived from regional groundwater flow. Regional flow patterns revealed by aerial distributions of these natural parameters include preferential flow corridors, zones of slower flow, and zones of hydrothermal upwelling.

ISOTOPE-DELINEATED FLOW PATHS

Isotope and chemical tracer studies have shown that long-range (tens of kilometers) "fast paths" exist within the aquifer. These fast paths potentially could transport contaminants in groundwater down gradient more rapidly than expected from previous hydrologic analyses.

Isotopes of heavy elements such as those in the uranium and thorium series are powerful tools that can be used to identify physico-chemical, geologic, and hydrologic variables of groundwater systems. Because of their high atomic mass, these elements do not fractionate in natural systems. In rocks older than about 1 million years the ratios of U-234/U-238 are in secular equilibrium (5.49×10^{-6}). However, in groundwater, U-234 is typically enriched relative to U-238 by factors most commonly ranging from 1.5 to 10 because of preferential dissolution of U-234 from crystallographic defects and because of direct ejection of U-234 into groundwater by recoil (Osmand and Cowart 1992). Variations in U-234/U-238 in short-residence (ten to a few hundred years) waters, such as those in the SRPA, reflect the competing effects of U-234 enrichment processes and host rock dissolution, which will modify isotope ratios toward secular equilibrium values.

Strontium isotope ratios (Sr-87/Sr-86) in groundwater reflect the water-rock reaction histories and flow pathways of the water. Groundwater Sr-87/Sr-86 ratios are inherited from soil or rock through which the water passes. Both Sr-87 and Sr-86 are stable isotopes, but because Sr-87 is produced by radioactive decay of Rb-87 ($t1/2 = 4.8 \times 10^{10}$yr), the Sr-87/Sr-86 ratios of rocks and soils depend on their original Rb concentrations and their ages. Strontium isotopes are useful as groundwater tracers in a system like the ESRP, because the rock types in the recharge regions are different than the aquifer host rock. The strontium isotope ratio inherited from the recharge region will evolve toward isotopic equilibrium with

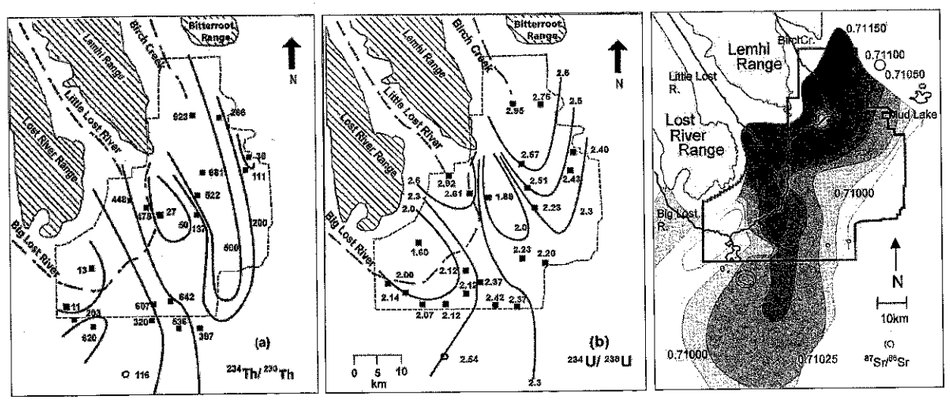


Figure 1. Distributions of (a) $^{234}Th/^{230}Th$, (b) $^{234}U/^{238}U$, and (c) $^{87}Sr/^{86}Sr$ activity rations in INL Site groundwater (after Luo et al. 2000 and Johnson et al 2000). Substitute our U map

the aquifer host rock. The rate at which this equilibration will occur is largely a function of the reaction rates and the amount of time that the groundwater is in contact with the aquifer host rock .

Groundwater from the SRPA in the vicinity of the INL has been analyzed for both uranium and strontium isotopes (Roback et al. 2001; Johnson et al. 2000; Luo et al. 2000). Contour plots of uranium and strontium isotope ratios (Figure 1) show that water entering the aquifer from the river valleys to the north has high Sr-87/Sr-86 (> 0.71100), U-234/U-238, and thorium values. In some areas, the high isotope ratios of this water persist 19 to 30.5 km (12 to 19 mi) into the aquifer along zones of preferential flow. In contrast, two zones have relatively low Sr-87/Sr-86, U-234/U-238, and Th-234/Th-238 ratios in the center of the INL , one near the southern extent of the Lemhi Range and one near the western boundary of the site near the southern end of the Lost River Range (Figure 1).

Fast flow paths of groundwater through the high-ratio zones and slow flow through the low-ratio zones provide an explanation for the isotope-ratio pattern. In this scenario, the high-ratio zones are interpreted as preferential-flow corridors containing groundwater with high strontium, uranium, and thorium ratios. High-ratio groundwater in these corridors is derived primarily from the tributary recharge zones northwest of the INL and persists far into the regional aquifer system. Groundwater in these corridors moves more rapidly then groundwater in adjacent areas and therefore has less time to react with the aquifer host rock (Roback et al 2001). In contrast, groundwater characterized by low isotope ratios has evolved until it is closer to the isotopic composition of the host rock. This evolution likely is a result of longer residence time and increased dissolution of the basalt host rock. Geochemical models and temperature profiles supporting this conclusion suggest that groundwater located at the toes of the Lost River and Lemhi Ranges is moving slower relative to flow in the rest of the aquifer (Luo et al. 2000), with calculated residence times for water in these "stagnant" zones ranging from 2 to 10 times longer than those in the high-isotope ratio zones.

HYDRAULIC HEAD VERSUS CHEMICALLY DEFINED FLOW PATHS

Since characterization of the SRPA began in the 1950's, little has changed with respect to the generally accepted northeast-to-southwest flow direction of the SRPA. However, as more wells have been drilled and more studies have been conducted, especially at the INL, it has become apparent that hydraulic head data do not provide sufficient detail to identify potential pathways of preferential flow delineated by the geochemical and isotopic studies. For instance, the regional hydraulic head gradient (Bartholomay et al. 1995) indicates that groundwater in the SRPA flows to the southwest. However, in places, the isotope-defined flow paths are at nearly right angles to the regional hydraulic head gradient (Roback et al. 2001; Johnson et al. 2000; Luo et al. 2000). This divergence indicates a strong, localized, geologic control on anisotropy in the aquifer. Isotope-delineated flow pathways are generally oriented in a northwest-to-southeast direction near the recharge zones, bending to the southwest farther downgradient in the regional flow system. This local-scale flow-path delineation is consistent with the distribution of contaminant plumes in groundwater at Test Area North and Idaho Nuclear Technology and Engineering Center. This delineation also is consistent with the orientation of primary volcanic features on the ESRP (Rodgers et al. 1990) and with the Welhan and Reed (1997) predictions of a preferred northwest-to-southeast orientation of hydraulic conductivity.

Determination of preferential flow from temperature and isotope data requires the assumptions that samples were representative of the entire aquifer thickness and that the density of data is sufficient to adequately define preferential flow corridors. However, because wells are limited in preferential flowpath

areas and because water samples used in this temperature and isotope study were collected from wells completed primarily in the upper part of the aquifer, it is not possible to make definitive statements about the cause or exact boundaries of the preferential flow corridors.

Groundwater Temperature and Flow Paths

Groundwater temperatures and borehole temperature profiles offer another window into the geometry of the SRPA and generally support the conclusions of the isotope-defined preferential flow path studies (Roback et al. 2001; Johnson et al. 2000; Luo et al. 2000). The ESRP has a very high heat flow (~110 mw/m^2), which is largely masked by the large volume of water in the upper aquifer. The cold, fast moving aquifer water acts like a large radiator efficiently sweeping heat down gradient and keeping it from reaching the surface in the form of hot springs. However, areas of the aquifer are characterized by anomalously high or low temperatures as shown in figure 2. Possible explanations for these anomalies are that groundwater in high temperature areas is moving very slowly allowing the high heat flow to affect the water, or that groundwater is moving very fast in low temperature areas, keeping the thermal signature at bay. For example, groundwater temperature at the top of the SRPA beneath the INL Site ranges from less than 8°C to more than 18°C (Figure 2). The coldest of this water correlates with the preferential flow corridors identified by Roback et al. (2001) and is associated with areas where cold recharge water moves rapidly through the system. In contrast, regions where water temperature is warmer generally correlate with the slower flow regions identified by the

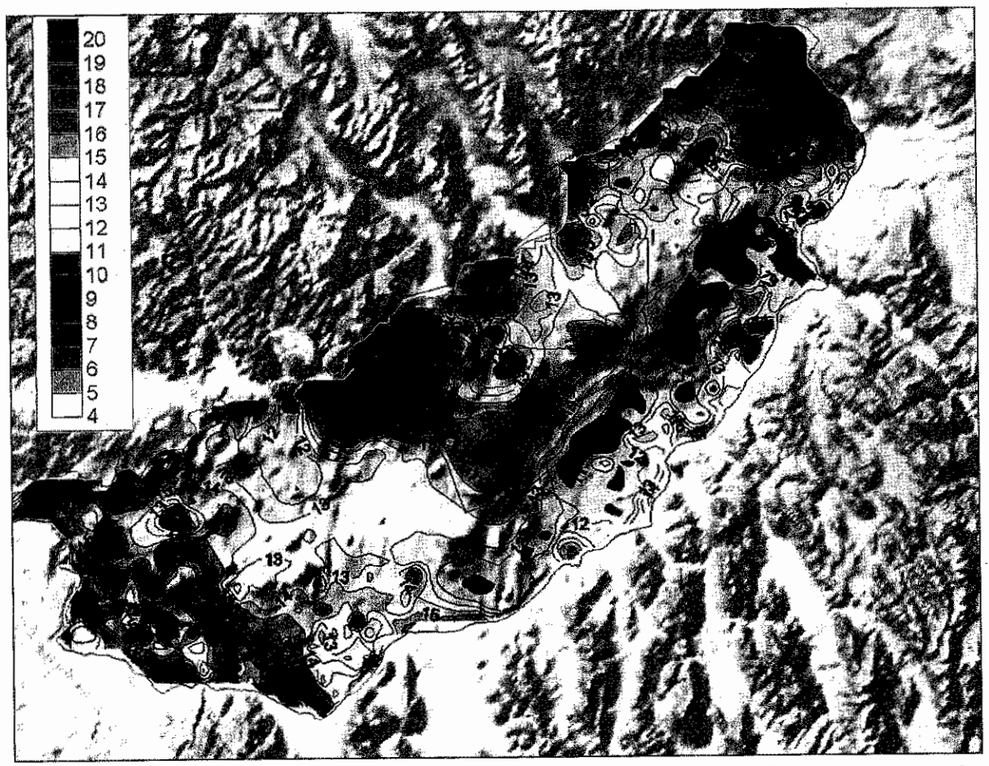


Figure 2. Groundwater temperature (°C) in the eastern SRPA, based on groundwater temperature data obtained from the NWIS Web Data for Idaho (http://nwis.waterdats.usgs.gov/id/nwis/nwis/).

previous studies (Luo et al. 2000; Roback et al. 2001). This correlation supports the conclusion that in areas where water temperature is higher, groundwater flow is slow enough that the thermal gradient of the ESRP overwhelms flow velocity.

McLing and Smith (2002) determined that upwelling thermal water is an active process that affects the upper aquifer water chemistry in the SRPA. They discovered that waters from deep in the ESRP have a distinct chemical signature different from that of the upper aquifer. While the upper aquifer is chemically a Ca-Mg-HCO_3 type water, the deep system is dominated by Na-K-HCO_3. Additionally, it was discovered that there is a continuum of water chemistry in the SRPA ranging from Ca-Mg- HCO_3 to Na-K-HCO_3 type water. The closer water was to a Na-K-HCO_3 type water, the more it had been influenced by thermal fluids emanating from depth. In general, these affected waters were located in areas with high thermal signatures (figure 2) and were associated with slow flow zone, providing additional support for the fast path model proposed by Roback et al. 2001; Johnson et al. 2000; Luo et al. 2000.

SUMMARY

Isotope and temperature data from the SRPA at the INL indicate that long-range fast flow paths transect the INL. The data also indicate that these fast paths transmit water down gradient at a rate 2-5 times faster than do the surrounding areas (Luo et al 2000). There is also some indication that these fast paths are manifested in areas where the active flow thickness of the SRPA is largest. Within these paths, the chemical signature of groundwater remains less equilibrated with the host rock and the groundwater temperature in these fast paths remains relatively cold. These characteristics are consistent with water that is moving rapidly down gradient and is not being equilibrated with the regional thermal regime. These conclusions indicate that the SRPA is a dynamic system, with groundwater flow controlled by a number of geologic factors, all of which combine to form a complex, heterogeneous system.

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Two-Dimensional Flow Model Development for the Idaho National Laboratory OU 10-08 Sitewide Groundwater Model

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ABSTRACT

A preliminary two-dimensional (2D), steady-state groundwater flow model was developed as an intermediate step in support of fully three-dimensional flow and transport numerical tools for the Idaho National Laboratory (INL) sitewide groundwater model. A total of 224 wells inside the model domain were used to calibrate the 2D flow model. Three different calibration techniques, zonation approach, pilot point approach and coupled zonation/pilot point approach, were explored and applied during the model development. The pilot point approach allows modelers to model aquifer heterogeneities at various scales, and extract the maximum amount of data from available monitoring data, permitting the best possible representation of flow and transport at the INL.

INTRODUCTION

A preliminary two-dimensional (2D), steady-state sitewide groundwater flow model was constructed for the INL Operable Unit 10-08 as an intermediate step in cumulative risk evaluation of INL-derived contaminants in groundwater. This article describes the development and calibration of this preliminary 2D model and discusses modeling results that demonstrate the necessity of developing fully three-dimensional numerical tools to adequately represent groundwater flow, contaminant transport, and cumulative risk to groundwater within Operable Unit 10-08.

DEVELOPMENT OF THE 2D FLOW MODEL

The computer codes used to develop the 2D flow model consisted of the MODFLOW-2000 (Harbaugh et al. 2000) groundwater flow simulation code, the PEST (Doherty 2005) parameter estimator, and the Groundwater Modeling System (GMS) (BYU 2003) pre- and post-processor and data analyzer. The following subsections summarize the implementation of the conceptual model into a 2D steady-state numerical flow model using GMS/MODFLOW-2000/PEST.

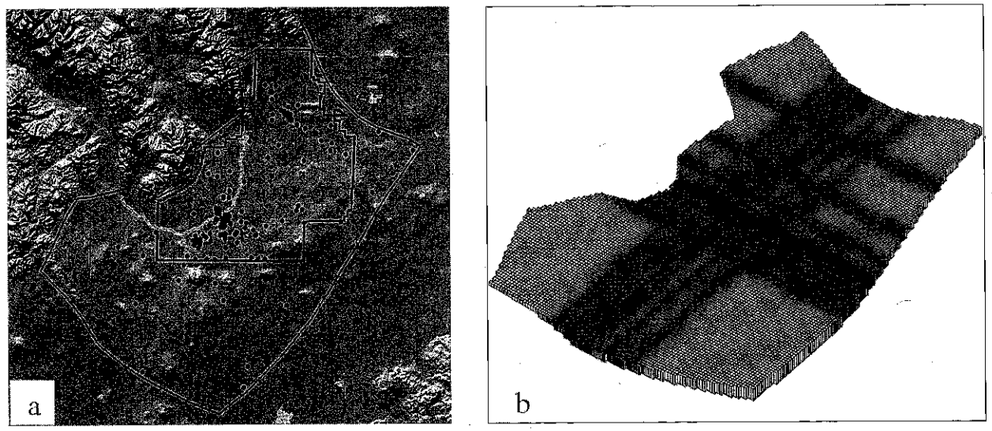


Figure 1. (a) The model domain boundaries and locations of calibration wells; (b) model grid of the 2D flow model

MODEL DOMAIN/BOUNDARY CONDITIONS AND CALIBRATION WELLS

Figure 1a shows the model domain implemented in the 2D flow model. The northeastern and southwestern boundaries of the OU 10-08 model domain were treated as specified head boundaries. Head values along these two specified head boundaries were derived from the June 2004 water table map. The southeastern boundary of the model domain corresponded to an estimated groundwater flow line across which no flow occurs. The model domain was bounded on the northwest by a Type 2 boundary (part no-flow and part specified-flux) that represents mountain ranges and the mouths of significant tributary streams.

The major sources of inflow to the flow model included regional underflow across the northeastern boundary, underflow from the adjacent tributary drainage basins to the northwest, infiltration recharge from the Big Lost River, and precipitation recharge (see Orr et al. 2006, this issue). Subsequent investigations will include comparison of estimated regional underflow volumes to simulated underflow across the northeastern specified-head boundary.

Figure 1a also shows the locations of all 224 wells that provided head measurements used in the calibration. At this preliminary stage of model development, all head measurements at these 224 wells were assigned an equal weight of 1. Because a larger number of wells are clustered in the vicinities of main facilities inside the INL, such assignment of equal weights to all wells effectively gives more weights to wells inside the INL. This is desirable since we are more interested in the flow and contaminant transport inside the INL.

CONSTRUCTION OF THE 2D NUMERICAL GRID

Figure 1b shows the numerical grid of the 2D flow model, consisting of a single layer with variable thickness derived from thickness estimates as defined in the conceptual model (see Orr et al. 2006, in this volume). The grid is refined near facilities inside the INL in order to capture some important local-scale features. The grid cell dimensions had a minimum size of 492 ft (150 m) near nine individual Waste Area Groups, and a maximum size of 2,460 ft (750 m) elsewhere inside the model domain. Such discretization resulted in a total of 53,658 grid cells.

CALIBRATION APPROACHES

Three calibration techniques (zonation, pilot point and coupled zonation/pilot point) were tested in the development of the 2D flow model. All three calibration techniques were implemented with PEST (Doherty 2005), an automated parameter estimator.

The zonation approach is a traditional method of calibration. This approach divides the model domain into zones of constant hydraulic conductivity, then adjusts the hydraulic conductivity values uniformly within zones to minimize the mismatch between the model simulated and measured heads at all calibration wells. The intent of this approach is to honor major geologic features that may affect groundwater flow within the area represented by the model domain.

The pilot point approach is a more numerically advanced inverse modeling technique. Instead of dividing the model domain into a number of zones, a number of "pilot" points are positioned within the model domain, then hydraulic conductivities at these pilot points are adjusted to minimize the mismatch between model simulated and measured heads. The hydraulic conductivities of each model grid cell are interpolated from the conductivity values at all pilot points via inverse distance weighting or Kriging. This approach does not necessarily incorporate known geologic features that affect groundwater flow.

The coupled zonation/pilot point approach takes advantage of both approaches. In this coupled approach, the model domain is first divided into different zones. Then within each zone, a set of pilot points is distributed and the hydraulic conductivity values of grid cells located within a particular zone are interpolated from the pilot points within the same zone, resulting in the capability to vary the hydraulic conductivity within each zone. The coupled pilot-point/zonation approach should provide a good combination of the large-scale heterogeneity (from zone to zone) and local-scale heterogeneity (inside a zone).

Table 1. Statistics of the residuals (in meters) between measured and model simulated heads.

	Zonation	Pilot point	Coupled zonation/pilot point
Mean Error	0.240	-0.246	0.054
Mean Abs. Error	1.521	0.488	0.273
Root Mean Sq. Error	3.069	0.684	0.413

CALIBRATION RESULTS

Table 1 summarizes residual statistics between the measured and simulated heads in the OU 10-08 model domain, as obtained from the three calibration approaches. As shown in Table 1, the zonation approach provided the worst fit to the measured heads, while the coupled approach provided the best fit. The pilot point approach also provided a good fit to the measured heads, compared with the zonation

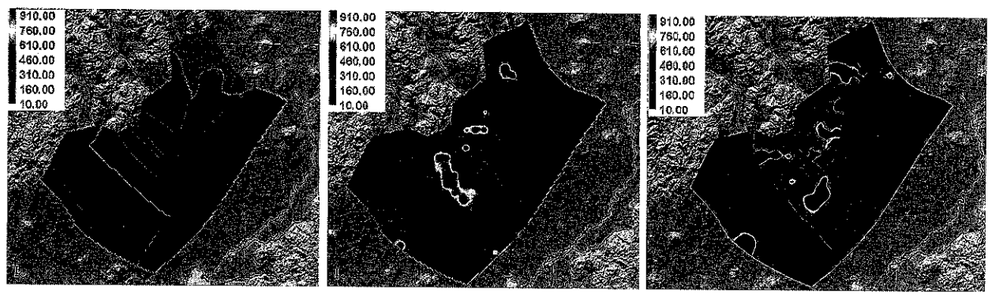


Figure 2. The estimated hydraulic conductivity fields obtained by three approaches: (left) zonation; (middle) pilot point; and (right) coupled zonation/pilot point.

approach. However, simple comparison of residual statistics alone was misleading. A more definitive comparison required evaluation of the reliability of the estimated parameters.

Initially, reliability of the estimated parameters were qualitatively evaluated by comparing the parameter field to known geological features within the model domain. Figure 2 shows the hydraulic conductivity fields obtained by three calibration approaches. The most significant result from this comparison was that the pilot point approach provided the conductivity field most consistent with the known large-scale geological features inside the model domain (Helm-Clark, 2006, this volume).

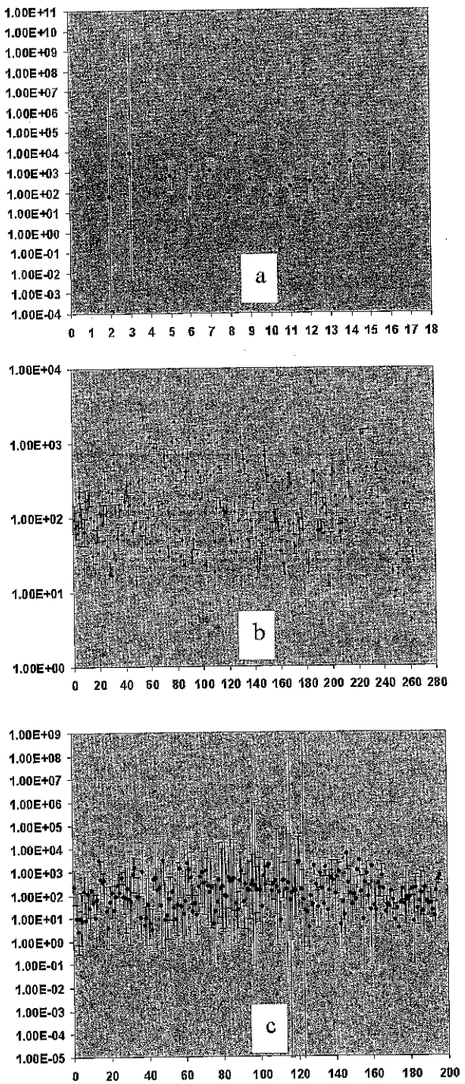


Figure 3. The 95% confidence bounds of the estimated hydraulic conductivities. (a) zonation approach; (b) pilot point approach; and (c) coupled zonation/pilot point approach.

Given the nonuniqueness nature of almost all subsurface inverse simulation problems, it is always worthwhile to examine the variabilities of the estimated parameters using the parameter covariance matrix which is obtained by PEST during inversion. The diagonal terms of the parameter covariance matrix are the variances associated with parameters. Using the assumption of Gaussian distribution, the 95% confidence bounds associated with each estimated parameter can then be calculated from the parameter variance. In general, the smaller are the confidence intervals, the more likely the inverse solution approaches to a unique solution. More importantly, the confidence intervals are important indicators of the relative sensitivities of estimated parameters. Extremely sensitive parameters (small intervals) and extremely insensitive parameters (large intervals) will cause serious convergence problems to the inverse procedure. Ideally, all parameters should have similar sensitivities. Figure 3 shows the 95% confidence intervals of the estimated hydraulic conductivities for the three calibration approaches.

Both the zonation approach and the coupled approach exhibited very large confidence bounds of several orders of magnitude difference between the upper and lower bounds, indicating that the estimated conductivity fields using these two approaches were highly uncertain. However, the confidence bounds for the pilot point approach were much narrower, and most bounds were less than 1 order of magnitude, indicating the parameter field estimated by this approach was more reliable.

CONCLUSIONS

The objectives of developing this preliminary 2D flow model were to better understand the hydrologic influence of regional and local-scale features, to investigate the validity of various calibration approaches, and to investigate the feasibility of using all available wells as calibration wells as an intermediate step in development of a fully three-dimensional numerical tool.

Although the preliminary 2D modeling results (primarily the pilot-point approach) proved to be satisfactory in terms of meeting the above objective, this 2D model had some important limitations, particularly in the area of accurately addressing the vertical dimension of contaminant transport problems.

Although we represented variable aquifer thickness in the 2D model, the distributions of hydraulic conductivity and head were assumed to be the same in the vertical dimension. Therefore, the estimated hydraulic conductivity field and simulated distribution of head represented averages across the entire aquifer thickness. However, strong evidence exists that the vertical heterogeneity of the aquifer may control potential vertical flow within the system.

In addition, the averaged hydraulic properties represented by the 2D model precluded representation of the "preferential" flow path identified through geochemical and isotope studies in the INL Site. This preferential flow path again may have an important impact on the transport of contaminants. One hypothesis is that the preferential flow path observed from geochemical information may be a feature occurring only within the upper portion of the aquifer, while the 2D model only addressed the lumped (averaged) effect across the entire thickness of the aquifer. Only a three-dimensional model can incorporate such vertical heterogeneity in order to test this hypothesis.

Evidence presented elsewhere (Johnson et al, 2000; Luo et al, 2000; Roback et al, 2001) and recent water chemistry data from newly constructed multiport sampling wells indicate that contaminants are preferentially transported in the upper portion of the aquifer and in narrow flow pathways. However, the two-dimensional model was capable only of the assumption of uniform concentrations across the entire thickness of the aquifer. Thus, contaminant flux entering the aquifer immediately mixes (or dilutes) in the vertical direction across the full thickness of the aquifer. This leads to an unrealistic underestimate of contaminant concentrations in the 2D model.

Based on results of this preliminary 2D flow model, we conclude that a fully three dimensional model is required to accurately depict and predict contaminant transport in groundwater within the SRPA. This numerical tool must be able to adequately incorporate both horizontal and vertical heterogeneities at various scales.

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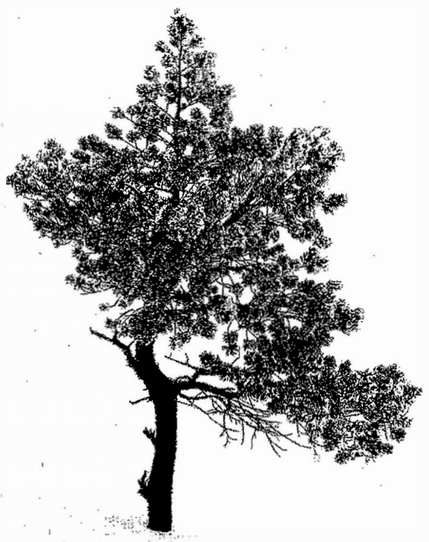




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Potential Controls on Temperature in the Snake River Plain Aquifer Examined with a Simple 2-D Numerical Heat Flow Model

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ABSTRACT

The Idaho Cleanup Project (ICP) and the Idaho National Laboratory (INL) are conducting a heat flow study of the Snake River Plain aquifer (SRPA) to help constrain aquifer properties for contaminant transport modeling at the site. Here, a simple model similar in scale and boundary conditions to the SRPA illustrates how a variety of aquifer properties and boundary conditions might affect the 2-D temperature distribution along a hypothetical cross-section of the aquifer. Results illustrate that changes in temperature along a flow-line are largely controlled by the horizontal groundwater flux, and that vertical temperature gradients are very sensitive to the transverse dispersivity parameter. Conversely, temperature distribution is relatively insensitive to longitudinal mixing behavior because of the great length of the system. Overall, the preliminary modeling demonstrates that groundwater temperatures provide an excellent means of refining large-scale aquifer flow and transport properties.

INTRODUCTION

One of the aims of the current ICP/INL modeling study of groundwater flow and transport in the Snake River Plain aquifer (SRPA) beneath the Idaho National Laboratory (INL) is to exploit non-traditional data sources to help constrain aquifer properties. Accordingly, we are conducting groundwater heat flow modeling to quantitatively relate the observed groundwater temperature distribution to groundwater flow and transport characteristics of the aquifer. Although numerous thermal investigations of the Snake River plain have been conducted (eg. Brott et al. 1981; Blackwell 1983; Ziagos and Blackwell 1986), most of those studies have focused on the tectonic implications of the observed temperature distribution. This study focuses on how the horizontal and vertical movement of water affects temperature distribution in the aquifer, and how that information can be used to better constrain hydrologic conditions.

Previous studies (Brott et al. 1981) emphasize the importance of horizontal

groundwater flow in controlling temperatures in the aquifer. The potential for free convection in the system, and the role it may play in controlling temperatures, appears not to have been addressed. The potential for free convection in groundwater systems can be assessed by calculating the Rayleigh number, a dimensionless number that expresses the ratio of thermal energy transport by free convection to transport by heat conduction:

$$N_{Ra} = \frac{g \cdot \rho_0 \cdot c_w \cdot \rho_w \cdot L \cdot k \cdot \alpha_w \cdot \Delta T}{\mu_w \cdot \kappa_{eff}} \quad (1)$$

where

- g = gravitational acceleration constant
- ρ_0 = water density at a specified background temperature
- c_w = the specific heat of water
- ρ_w = water density
- L = aquifer thickness
- k = intrinsic permeability
- α_w = coefficient of volume expansion
- ΔT = temperature difference across the system
- μ_w = dynamic viscosity of water
- k_{eff} = effective thermal conductivity.

Analysis indicates that free convection in groundwater does not occur until the Rayleigh number exceeds ~40 (Lapwood 1948), and that this is unchanged by forced convection in the horizontal direction (Prats 1966). Assuming a temperature gradient (~0.07°C m^{-1}) similar to that observed in the subaquifer in one of the deep wells installed at the site (Middle-1823),

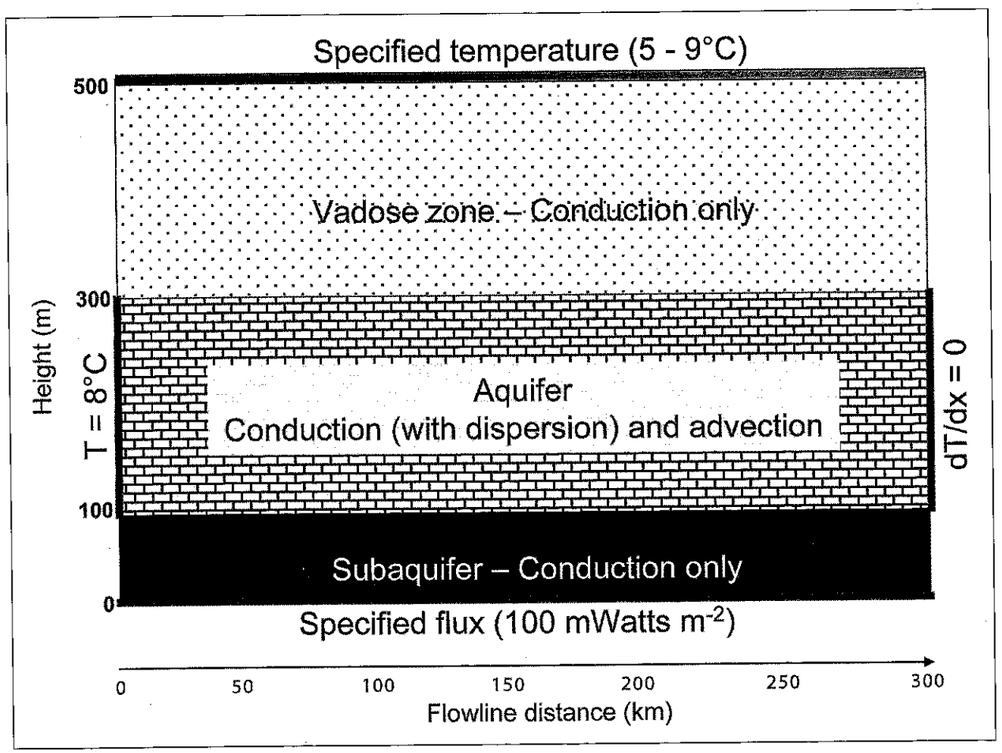


Figure 1. Schematic representation of the two-dimensional heat transport model. Numbers along abscissa and ordinate axes represent distance in kilometers and meters, respectively.

an aquifer thickness of 200 m, and typical values for water at 15°C for the remaining parameters, the Rayleigh number for the SRPA exceeds 40 where the hydraulic conductivity is greater than ~6 m day^{-1}. The transmissivity of the SRPA ranges from 0.1 to 71,000 m^2 day^{-1} (Ackerman 1991). The implied hydraulic conductivity range, again assuming an aquifer thickness of ~200 m, is 5 x 10^{-4} m day^{-1} to 350 m day^{-1}. Previous studies indicate that flow velocities in the aquifer average ~3 m day^{-1} (e.g. Robertson, 1974), that the average hydraulic gradient is ~0.0019 (Wood and Low, 1986) and that porosity is typically about 0.05. Those values suggest that hydraulic conductivity values of ~80 m day^{-1} are common in the aquifer.

While these data suggest that free convection is possible, vertical temperature gradients across the aquifer are also influenced by the aquifer recharge rates and by the degree of vertical mixing that occurs via advection and dispersion. Such effects likely eliminate the vertical temperature gradients necessary to initiate free convection. As a preliminary exploration of the effects of forced convection on vertical temperature gradients, neglecting free convection, we conducted a set of simple modeling experiments with a two-dimensional block model scaled to reflect average dimensions of the SRPA.

MODELING APPROACH

Using the MATLAB PDE Toolbox, we constructed a three-layer model of the system comprised of a 200-m thick vadose zone, a 200-m thick aquifer, and a 100-m thick subaquifer (Figure 1). Stratigraphic differences are represented by differences in effective thermal conductivity, advective velocity, and boundary conditions. The PDE Toolbox solves the steady-state convection-dispersion governing equation (eq. 2) using the finite element method, with Gauss-Newton iteration.

$$\left[\frac{\partial}{\partial x}\left(k_{eff}\frac{\partial T}{\partial x}\right)+\frac{\partial}{\partial y}\left(k_{eff}\frac{\partial T}{\partial y}\right)\right]-\left[\frac{\partial}{\partial x}\left(C_w q_x T\right)+\frac{\partial}{\partial y}\left(C_w q_y T\right)\right]=0 \quad (2)$$

where the effective thermal conductivity, κ_{eff}, is defined as

$$\kappa_{eff} = \kappa + \alpha_i q_x C_{eff} \quad (3)$$

where

- κ = thermal conductivity of the solid matrix
- α_i = dispersivity, in direction i (longitudinal or transverse)
- q_x = flux density of water in the x direction
- C_{eff} = effective heat capacity of the solid/water matrix.

We assumed a thermal conductivity of the solid/water matrix, κ, of 1.9 J m^{-1} sec^{-1} K^{-1}; an effective heat capacity, C_{eff}, (solid + water), of 2.3 × 10^6 J m^{-3} K^{-1}; and a heat capacity for water, C_w, of 2.1 × 10^6 J m^{-3} K^{-1}. The flux density, q_x, was calculated from the average groundwater velocity assuming a porosity of 0.05. The dispersion coefficients, α_L and α_T, for dispersion of heat in the horizontal and vertical directions, respectively, are described below.

The model broadly represents a vertical cross section along a flowline through the ESRP, extending from the edge of the Yellowstone Plateau to the Snake River near Thousand Springs, a distance of ~300 km. In the aquifer layer, a uniform groundwater velocity of 3 m day^{-1} is assumed. The advective term is zero in the other layers. A heat flux of 100 mWatts m^{-2} is specified along the bottom boundary. The fixed temperature along the top boundary increases linearly with distance, from 5°C to 9°C, simulating the average annual air/ground temperature distribution (Spatial Climate Analysis Service). Based on groundwater temperature data (USGS 2000), the groundwater temperature on the recharge boundary was fixed at 8°C. The discharge boundary is a zero-gradient condition, where heat flux equals that advected across the boundary. All other boundaries are zero-flux boundaries.

RESULTS

A base case simulation that includes longitudinal and transverse (vertical mixing) dispersivities of 1 m and 0.1 m, respectively, describes a temperature distribution (Figure 2a) with several similarities to previous descriptions (Smith, 2002, Brott, et al. 1981) of temperature

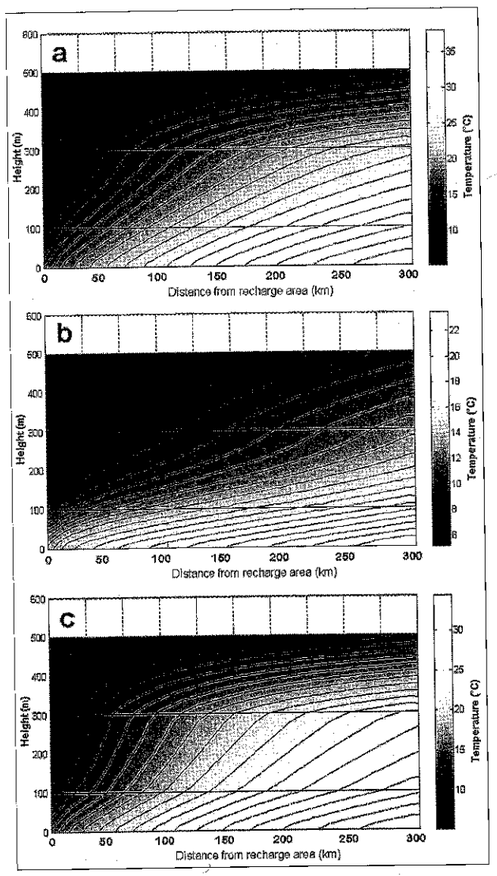


Figure 2. Simulated temperature distributions for the model depicted in Figure 1 for four scenarios described in the text: (a) the base case simulation, with α_L = 1 m, α_T = 0.1 m, v = 3 m day^{-1}; (b) the effect of a 5-fold increase in horizontal groundwater velocity, with the higher α_L, but without a concomitant increase in vertical dispersion (base case with α_L = 100 m, v = 3 m day^{-1}), and (c) the effect of a slight increase in the transverse dispersivity term, base case condition with α_L = 100 m and α_T = 10 m. Temperature scales are shown to the right of each plot.

trends along a flowline in the SRPA. First, the effect of advection is clearly evident in the substantial horizontal gradient that develops as cold water injected at the boundary is gradually heated along its flowpath. At much lower velocities, the horizontal temperature distribution is nearly isothermal. Second, vertical temperature gradients throughout the system are negative (temperature decreasing with elevation), because the specified recharge temperature is warmer than the mean annual air temperature in the recharge area and downgradient heating is sufficient to maintain that relationship. This differs from results of Brott et al. (1981) because they assumed groundwater temperatures in the recharge area were colder than the overlying ground temperature.

Temperature profiles through the active portion of the aquifer are commonly nearly isothermal and the transition to strong vertical gradients at depth is interpreted as indicative of the top of the less conductive subaquifer (Smith, 2002). Near-isothermal vertical gradients in the base-case simulation, however, exist only very near the recharge zone and little contrast exists in the gradient between the aquifer and subaquifer anywhere in the system. Discharge temperatures in this base case simulation (>25 to 30°C) are also considerably warmer than observed temperatures (approximately 15°C) at the recharge area. These differences suggest either that the specified heat transport parameters (boundary conditions, thermal conductivities, advective velocity, and dispersivities) are incorrect or that this highly simplified model does not adequately capture the processes important to temperature control along a flowline through the aquifer. While both are certainly true, the sensitivity of the system to first-order heat flow processes is instructive, and we now examine how changes to some of these parameters affect the simulated temperature distribution, particularly the vertical temperature distribution in the aquifer.

Previous studies (Robertson, 1974; Goode and Konikow, 1990b) indicate that longitudinal

dispersivities in the system are on the order of 90 m in the aquifer beneath the INL. Combined with high seepage velocities observed, the resulting mechanical dispersion is large even when compared with the relatively rapid process of heat diffusion. To examine the impact of this mixing process on the 2-D temperature distribution, we conducted simulations with several orders magnitude larger effective horizontal thermal conductivity. Including a longitudinal dispersivity of up to 1000 m in the simulation has an insignificant effect on the large-scale temperature distribution, primarily because the mixing scale is still small compared to the length of the system and the resulting horizontal temperature gradients in the first term of equation 2 are small.

The horizontal advective velocity is an important control on the 2-D heat distribution, as the ratio of the water flux to the vertical heat flow from below largely dictates the magnitude of the heating effect. Increases in velocity, however, also affect mixing, as mechanical dispersion is assumed proportional to seepage velocity. To separate the effect of increased vertical mixing from increased horizontal velocity, we simulated a five-fold increase in horizontal velocity without changing the effective thermal conductivity along the vertical axis. The increased velocity (Figure 2b) yields a significant reduction in temperatures along the flow-line, and discharge temperatures of ~15° to 18°C, demonstrating how temperatures can very effectively constrain groundwater fluxes. While this simulation shows weaker vertical gradients in upgradient areas, it also produces stronger gradients in the discharge area and throughout the subaquifer. This suggests if nearly isothermal vertical profiles exist throughout the system, they are not simply a product of large horizontal groundwater fluxes.

Vertical mixing within the aquifer could be the result of mechanical dispersion transverse to the general direction of groundwater flow. In the base case simulation, the transverse dispersivity is set to 0.1 m, one tenth of the longitudinal dispersivity. Increasing longitudinal dispersivity to that estimated from previous studies, 90 m, but also maintaining the 10:1 ratio of longitudinal to transverse dispersivity, demonstrates that vertical gradients are very sensitive to transverse dispersivity (Figure 2c). In this example, temperature gradients in the aquifer are nearly isothermal along the entire flowline, contrasting markedly with the underlying and overlying vertical gradients. Previous modeling studies (Robertson 1974; Goode and Konikow 1990b) indicate that transverse dispersivities (in the horizontal plane) are much larger than is commonly expected (i.e. $\alpha_T > \alpha_L$); it is possible that dispersivity effects on vertical mixing are also larger than expected. This example demonstrates that the isothermal profiles commonly observed in SRPA wells might be excellent indicators of the degree of vertical mixing occurring along a flow path and thus provide a means of constraining the large-scale 3-D dispersivity of the system.

SUMMARY

Rayleigh numbers calculated for the SRPA indicate that free convection is possible and this suggests that heat flow modeling of the system should consider the potential feedbacks between heat flux and groundwater flow. This preliminary modeling study neglects those effects in order to provide a simple demonstration of the sensitivity of groundwater temperature to other controls on heat transport in groundwater. Results demonstrate that changes in groundwater velocity and longitudinal and vertical mixing behavior have very different effects on the large-scale temperature distribution of the system.

Essentially isothermal portions of vertical temperature profiles in deep wells in the eastern SRP have been used to identify the bottom of the active aquifer. These results suggest that the high flux of water through the SRPA is probably not sufficient to produce such profiles throughout the system. Vertical mixing, due to vertical groundwater flow or mechanical dispersion, may provide a more likely explanation. We conclude that more detailed

heat transport modeling should be a valuable means of estimating vertical mixing behavior throughout the aquifer, as well as provide an excellent means of estimating groundwater velocities over large areas where aquifer properties are otherwise constrained only by the limited head data available.

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Using a Response Surface Model to Simulate Contaminant Transport in the Snake River Plain Aquifer at the Idaho National Laboratory

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ABSTRACT

A response surface model for the Snake River Plain Aquifer was developed and tested for contaminant sources at Idaho National Laboratory. A response surface model uses the convolution integral method coupled with source-receptor response functions and contaminant source loading to estimate contaminant concentrations within the groundwater modeling domain. The approach retains most of the complexity of the fluid flow and transport modeling performed using detailed numerical models, although some simplifying assumptions are necessary. The computational resources required for contaminant transport simulations are substantially reduced allowing for rapid assessment of multiple contaminants and multiple sources. The model was demonstrated using source-receptor functions developed from a two dimensional MODFLOW/MT3DMS simulation of the Snake River Plain Aquifer and a tritium source.

INTRODUCTION

Numeric models of groundwater flow and transport can be time consuming and resource intensive to run even on modern computing systems. This is especially true if many contaminant sources and multiple contaminants are simulated. Furthermore, changes in source loading rates require rerunning the contaminant transport model to obtain updated simulation results. A method is implemented to reduce the computational requirements for simulation of multiple contaminants and multiple contaminant sources in an aquifer system.

This implemented method is based on the response function introduced in Gorelick 1983. It uses the convolution integral coupled with source-receptor response functions and contaminant fluxes to the aquifer to estimate groundwater concentrations at selected receptor locations in the groundwater modeling domain. The entire process is termed response surface modeling. The approach retains most of the complexity of the flow and transport modeling performed using detailed numerical models, although some simplifying assumptions are necessary. Response surface modeling can be useful also as a management and decision-maker tool to quickly evaluate the remediation alternatives that impact the mass of contaminants entering the aquifer.

METHODOLOGY

Consider the model domain illustrated in Figure 1. There are three sources within the domain. Multiple contaminants may exist in each source. Each source has a "footprint" where contaminants from the vadose zone enter the aquifer. Eight receptor locations are defined in the model domain. These locations can represent existing wells, future wells, and

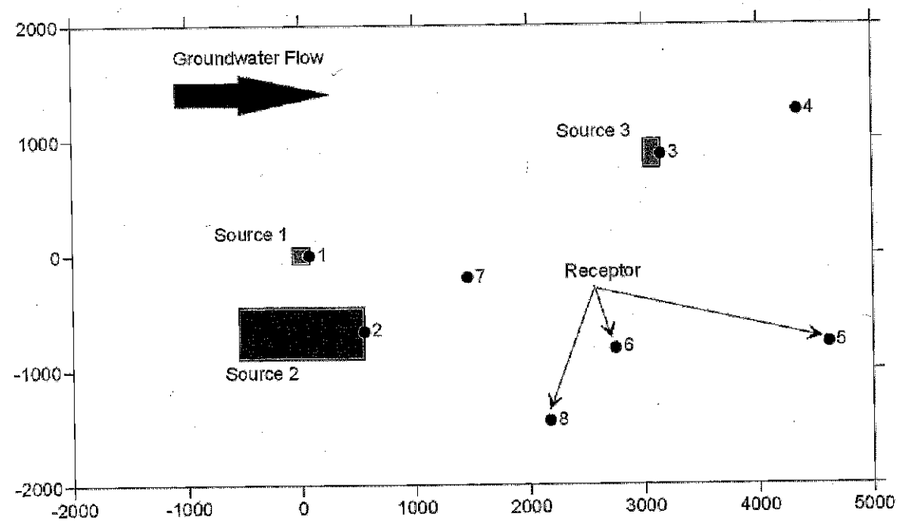


Figure 1. Hypothetical aquifer domain for illustration of the response surface model. The problem has three contaminant sources and eight receptor locations.

points of interest in the aquifer. For example, receptors 1, 2, and 3 do not represent actual wells, but are situated at points in the aquifer where the maximum contaminant concentration in groundwater from an individual source is found.

The response function represents the breakthrough curve at each receptor to a unit mass input from each source. For Source 3, only three response functions are needed (for receptors 3, 4, and 5) because the remaining receptors (receptors 1, 2, 6, 7, and 8) are upgradient from Source 3 and are therefore unaffected by releases from the source. In this case, the response function for the upgradient receptors is zero for all time with respect to Source 3. The response function for each source with respect to each receptor is determined using a detailed groundwater flow and transport model and represents the concentration in the aquifer as a function of time for a conservative, non-decaying, non-sorbing tracer of unit mass that is instantaneously released to the aquifer over the source footprint.

The contaminant loading rates to the aquifer (i.e. the contaminant mass flux to the aquifer) is described by a tabular function of time and mass flux. Contaminant fluxes can represent output from a vadose zone flow and transport model or anthropogenic sources released directly into the aquifer. Contaminant loading rates must be developed for each source-contaminant combination. All contaminant release times are synchronized to a common reference time.

The contaminant concentration in the aquifer at a given receptor location is obtained by the convolution of the contaminant loading rates and the response function. That is, concentration in the aquifer can be represented by a series of individual "pulses" where the magnitude of the pulse is equal to the product of the source-loading rate at a given time, the response function at some time thereafter, and a time step. When summed together, the individual pulses form a continuous function of concentration over the time period of interest. The contaminant concentration is given by:

$$C_{i,j,k}(t) = \int_0^t RF_{i,j}(t-\tau) S_{i,k}(\tau)\, d\tau \qquad (1)$$

where

$C_{i,j,k}(t)$ = aquifer concentration of contaminant k at time t for source i and receptor j ($M\,L^{-3}$)

$RF_{i,j}(t\text{-}\tau)$ = response function for source i and receptor j at time $t-\tau$ (L^{-3})

$S_i(\tau)$ = contaminant-loading rate for contaminant k and source i at time τ ($M\,T^{-1}$)

i = source index

j = receptor index

k = contaminant index

Equation (1) is valid for a non-decaying, non-sorbing contaminant. The quantity $t-\tau$ is the "age" of the pulse. To account for the decay and sorptive properties of different contaminants, and decay and ingrowth of radioactive progeny, several simplifying assumptions are made: (1) Retardation is uniform throughout the aquifer, (2) Decay is constant throughout the aquifer, (3) Parent and progeny travel at the same rate in the aquifer.

The aquifer concentration for a decaying and sorbing contaminant that may generate decay products in transit is given by:

$$C_{i,j,k(m)}(t) = \frac{1}{Rd_m}\int_0^t RF_{i,j}\left(\frac{t-\tau}{Rd_{m=1}}\right) S_{i,k(m=1)}(\tau)\, DIF_m(t-\tau)\, d\tau \qquad (2)$$

where

$C_{i,j,k(m)}(t)$ = concentration of decay product m at time t for source i and receptor j ($M\,L^{-3}$)

$RF_{i,j}(t\text{-}\tau)$ = response function for source i and receptor j at time $t-\tau$ (L^{-3})

$S_{i,k(m=1)}(\tau)$ = source-loading rate of parent (m=1) for source i at time τ ($M\,T^{-1}$)

Rd_m = the retardation factor for product m, [m=1 for parent] (unitless)

DIF_m = decay-ingrowth factor for decay product m at time $t-\tau$ (unitless)

$k(m)$ = decay product index [m=1 for parent] for contaminant k.

$t-\tau$ = the time since release to the aquifer of the contaminant mass

The decay-ingrowth factor is the activity of decay product m present at time $t-\tau$ relative to the original parent activity released at time τ. The sub-index m relates to the decay chain where m = 1 for the parent. For a single decay species with no progeny, the decay ingrowth factor is simply $e^{-\lambda t}$ where t is the age of the pulse (i.e., $t-\tau$). For a decay product other than the parent, the decay-ingrowth factor is given by:

$$DIF_m(t) = \frac{\lambda_m}{\lambda_{m=1}}\left[\left(\prod_{i=1}^{m-1}\lambda_i\right)\sum_{i=1}^{m}\frac{e^{-\lambda_i t}}{\prod_{\substack{j\neq i\\ j=1}}^{m}(\lambda_j-\lambda_i)}\right] \qquad (3)$$

where

$\lambda_{m=1}$ = decay constant for the parent = $\ln(2)/T_{1/2}$ where $T_{1/2}$ is the half life (T^{-1})

λ_m = decay constant for the mth progeny (T^{-1})

t = age of pulse (T).

The total contaminant concentration from all sources is evaluated by superposition of each source-receptor pair. The contaminant concentration at a given receptor location from multiple sources is the sum of the concentration from each individual source.

$$C_{j,k}(t) = \sum_{i=1}^{n} C_{i,j,k}(t) \qquad (4)$$

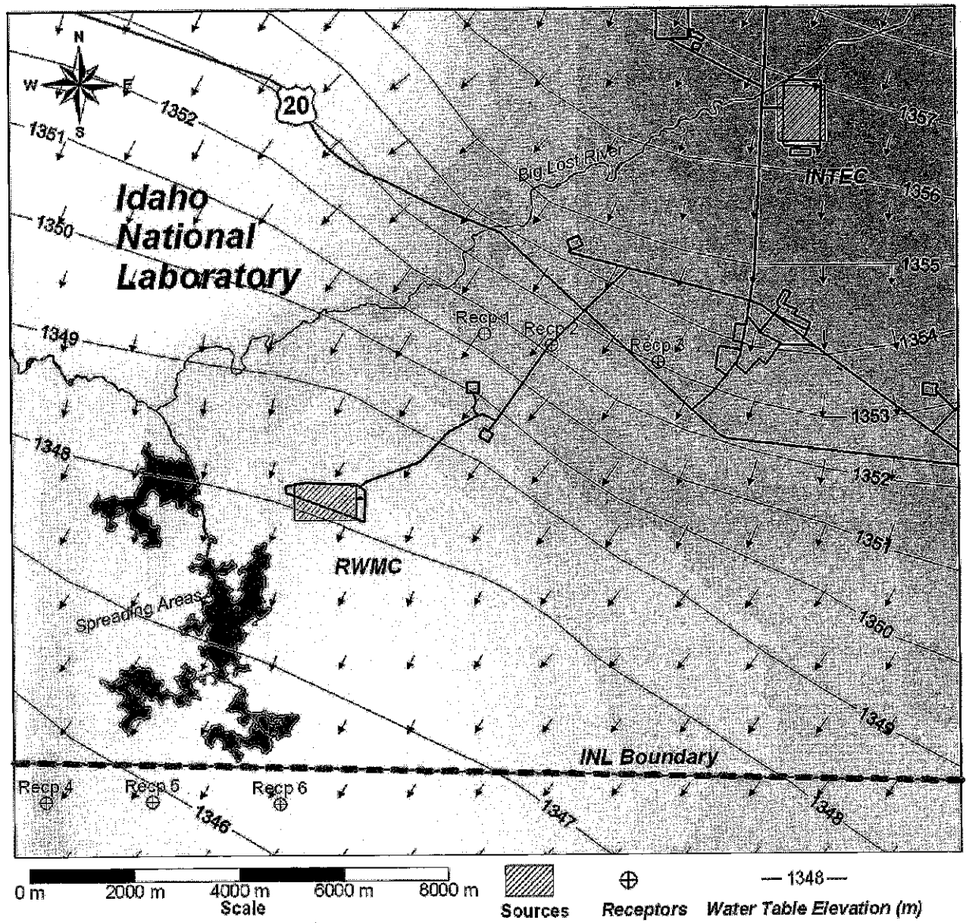


Figure 2. Map of the southern portion of the Idaho National Laboratory showing the location of the Radioactive Waste Management Complex (RWMC) and the Idaho Nuclear Technology and Engineering Complex (INTEC). Six receptor locations are used in the sample application of the response surface model. Water table surface (in meters) and gradient (arrows) are also shown.

Where

n = number of sources considered in the model domain

j = receptor index

i = source index

k = contaminant index

APPLICATION TO THE SNAKE RIVER PLAIN AQUIFER

The response surface model was applied to the Snake River Plain Aquifer (SRPA) system underlying the Idaho National Laboratory (INL) located in eastern Idaho (Figure 2). Response functions to instantaneous unit inputs (Figure 3) were developed with the OU 10-08 Project from a two dimensional MODFLOW/MT3DMS simulation. Tritium (3H, half-life = 12.3 years) fluxes to the SRPA from sources at

the Idaho Nuclear Technology and Engineering Center (INTEC) and the Radioactive Waste Management Complex (RWMC) were used with the response functions and the convolution integral to calculate aquifer concentrations at six downgradient receptor locations.

Historical releases of tritium at INTEC have occurred since 1952 and significant quantities of tritium have been disposed of at the RWMC. However, tritium source-loading rates for INTEC and RWMC (Figure 3) were only used to demonstrate the model and do not necessarily represent the current or best understanding of tritium releases from INL facilities. The OU 10-08 MODFLOW domain encompasses approximately 7,770 km2 of the eastern Snake River Plain. The domain is elongated in the southwest-northeast direction and is bounded by the Lemhi, Lost River, Pioneer, and Bitterroot mountain ranges in the northwest, and in the southeast by the groundwater flow path defined in previous groundwater studies (Garabedian 1992; Ackerman 1995). The southwest and northeast boundaries do not represent a natural geohydrologic boundary. Rather, these boundaries were chosen to run perpendicular to groundwater flow at sufficient distances down and upgradient from the INL to minimize effects in areas of interest. The model was calibrated to water-level data collected in June of 2004 (Wood et al., 2005).

Concentration time histories (Figure 4) show that receptor 5 had the highest tritium concentration, which is consistent with what would be expected based on examination of the response functions plotted in Figure 3. The primary source for receptor 5 is the RWMC. For comparison, tritium transport was also simulated directly using MODFLOW/MT3DMS, and these results are plotted alongside the response surface model results (Figure 4). Differences between the maximum tritium concentrations estimated with the response surface model and those estimated with MODFLOW were no greater than 6% and typically were less than 3%. Computer run times for the Response Surface Model were typically less than a second compared to MT3DMS simulation times of greater than 6 hours.

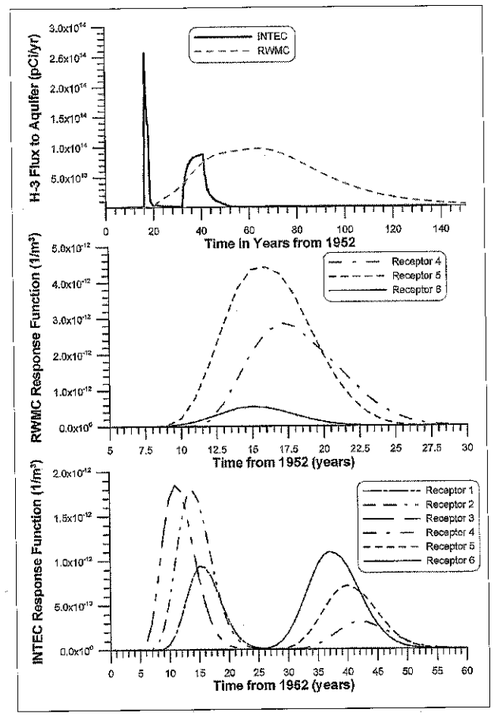


Figure 3. Tritium loading rates to the SRPA and response functions for INTEC and RWMC.

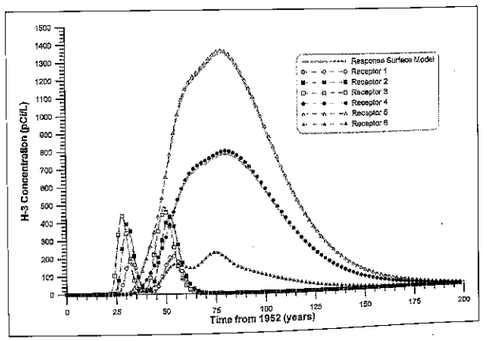


Figure 4. Comparison of MODFLOW/MT3D tritium concentrations and those calculated using response surface model.

SUMMARY

The response surface model is a viable method to simplify representation of the results of a complex groundwater flow and transport model into an assessment framework that considers arbitrary source-loading rates for numerous sources and contaminants. The primary benefit of such a model is to 1) provide a method to rapidly assess different source loading rates and remediation options and 2) provide a management tool for assessment of groundwater resources.

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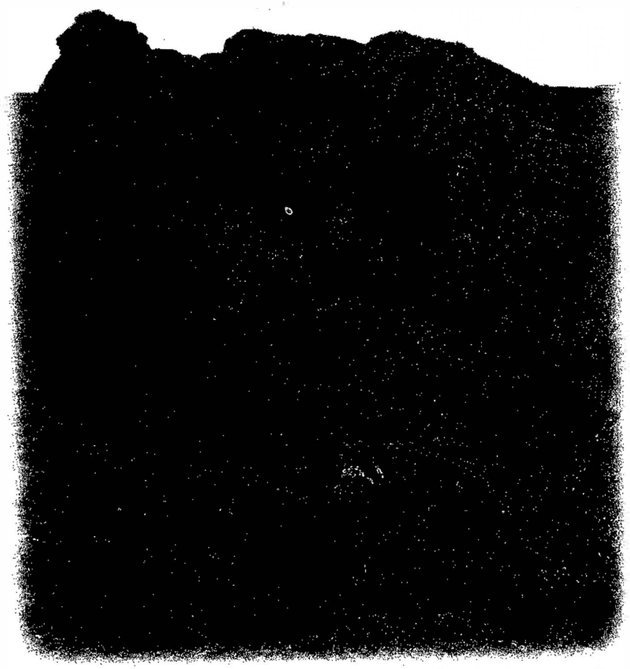


Photo by Scott Hughes

Status of Multilevel Groundwater Monitoring Systems Installations at the Idaho National Laboratory

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ABSTRACT

In late 2005 through mid 2006, two deep coreholes were drilled and completed with multi-level groundwater monitoring systems. The purpose of this work was to provide depth discrete aquifer information for the OU 10-08 sitewide groundwater model. Upon completion of coring monitoring zones were identified through examination of core photos, borehole geophysics, and video logs. Monitoring intervals were selected in zones that were permeable and that could be isolated through packer installation in zones of competent basalt. Two multi-level systems were installed in August and September 2005.

INTRODUCTION

The Idaho National Laboratory (INL) sitewide groundwater model is being completed for use in the OU 10-08 Remedial Investigation/ Feasibility Study (RI/FS). Data from individual Waste Area Group (WAG) models will be incorporated into a numerical model of three-dimensional groundwater flow and contaminant transport within the area represented by the OU 10-08 model domain. This domain includes the INL and adjacent areas.

The OU 10-08 three-dimensional model requires acquisition of depth-integrated geohydrologic data. Packer tests can provide these data, including aquifer geometry, vertical head gradients, contaminant distribution with depth, and thermal data. However, these tests are expensive, difficult to replicate due to positioning of packer seals, and do not easily provide a means of data acquisition over time. Multi-port systems allow for discrete sampling, pressure, and temperature monitoring through profiling. Permanent multi-port systems that can be used to monitor changes in chemistry, pressure, and temperature with time permit optimal borehole control and a method to evaluate predicted three-dimensional numerical model results.

Additionally, stratigraphic data, including paleomagnetic data for age-dating and whole-

rock geochemistry data, are required to refine the understanding of the aquifer geohydrologic framework. The OU 10-08 Groundwater Model Work Plan (DOE 2004) and a drilling prioritization document (ICP 2004) identified and prioritized drill sites needed to acquire these stratigraphic data and to provide boreholes for installation of permanent multi-port monitoring systems. Two deep coreholes were drilled in 2005 and were completed with multilevel groundwater monitoring systems.

WELL LOCATIONS

Initial planning for this project included a close review of several documents and memos previously generated by INL personnel concerning desired drilling locations and data needs. Seventeen potential drilling locations were identified (ICP 2004). One of these locations had been drilled in 2003 and completed as a deep monitoring well (MIDDLE-1823). The remaining 16 locations were ranked based on the need for the following information:

- Hydrogeologic Unit Definition
- Aquifer Geometry
- Aquifer Hydraulic Characteristics
- Large-Scale Field Flow Definition
- Refinement of Anthropogenic Plumes
- Long-Term Monitoring Value

Based on these data requirements, the top five locations for drilling and completion with multiport sampling systems consisted drilling site 15 between INTEC/RTC and RWMC (transport and commingling of contaminant plumes), drilling site 6 west of RTC (aquifer thinning and preferential flow), drilling site 16 between RTC and INTEC (stratigraphic transition), drilling site 17 in the southwestern corner of the INL (aquifer geometry), and

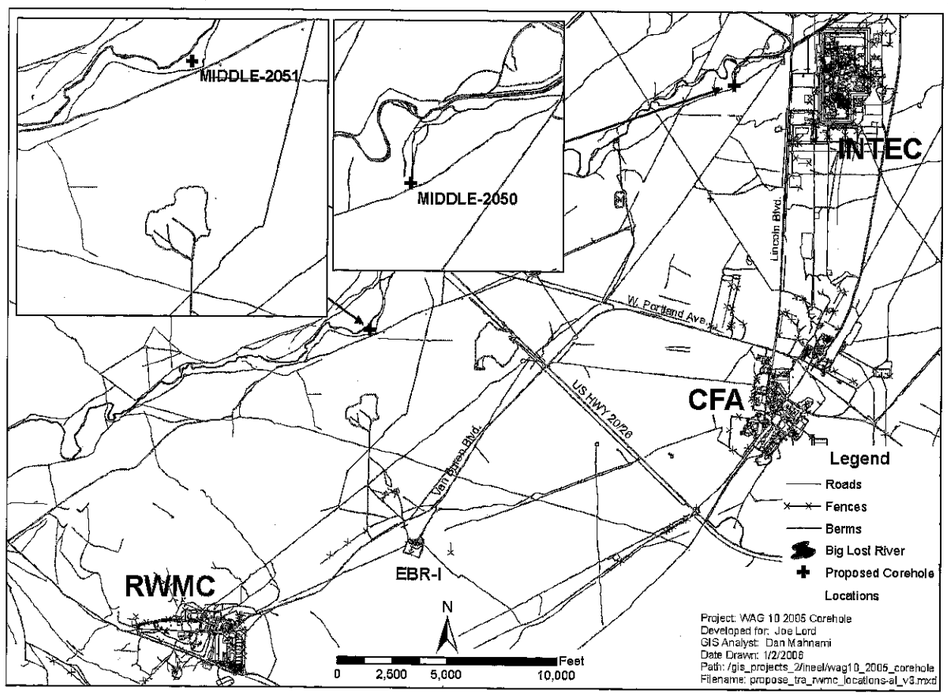


Figure 1. Location of wells MIDDLE-2050 and MIDDLE-2051.

drilling site 5 south of the RWMC (contaminant extent). Of these locations, the USGS was planning to construct multiport wells at drilling sites 6 and 17. OU 10-08 drilling activities in 2005 consisted of deep drilling and multiport sampling wells at drilling site 15 (well Middle 2051) and drilling site 16 (well Middle 2050a). Well MIDDLE-2050 is located between the RTC and INTEC. Well MIDDLE-2051 is located south of Highway 20/26 between the Radioactive Waste Management Complex (RWMC) and Reactor Technology Complex/ Idaho Nuclear Technology and Engineering Center (RTC/INTEC) facilities. Well locations are shown in Figure 1.

The primary objective for drilling well MIDDLE-2050a was to evaluate the stratigraphic sequence in the area between the INTEC and the RTC where a potential stratigraphic offset of as much as 400 ft has been observed (ICP 2004). Additionally, vertical distribution of water-chemistry and head data were required to evaluate the effect of this potential stratigraphic transition on groundwater flow and contaminant transport (ICP 2004).

The primary objective at MIDDLE-2051 was to evaluate the origin of contaminants and potential commingling of contaminant plumes in the area between the INTEC/RTC and RWMC (ICP 2004). Limited areal and vertical contaminant data in that area precluded determination of commingling of these plumes. These plumes included tritium and iodine-129 plumes that originated from the INTEC and RTC. A well at this location would provide a point for vertical and areal distribution of head, contaminants, and temperature, as well as distribution of natural and anthropogenic tracers (ICP 2004). These data are needed in calibration of the OU 10-08 three-dimensional model of groundwater flow and contaminant transport and will be used in support of the OU 10-08 RI/FS.

DRILLING ACTIVITIES

Drilling activities at coreholes MIDDLE-2050A and Middle-2051 commenced in 2005. Subsequent sections describe these activities.

COREHOLE MIDDLE-2050A

Drilling of corehole MIDDLE-2050 commenced in May 2005 but was abandoned at a depth of 385 ft bls after the core rods and barrel were stuck in the corehole by sloughing sand at a depth of 290 ft bls. The core rods were cut, leaving the core bit, barrel and portions of a rod in place from 274.5 to 295.5 ft bls. The corehole was abandoned and the hole was offset to restart the drilling of a corehole designated MIDDLE-2050A.

Corehole MIDDLE-2050A was drilled to basalt using a casing advancing, dual rotary drill rig using 16-in. and 15-in. bits. Top of basalt was penetrated at a depth of approximately 54 ft bls. Drilling was then continued using a 13-in. bit to a depth of 420 ft bls. Permanent 6 5/8-in. casing was installed to 420 ft bls and grouted in place. The hole was cored from 420 ft to a total depth of 1,422 ft bls, with the exception of several thick sedimentary interbeds in the depth interval between approximately 1279.9 and 1385 ft bls. which were drilled with a 5 3/4-in. tricone bit. Recovery of core was approximately 95% and the core log was used to assist in the determination of packer and monitoring zone placement.

The measured depth to water in the completed corehole was 481 ft bls. A set of geophysical logs was collected by the U.S. Geological Survey on July 5 and 6, 2006 and included gamma-gamma, natural gamma, neutron, caliper, resistivity, and video logs. Although preliminary temperature measurements were obtained at each measurement port, a temperature log covering the entire length of the corehole has not been completed. Temperature logging is planned for FY 2006. The lithology of MIDDLE-2050A is illustrated in Figure 2.

COREHOLE MIDDLE-2051

Well MIDDLE-2051 was drilled to basalt using a casing advancing, dual rotary drill rig using 16-in. and 15-in. bits. Top of basalt was

penetrated at a depth of approximately 125 ft bls. A permanent 12 ¾-in. casing was installed to the base of the hole at 127 ft bls. Coring was continued to a depth of 491 ft at which point sloughing materials precluded further coring. The corehole was over reamed with a 10-3/4-in. button hammer drill bit from 91 to 430 ft bls. Permanent 6 5/8-in. casing was installed to 430 ft bls and grouted in place. Coring was then continued to the total depth of 1179 ft bls. Recovery of core was approximately 95% and the core log was used to assist in the determination of packer and monitoring zone placement.

The measured depth to water in the completed corehole was 571 ft bls. A set of geophysical logging was collected by the U.S. Geological Survey on April 20, 2006 and included gamma-

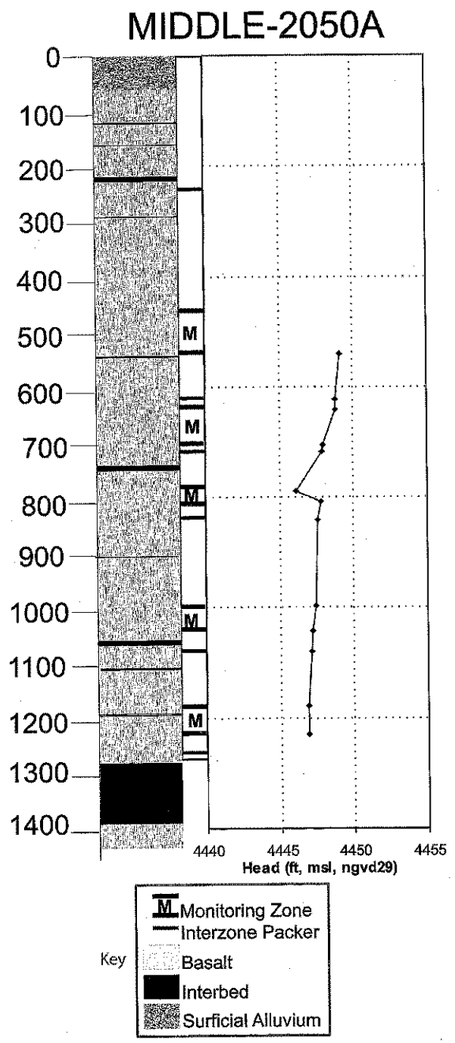


Figure 2. Lithology, completion, and head profile in MIDDLE-2050A.

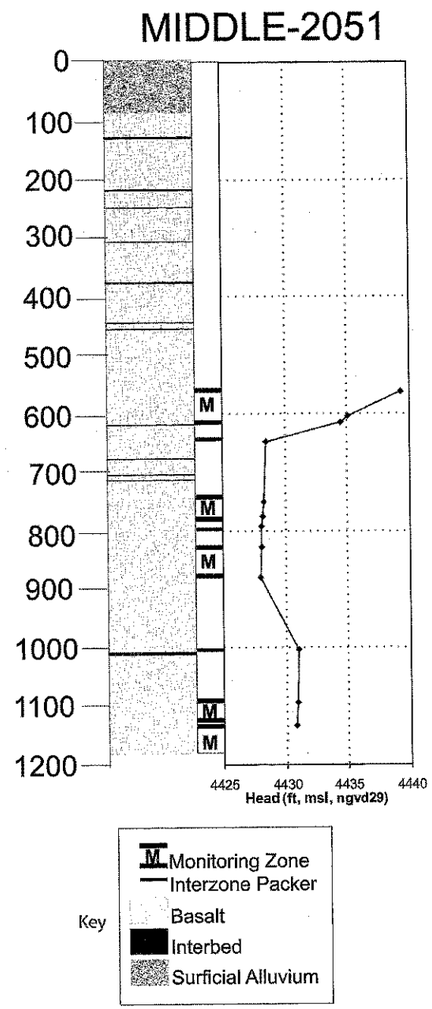


Figure 3. Lithology, completion, and head profile in MIDDLE-2051.

gamma, natural gamma, neutron, caliper, resistivity, and video logs. Although preliminary temperature measurements were obtained at each measurement port, a temperature log covering the entire length of the corehole has not been completed. Temperature logging is planned for FY 2006. Lithology at MIDDLE-2051 is illustrated in Figure 3.

COMPLETION OF MULTIPORT SAMPLING WELLS

Once drilling and borehole surveys were completed, a multi-level Westbay monitoring system was installed in each of the coreholes. The following sections provide an overview of the Westbay system and the specifics of each installation.

WESTBAY OVERVIEW

Westbay multilevel groundwater monitoring systems are a single tube sampling system, capable of obtaining discrete samples from multiple depths. The system utilizes multiple, independently inflated packers to isolate sampling zones within the borehole. Each sampling zone consists of a measurement port, pumping port and two packers. Additional packers are placed between each sampling zone to prevent vertical mixing of water within the hole. Samples are collected using a MOSDAX sampling probe equipped with collection canister(s). The sampling probe is capable of measuring pressure and temperature inside and outside the casing through an access valve located on each of the sampling and quality assurance ports. The sampling team operates the probe from a hand-held MOSDAX controller connected to the probe by a wire-line winch.

The probe is lowered via wire line to each sample or quality assurance port and the probe is rotated into position through the use of a location arm. The water pressure inside the casing is measured and recorded. The backing shoe is then activated, engaging the sampling probe faceplate with the measurement port. The pressure outside the casing is recorded and compared to the pressure inside the casing, verifying that the probe is sealed against the measurement port. The sample valve is opened, allowing the water to pass through the probe for collection in the sample collection canisters. After the sample is collected, the sample valve is closed and the backing shoe is deactivated, releasing the probe from the measurement port. The pressure inside the casing is measured and recorded and the sample probe is withdrawn. The measurements of the pressures inside and outside the casings provide quality assurance checks of the system and assessment of leakage. The pressure inside the casing should remain constant at each depth; changes within the pressures may indicate leakage around the faceplate of the probe indicating an improper seal and the need to resample.

The single tube system of the Westbay will allow for future temperature logging over the entire length of the installation. Additionally, the system allows for continued long term collection of depth discrete pressure data and water chemistry.

WESTBAY INSTALLATIONS

Upon completion of coring at the second location, both coreholes were hydraulically developed using pumps. Corehole pumping was initiated at or near the bottom of each hole. After pumping at the initial depth, development continued by lifting the pump and packer system to the depths for each monitoring zones. Pumping was continued until all field parameters (pH, dissolved oxygen, temperature, conductivity, turbidity) were stable, indicating that fluids that had entered the formation during the drilling and coring process had been removed.

Five monitoring zones were selected for the Westbay installations at wells MIDDLE-2050A and MIDDLE-205. The Westbay systems were installed via guide tubes in uncased holes. The PQ size core rods were used as a guide tube. For each borehole, a rod was inserted to a depth just above the deepest planned monitoring zone. The Westbay system was then placed into the hole inside the guide tube. The packers

were then inflated and a portion of the guide removed. This process of sequential inflation of packers and removal of the guide tube was repeated until all the packers were inflated and the guide tube completely removed. During the installation and again upon completion of inflation, the water level within the system was monitored for any fluctuations, which would indicate that the system casing was not correctly sealed. Pressure measurements were made at each monitoring point, as well as at each quality assurance port, located beneath the packers and placed between each monitoring zone. Figures 2 and 3 illustrate the lithology of MIDDLE 2050A and Middle 2051, the packer placement and monitoring port depths for each completion and the pressure data, converted to water level in elevation above sea level, for each well. Note that the packers are not drawn to scale in the diagram.

HYDROLOGIC SAMPLING ACTIVITIES

Hydrologic sampling activities included collection of samples for water chemistry and core samples for whole rock geochemical analyses. These sampling activities are described in subsequent sections.

WATER CHEMISTRY SAMPLING

Water samples were collected to evaluate the chemical composition of groundwater, contaminant concentrations, and natural and anthropogenic tracers. Analytical results will be used to characterize aquifer geometry and flow characteristics, assist in the identification of preferential flow paths, and provide information regarding contaminant transport and potential commingling of plumes. Water quality sampling began two weeks after the installations were completed.

Samples for were collected for selected analytes from each of the five monitoring zones in both wells (ICP 2005). Inorganic/organic chemical analytes and field parameters included major anions, metals (filtered), nitrate/nitrite expressed as nitrogen, a suite of selected volatile organic compounds, and alkalinity. Radioactive analytes included gamma spectroscopy, gross alpha, gross beta, chlorine-36, iodine-129, carbon-14, strontium-90, technetium-99, tritium, and uranium isotopes.

LITHOLOGIC SAMPLING

Samples were collected from selected intervals of the basalt cores from both coreholes. These rock samples are being analyzed for polarity and inclination of paleomagnetic remanence, radiometric age data, and geochemical concentrations of diagnostic major and trace elements. These data will assist in characterization of the basalt stratigraphy in the vicinity of wells MIDDLE 2050A and Middle 2051. Selection of the sample locations within each basalt core were determined based on review of the lithologic log, geophysical logs, and core material (ICP 2005). A total of 528 paleomagnetic samples, 240 geochemical samples, and six radiometric age date samples were collected.

MEASUREMENTS OF HYDRAULIC HEAD

Pressure measurements obtained after the completion of installation indicated that variations in hydraulic head occur vertically across the aquifer. Preliminary head measurements from well MIDDLE-2051 indicated that the hydraulic head decreased nearly 12 ft within a 230-ft interval. Within well MIDDLE-2050A, preliminary measurements indicated that head changes were less variable vertically, with the hydraulic head decreasing 3 ft within a 250 ft interval. Pressure data indicate that upward and downward hydraulic gradients occur in both wells. Additional pressure measurements and analytical data are required over time to determine if any residual effects from the drilling were present in this data set and to examine longer term trends.

ONGOING WORK

Installation of three additional Westbay systems is planned for late spring to early summer of FY2006. Up to three Westbay systems will be installed in coreholes drilled by the USGS. These coreholes will be sampled for the same parameters as MIDDLE-2050A and MIDDLE-2051. Additional pressure and temperature measurements will be made during FY2006, as well as the collection of additional samples.

In summary, data collected from MIDDLE 2050A and Middle 2051, consist of geophysical logs, measurements of hydraulic head and water chemistry analyses with depth, temperature measurements, and whole rock analyses. These data, in conjunction with similar data sets from additional planned multiport monitoring wells will assist in further characterization of basalt stratigraphic relationships and the vertical distribution of hydraulic head and water chemistry and will be used in the development and calibration of the OU 10-08 three-dimensional model of groundwater flow and contaminant transport.

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Ojos de Dio
Eyes of God:
spiral galaxies
blossom like flowers
in the Flows:
signatures of God!

Cyclops proclaims these
the Holy Fields;
altars of a merciless blessing!

Eye of God:
look into it
look into the eye of Creation!

- Will Peterson



Photo by Scott Hughes

ECOLOGY

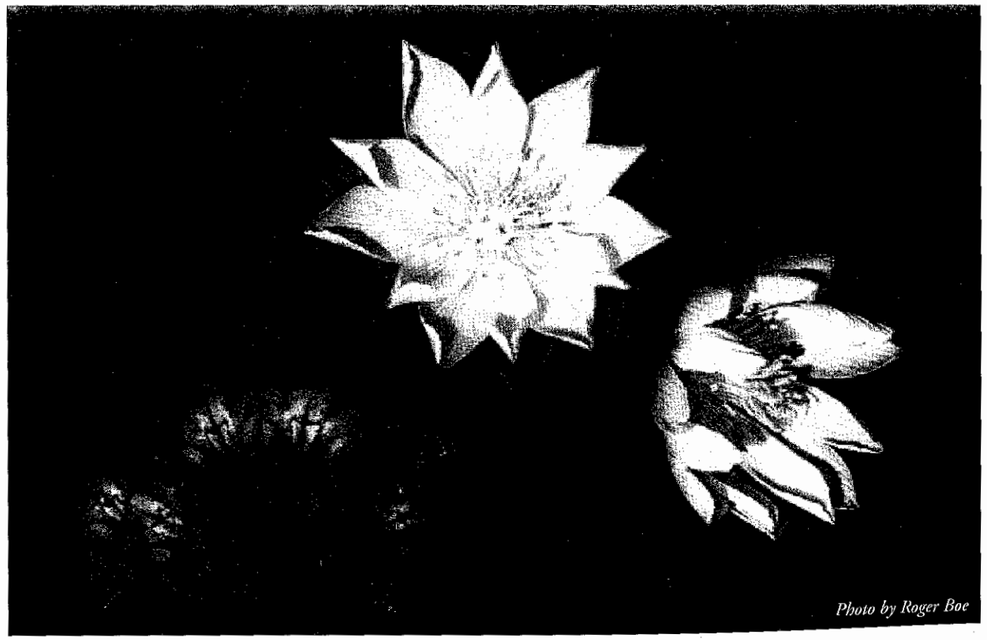


Photo by Roger Boe

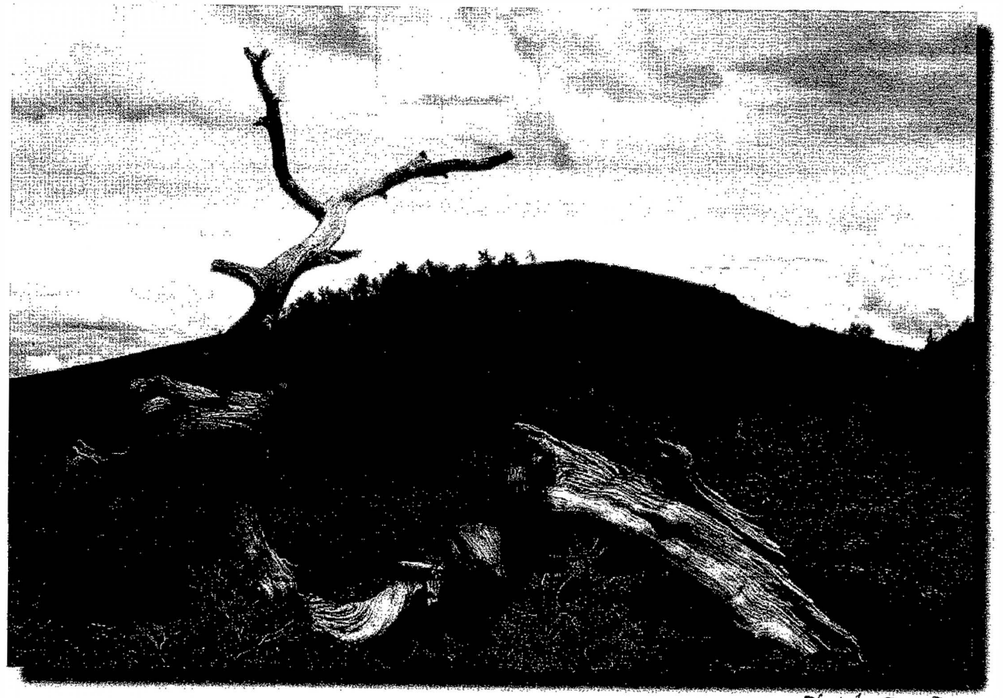


Photo by Roger Boe

A hundred years
this limber pine
by North Crater
just held on to its branches:
purchase for the wind.

A hundred years
bent this way and that
to become muscular
to become finally
the image of its adversary:

past all resistance now
hand rubbed by the Old Woman
if not with love
at least a kind of faithfulness.

- Will Peterson

Greater Sage-Grouse Use of Threetip Sagebrush Communities in Idaho's Great Rift Region

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ABSTRACT

Threetip sagebrush (*Artemisia tripartita*) and big sagebrush (*A. tridentata*) were the only species of sagebrush used as nest cover by 21 nesting sage-grouse in the Great Rift area southwest of Craters of the Moon National Monument, Idaho. We were interested in looking at whether sage-grouse used one of the two species of sagebrush in greater proportion than they were available throughout the study site and if there was a difference in nest success when either species was used as nest cover. Nesting hens used big sagebrush in greater proportion than it was available and experienced greater nest success in big sagebrush versus threetip sagebrush.

INTRODUCTION

Sage-grouse have experienced dramatic population declines throughout their range for the past century (Patterson, 1952; Autenrieth, 1981; Connelly and Braun, 1997). Reasons for these declines are varied and include degradation or fragmentation of habitat through overgrazing, drought, agricultural and urban development, and broad-scale applications of herbicides (Klebenow, 1970; Martin, 1970; Swenson et al., 1987; Beck and Mitchell, 2000). Because sage-grouse populations are low, their sensitivity to habitat degradation may have increased such that additional habitat degradation will lead to population collapse in these areas. Habitat alterations due to fire are of particular interest because of the increasing frequency of fires (Morgan et al., 1996). Threetip sagebrush can be an early and abundant colonizing sagebrush species following fire. Little is known about sage-grouse use of threetip sagebrush. Knowing how sage-grouse use threetip sagebrush in the presence of other sagebrush species will provide valuable insight into how sage-grouse respond to fire.

We addressed three questions regarding sage-grouse use of threetip sagebrush as nest cover: 1) Are sage-grouse using threetip sagebrush in proportion to its relative abundance within the landscape? 2) Is there a difference in the vegetation component associated with differing shrub species chosen as nest cover? 3) Does sage-grouse nest success vary between sagebrush species used as nest cover?

STUDY AREA AND METHODS

Birds were captured on multiple leks in and adjacent to Laidlaw Park, located immediately southwest of Craters of the Moon National Monument, approximately 28 km west of Arco, Idaho. The study area encompasses approximately 90,000 ha and lies within portions of Blaine, Lincoln, and Minidoka counties. Elevations in the study area range from 1300 m in the southern portion to 2300 m near the northern boundary. The study area

is semi-arid with extreme seasonal temperature variation. Annual precipitation ranges from 30-38 cm with most of the precipitation falling as snow. Temperatures range from 40°C to -10°C.

Threetip sagebrush is the dominant shrub species throughout much of the study area with basin big sagebrush (*A. tridentata tridentata*), mountain big sagebrush (*A. t. vaseyana*), antelope bitterbrush (*Purshia tridentata*), green rabbitbrush (*Chrysothamnus viscidiflorus*) and rubber rabbitbrush (*Ericameria nauseosa*) also present. The understory consists largely of bluebunch wheatgrass (*Pseudoroegenria spicata*), Siberian wheatgrass (*Agropyron fragile*), Sandberg's bluegrass (*Poa secunda*), and needle and thread grass (*Hesperostipa comata*).

Female sage-grouse were captured at night using spotlights (Wakkinen et al., 1992) from 31 March to 23 April 2005. Captured grouse were banded with aluminum leg bands and fitted with 16g radio transmitters and monitored through 17 September 2005. Hens were monitored at least twice per week from 25 April to 20 June to determine nest initiation. Nests were monitored daily in the week of anticipated hatch (approximately 27 days after locating the nest) to ascertain hatch date.

Vegetation measurements were taken at the nest site once a nest hatched or, in the case of depredated nests, once the nest should have hatched (judging from date of nest initiation). Grass height, shrub height, shrub density, percent canopy cover (Canfield, 1941), grass and forb density (Daubenmire, 1959), and percent horizontal cover (Robel et al., 1970) were measured along four 10 m transects centered at the nest bowl and spaced 90° apart. For both grass and shrub heights, measurements of one plant per species were taken at 1 m, 3 m, and 5 m. Only the specimen closest to the tape and within 1 m of the line was measured. Measurements made at the nest site were also made at randomly selected sites. Random sites provided a comparison of use versus availability. We used the percent of shrub canopy cover for both threetip and big sagebrush to derive an estimate of the number of expected nests under each species of sagebrush. Here, we provide summary values for our preliminary results following our first field season.

RESULTS AND DISCUSSION

Twenty of 24 female sage-grouse captured in spring 2005 initiated a nest. Sage-grouse used big sagebrush as nest cover in greater proportion than big sagebrush availability as measured by surveys of randomly selected sites (Figure 1). This use of big sagebrush over threetip sagebrush suggests that there are differences in the environment surrounding nests associated with the sagebrush species providing cover. It may also point to some advantages in using big sagebrush as nest cover.

Preliminary analyses of vegetation data point to three potentially significant differences between threetip and big sagebrush. We found that the diversity of forbs and grasses was greatest surrounding nests under threetip sagebrush (Figure 2). However, shrub heights surrounding nests under big sagebrush were generally taller (Figure 3). Other studies have reported similar results regarding shrub heights (Wakkinen 1990; Gregg et al., 1994; Sveum et al., 1998). Furthermore, sage-grouse have increased nest success in areas with taller shrub heights (Wallestad and Pyrah, 1974; Sveum et al., 1998) which is consistent with our results.

Overall nest success was 45% (Table 1). Nest initiation and overall nest success were within the range of other studies (Connelly et al., 2000), although nest success was lower than is typically found in Idaho (Klebenow, 1969; Connelly et al., 1991; Connelly et al., 1993). Low nest success may be due to unusually high precipitation and long duration of rain events in spring 2005. Nest success was substantially lower when threetip sagebrush was used as nest cover relative to nest success in big sagebrush (Table 1). Additional data will be collected in 2006 and should improve our estimates. This information may increase our knowledge of suitable nest habitat.

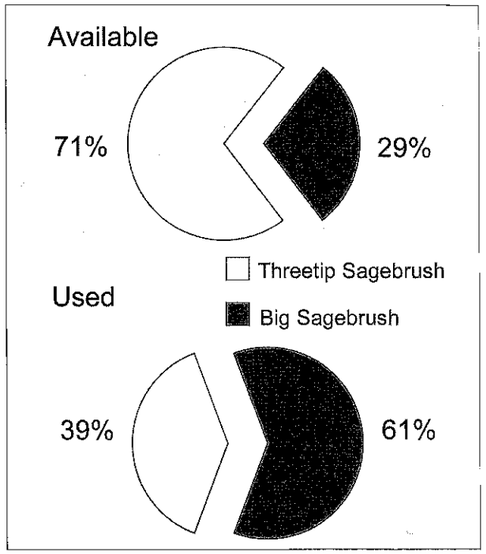


Figure 1. Expected proportion of nests under each species of sagebrush based on availability within the study site relative to the proportion of each species of sagebrush actually used as nest cover by sage-grouse.

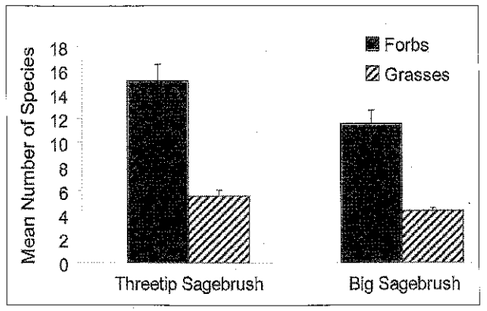


Figure 2. Mean number of grass and forb species (± SE) surrounding each species of sagebrush used as nest cover for sage-grouse nests in the Laidlaw Park study area, 2005.

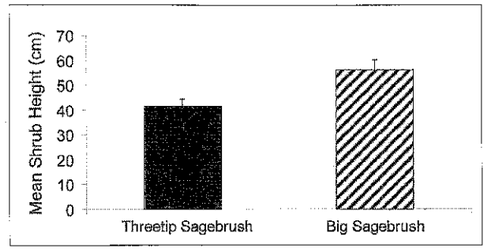


Figure 3. Mean live shrub height (± SE) surrounding each species of sagebrush used as nest cover for sage-grouse nests in the Laidlaw Park study area, 2005.

If it is advantageous to nest in big sagebrush, there may be competition for desirable nest sites, not previously documented, which would force subdominant individuals to seek alternative nest sites including threetip sagebrush. This hypothesis is supported by our finding that yearlings made up 67% of the nesting birds in threetip sagebrush compared to 27% in big sagebrush (Table 1).

While our results are preliminary and should be used with caution, we found that threetip sagebrush may be less desirable as nest cover for sage-grouse. Hence, careful consideration should be made when using prescribed fire as a management technique where there is a strong likelihood of substantial threetip sagebrush regeneration. In the event of large fires, where threetip sagebrush is likely to constitute a large portion of the seed base, it may be beneficial to seed big sagebrush to promote quality sage-grouse nesting habitat. Furthermore, caution should be used when seeding rehabilitated

Table 1. Nest success for adult and yearling sage-grouse by shrub species in the laidlaw park study area, 2005. Numbers in parentheses are sample sizes.

Age	*Artemisia tridentata*	*Artemisia tripartita*	*Ericameria nauseosa*	*Purshia tridentata*	Overall
Adult	50.0% (8)	50.0% (2)	50.0% (2)	100.0% (1)	53.8% (13)*
Yearling	66.7% (3)	0.0% (4)	--	--	28.6% (7)
Overall	54.5% (11)	6.7% (6)	50.0% (2)	100.0% (1)	45.0% (20)

*One adult female was excluded from analysis because the exact location of her nest bowl could not be determined.

areas with threetip sagebrush where sage-grouse populations may exist.

ACKNOWLEDGMENTS

The Bureau of Land Management, Idaho Department of Fish and Game, Lava Lake Land and Livestock, and Idaho State University provided technical and financial support for this work. We thank Jack Connelly and David Musil for providing essential assistance in all aspects of this project and Joseph Warwick, Kaleb Wilson, Brandy Nance, and Aren Eddingsaas for their contributions in the field.

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Landscape Scale Conservation and Science Based Land Management Program in the Greater Great Rift Region

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ABSTRACT

Lava Lake Land and Livestock was organized in 1999 to (i) achieve landscape-scale conservation in the Pioneer and Boulder Mountains and in the Craters of the Moon area and (ii) establish an ecologically-sound and financially-viable business that supports our conservation activities. The Company's business is currently focused on all-natural and organic lamb production. Our grazing and conservation activities take place on 24,000 acres of private lands and 850,000 acres of state and federal lands administered by the Bureau of Land Management (BLM), the U.S. Forest Service (USFS), and the Idaho Department of Lands (IDL).

We are pursuing our conservation mission by establishing a comprehensive scientific program, protecting private lands, restoring habitat for wildlife, managing livestock in ways that are compatible with habitat recovery and native wildlife, participating in public lands management, and managing noxious weeds. Our science program includes ecological inventory and assessments, conservation planning, monitoring of aspen, sagebrush steppe, and riparian ecosystems, and research. A major thrust of the ecological surveys included mapping the vegetation of approximately 200,000 acres within our operating area. We are focusing our science and conservation efforts on two wide ranging species, (sage grouse and gray wolf), two endemic species, (Wood River Sculpin and bugleg goldenweed), and the dominant habitat types, (aspen, sagebrush steppe, riparian and coniferous forest ecosystems).

Our partners include The Nature Conservancy, BLM, National Park Service, USFS, U.S. Fish and Wildlife Service, IDL, Idaho Department of Fish and Game, Blaine County, Defenders of Wildlife, Department of Environmental Quality (DEQ), and the NRCS.

INTRODUCTION

Lava Lake Land and Livestock was organized in 1999 to (i) achieve landscape-scale conservation in the Pioneer and Boulder Mountains and in the Craters of the Moon area and (ii) establish an ecologically-sound and financially-viable business that supports our conservation activities. The Company's business is currently focused on all-natural and organic lamb production. Our grazing and conservation activities take place on 24,000 acres of private lands and 850,000 acres of state and federal lands administered by the Bureau of Land Management (BLM), the U.S. Forest

Service (USFS), and the Idaho Department of Lands (IDL).

The Lava Lake operating area is bisected by two major ecoregions: the Middle Rockies and the Columbia Plateau. BLM grazing permits are located along the northern Snake River Plain and in the foothills of the Pioneer, Boulder, and Smoky Mountains. State leases and deeded lands occur amidst BLM allotments primarily in the Pioneer Mountain foothills. USFS grazing permits are in the mountainous region to the north of the deeded properties. Elevation ranges from below 4,100' to above 11,000' with average annual precipitation ranging from 9" to over 25".

The ecological significance of this region has long been recognized, evidenced in part by the expansion of the neighboring Craters of the Moon National Monument from 54,440 acres to over 750,000 acres in 2000. Lava Lake shares approximately $6^{3/4}$ miles of boundary with the Craters of the Moon National Monument along the northern edge of the Great Rift.

The Lava Lake operating area supports a diverse range of vegetation. The most common cover types include Wyoming big sagebrush, basin big sagebrush, and mountain big sagebrush. Low sagebrush, Douglas fir, and sub-alpine fir are also common. Riparian and aspen habitat, while critical to sustaining biological diversity, covers only about 2% of this landscape.

The region's diverse topography and transitional vegetation provides habitat for many animals including mule deer, pronghorn, black bear, coyote, river otter, and silver-haired bat; several amphibian and reptile species including the Columbia spotted frog; and number of fish including the locally endemic Wood River sculpin and redband trout.

There is also a rich diversity of bird species on Lava Lake. Over 100 bird species have been recorded to date, 33 of which have been given a high conservation priority by the Idaho Bird Conservation Plan including sage grouse, sage thrasher, Calliope hummingbird, yellow warbler, and sandhill crane (Paige 2005).

GOALS AND APPROACH

Our conservation goals are to implement environmentally sound livestock management practices, improve and protect biological diversity at a landscape scale, and restore degraded habitats within Lava Lake's deeded lands and grazing allotments.

We recognize that we cannot accomplish this work independently and have engaged a number of partners. Our partners extend the reach and breadth of Lava Lake's own efforts. Lava Lake's partners include the BLM, National Park Service (NPS), USFS, U.S. Fish and Wildlife Service, Idaho Department of Fish and Game (IDFG), The Nature Conservancy (TNC), Defenders of Wildlife, University of Idaho, Montana State University, Nez Perce Tribe, DEQ and NRCS.

A key component of our strategy for achieving these goals is to employ science to guide management decisions. Lava Lake is dedicated to achieving a scientific understanding of the ecological systems, the native species dependent on those systems, and the natural processes that shape and sustain the systems and species within Lava Lake's surrounding landscape. Lava Lake needs this understanding to make scientifically based resource decisions that ensure Lava Lake's actions protect the ecological integrity of the native systems and species.

INVENTORY AND ASSESSMENT

At the time of the first ranch acquisition in 1999, we knew Lava Lake was a wildlife-rich area, but we lacked detailed and current ecological information, especially for the private ranch units. Data were more readily available for the public lands but, in nearly all cases, the information was dated, having been gathered and analyzed 20 or more years earlier. We began to develop baseline data so that we could base resource decisions on current ecological conditions. Moreover, current data were also needed to determine if management actions were having the desired outcome. Consequently, an intensive scientific effort was begun during the spring of 2001.

We started by compiling existing information on the species, conservation concerns, and ecological systems for the operating area from our network of partners. Once we understood the gaps in ecological knowledge we initiated several studies. Our first and largest effort was to develop an understanding of the vegetative communities. Information on vegetation would help us to understand fish and wildlife habitats and to make resource management decisions, especially with regard to livestock grazing. As of January 2004, mapping and condition assessment had been completed on 292,500 acres within the operating area. BLM was a major funder and partner on these vegetation surveys. The vegetation inventory work, conducted by ecologists and botanists at the IDFG Conservation Data Center, revealed that over 50% of the sagebrush steppe habitat in the Pioneer foothills was in good or excellent condition, further highlighting the conservation significance of this region. In addition, over 50% of the coniferous forest habitat was in excellent condition. On the other hand, the riparian and aspen habitats were generally in fair to poor condition at the time of the field surveys conducted during 2001-2002 (Rust et al. 2001, Rust et al. 2003).

In addition to mapping vegetation, we also wanted to learn more about the distribution and condition of wildlife species, especially rare and/or sensitive species. In total, we have initiated and/or supported 18 studies including surveys of amphibians and reptiles, rare plants, and riparian birds.

DEVELOPMENT OF CONSERVATION PLAN

We then developed a Conservation Plan to integrate all of this information and to structure our approach to conservation in this large and complex landscape. We followed The Nature Conservancy's Site Conservation Planning approach (TNC 2000). This required us to identify conservation targets on which we would focus our management actions and conservation strategies. We selected eight conservation targets on the basis of their conservation significance in the area. We identified four ecological systems targets:

- sagebrush steppe
- riparian zones
- aspen
- coniferous forest

We then selected gray wolf due to its status as a federally-listed species; sage grouse due to its wide-ranging use of habitat in this region and its evident declining trends across the West; Wood River Sculpin and bugleg goldenweed because they are locally endemic species, unique to this area.

For each target we identified threats, set objectives, and determined the most important actions to achieve those objectives. We then outlined a detailed action plan for accomplishing these objectives. Our plan was peer-reviewed by our volunteer Science and Conservation Advisory Board.

PRIORITY MANAGEMENT ACTIONS

The Conservation Plan helped identify priority management actions to protect biological diversity and improve the ecological condition of the lands under our use and management; some of these actions were already underway before we completed our Conservation Plan. These actions have included private lands protection, livestock management, habitat restoration, noxious weed management, non-lethal management approach to predators, and participation in public lands management.

In 2000, a 7,500 acre portion of Lava Lake Ranch was placed under a perpetual conservation easement, forever preventing development of this area.

Livestock management has and will continue to be the most important aspect of our conservation strategy. We recognize that livestock grazing represents a potential threat to the ecological condition of our targets and

we keep this in mind as we design our approach to grazing. We have taken a science based approach and have conducted a capability and capacity analysis to determine ecologically appropriate grazing levels in this landscape. Key components to our multi-year grazing management include stocking at conservative levels that anticipate continued cycles of below average precipitation and varying timing and intensity of use for a given area from year to year.

We recognize the contributions that predators make to overall ecosystem health and our goal is to coexist with the predators in our area. We also know that predators can have significant economic and operational impacts on a ranching business. As a result, we have been working with the federal and state agencies and predator conservation groups to develop and implement non-lethal and proactive strategies to prevent and reduce the loss of livestock to predators.

While much of the improvement in ecological condition throughout the Lava Lake operating area can occur through thoughtful livestock management, there are areas that have crossed an ecological threshold and require manipulative restoration efforts. Lava Lake is pursuing a comprehensive restoration program in these areas, particularly where these areas overlap with habitat for sensitive species (e.g., sage grouse). To date, we have pursued restoration strategies in aspen and riparian habitats in partnership with the BLM, IDFG, and the National Resource and Conservation Service.

Lava Lake has developed a strategic and cooperative approach to managing noxious weeds by working in partnership with Blaine County Cooperative weed management group. Lava Lake's integrated approach to weed management includes the use of sheep grazing and biological, manual, and chemical control.

An additional conservation strategy is our approach to recreation management on deeded lands. Motorized recreation was identified as one of the threats to our conservation targets and we have restricted motorized access to established roadways within Lava Lake's deeded lands while providing for foot- and horse-powered access to over 13,000 acres of private land with linked access to more than 50,000 acres of public land.

DEVELOPMENT OF MONITORING PROGRAM

In order to measure our success in meeting the objectives of the Conservation Plan, we have developed an extensive monitoring program for our conservation targets. Lava Lake is measuring ecological trends in the aspen, riparian, and sagebrush ecosystems. In addition, we are working with wildlife biologists to track the populations of our target species: sage grouse, Wood River sculpin, bugleg goldenweed, and the Gray wolf. Our goal is to document how the changes in our management are influencing the trends for these important ecosystems and sensitive species.

For the sagebrush steppe monitoring, we will use the line point intercept method to monitor ground cover, species composition, invasives, and a circular plot to evaluate soil erosion. We focus our evaluation on the cover of key perennial bunchgrass species, such as bluebunch wheatgrass and Idaho fescue.

Our aspen monitoring approach uses a belt transect method and focuses on aspen stems/acre, utilization, and understory composition as indicators for aspen stand condition. Our key metric will be stems/acre by size class to determine whether stands have a diverse age class structure and whether young aspen sprouts are growing beyond browsing height to establish a new mature age class.

The riparian method is based on a technique developed by the USFS (Winward 2000). We use a step point intercept and belt transects to monitor the key indicators of bare ground, stabilizer species, woody species, and invasive species. We installed the first transects in 2002 and re-sampled these in 2005.

In addition to the quantitative vegetation monitoring, we are using photo monitoring,

GPS collars, and avifaunal surveys to monitor the ecological condition of this landscape in relation to our management. We have established multiple permanently marked photo monitoring locations to document changes over time. In addition, each sheep band is outfitted with a GPS collar at the beginning of the grazing season. This provides us with daily movements of the sheep bands and the ability to compare conditions on the ground with the amount of time and dates when the sheep were located in the area. We have also established a riparian avifaunal monitoring survey using point counts along nine streams and three wetland areas in the Pioneer foothill region.

We intend to expand our monitoring program to include a remote sensing component to allow us to monitor a larger area of the landscape than we can efficiently reach on foot.

EXPERIMENTAL RESEARCH

In addition to the inventory and assessment work and the monitoring program, Lava Lake intends to function as a research site where long-term scientific research efforts can be conducted

The Lava Lake Foundation for Science and Conservation, founded in 2004, was created in part to promote this research. The mission of the Lava Lake Foundation is to promote, conduct and disseminate scientific research on the natural communities, wildlife populations and land use practices of the high desert and mountain regions of the Northern Intermountain region and to restore and conserve native ecosystems at a landscape scale.

In 2005, we established the Lava Lake Research Fund, which is part of the Lava Lake Foundation, to support research that will contribute to an improved understanding and management of sagebrush steppe and montane ecosystems in the West. We will support research on wide ranging species like sage grouse, pronghorn, and gray wolf and endemic species such as the Wood River sculpin. Research priorities that we have identified include:

- identification and development of the best methods for assessing ecological change at a landscape scale resulting from management changes
- sagebrush steppe restoration with the goal of identifying the best methods for restoring the native forb, bunchgrass, and sagebrush components of mountain big sagebrush communities
- invasive weed management with a focus on the best methods for promoting native species in communities with noxious and invasive weeds without long term reliance on herbicides, especially when working at a landscape scale, and
- aspen management with the goal of identifying the best methods to maintain (or improve) the condition of aspen stands within the context of ongoing livestock and wild ungulate use.

Lava Lake has supported two experimental research projects to date, both beginning in 2002. One completed study assessed the effects of cattle and sheep grazing on Lewis's woodpecker nest survival, riparian breeding bird densities, and vegetation in aspen riparian woodlands (Newlon and Saab 2004).

EDUCATION & OUTREACH

Lava Lake is interested in expanding our outreach efforts, particularly to include educational programs for school age students.

CONCLUSION

Lava Lake is pleased to be an immediate neighbor to the National Park Service and BLM and seeks to be an active participant in the conservation and restoration of the landscape surrounding the Great Rift.

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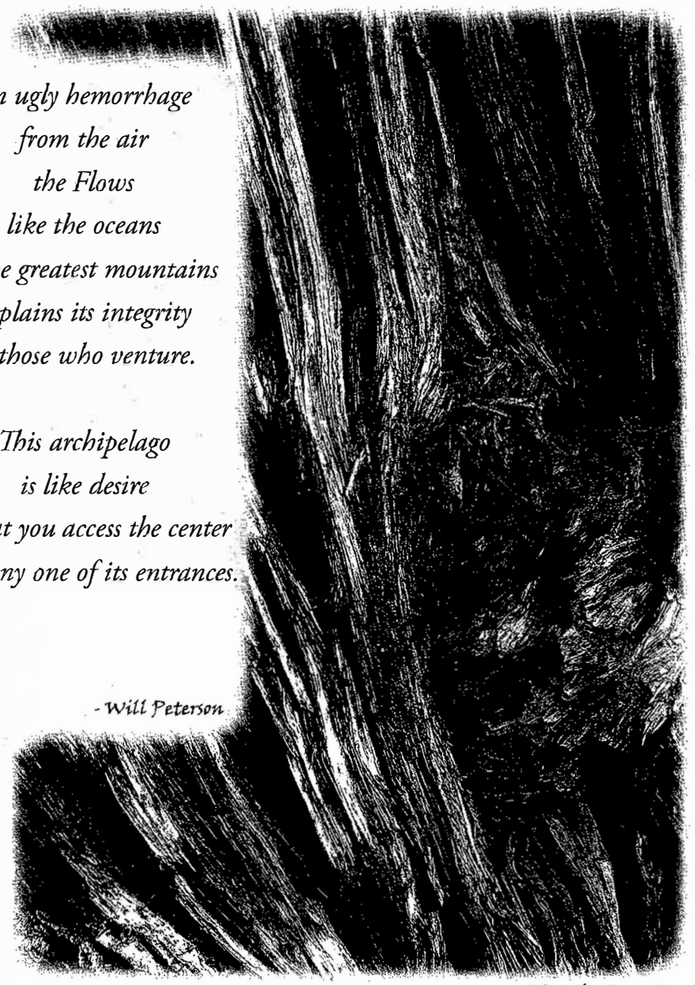
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An ugly hemorrhage
from the air
the Flows
like the oceans
or the greatest mountains
explains its integrity
to those who venture.

This archipelago
is like desire
in that you access the center
from any one of its entrances.

- Will Peterson

Photo by Roger Boe

Radioactivity at Hagerman Fossil Beds National Monument, Hagerman, Idaho

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ABSTRACT

The Idaho State Fossil, the "Hagerman Horse", is radioactive at 1,600 counts per minute. Naturally occurring radioactivity has been measured at Hagerman Fossil Beds National Monument, located in south-central Idaho, in both fossil and mineral deposits since 1996. New information from a sampling of over 300 fossils using a Geiger-Muller instrument indicates radioactive emission levels in some specimens near 7,000 counts per minute. About 45% of the 300 samples exhibited levels above 500 counts per minute. Mineral deposits have also exhibited above ambient background levels at about 130 counts per minute. Non-destructive analysis using X-ray fluorescence has shown the presence of uranium, iodine, strontium, yttrium and nearly all Lanthanide series or Rare Earth elements. The geologic association appears to be that fossils derived from coarse grained sediments are higher in radioactivity, than ones found in clay rich deposits, which are near ambient background levels. The authors suggest that ancient groundwater transported radioactive elements through sand bodies and cavernous basal sections of interbedded basalt flows which precipitated out of solution during the mineralization process. Field results indicate that a Geiger-Muller counter may be a viable tool in the search for and safety determination of fossils.

BACKGROUND

Hagerman Fossil Beds National Monument (HAFO), was commissioned in 1988 to preserve, protect, and provide for the study of the Pliocene fossil assemblage. The Idaho State Fossil, the "Hagerman Horse", was discovered at HAFO, located approximately 90 miles southeast of Boise. Over 1,000 fossil sites have been mapped with mostly terrestrial mammals represented from the floodplain environment of ancient Lake Idaho that deposited the Glenns Ferry Formation (Malde and Powers, 1958). At least 111 radioactive fossil sites have been documented at HAFO, including the "Hagerman Horse Site", but not all of the fossil sites have been tested for radioactivity.

EQUIPMENT

In 1996 high levels of radiation were detected in fossil specimens at HAFO using a Geiger-Muller (GM) instrument (Figure 1). The methods and equipment produce quasi-quantitative results for a surface emission rate but it is sufficient for a preliminary scoping-level investigation. The GM instrument detects primarily beta radiation and very small amounts of alpha and gamma. Readings from the meter are reported as gross counts per minute (cpm)

but the meter is only 33% efficient so the cpm value can be multiplied by a factor of three to obtain a value more representative of the actual emission rate. For example, a meter reading of 500 cpm x 3 equals 1,500 actual radioactive decays per minute. Further, the meter only detects emissions from the facing side of the specimen; the meter will not detect the emission from opposite side of the specimen. Therefore, the 1,500 value would need to be approximately doubled to 3,000 to more accurately reflect the total radioactive emission. Future investigations should use a counting chamber to obtain accurate, precise and total radiation emissions. A cursory analysis was performed at the University of Idaho which identified uranium in measurable quantities up to several percent concentrations (Farmer and Knowles, 1996) and mining claims were filed in the 1950"s within the Monument area for these radioactive deposits.

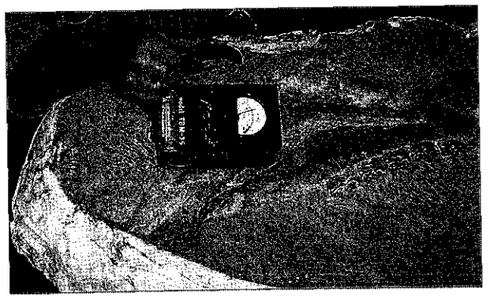


Figure 1. Hagerman Horse mandible fossil tested with a Geiger-Muller instrument.

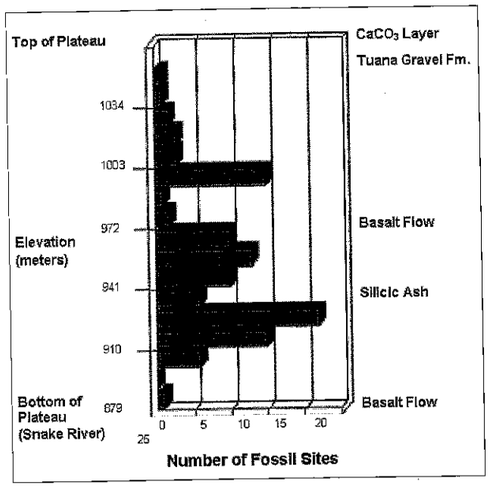


Figure 2. Vertical frequency graph showing 111 radioactive fossil sites (x axis) at HAFO relative to elevations (y axis in meters).

RADIOACTIVITY

During 2005, over 300 fossil specimens were tested with a Geiger-Muller counter TBM-3S manufactured by "Technical Associates" (Figure 1). One hundred thirty six fossils (45%) exhibit levels of 500 cpm or higher, one specimen (cat. # 256) responded at 7,000 cpm. Only one value was selected and included in the testing from the "Horse Quarry Site" to avoid bias in the data due to the high number of radioactive fossils from this one site. Seventy-five percent of the samples tested responded with measurements at twice the ambient background (20-50 cpm) or higher. The meter was checked before and after each sample for ambient background levels. A detailed chemical analysis (Data Chem, 1997) was performed on a fossil specimen that identified the following isotopes; uranium$^{235\ \&\ 238}$, lead $^{210\ \&\ 214}$, bismuth^{214}, radium$^{223\ \&\ 226}$, protactinium^{231}, and cesium^{137}. The chemical analysis correlates to the radioactive character of the fossil specimens during this investigation.

GEOLOGIC ASSOCIATION

A preliminary scoping study, to determine presence, absence and spatial distribution of radioactivity, revealed that most of the radioactive fossils are found in ancient river channels filled with porous fine to coarse grained sand. Generally, the presence and level of radioactivity dissipates in the upper and basal levels of stratigraphy of the plateau by about 30 meters (100 feet). The presence and levels of radioactivity increase in fossils deposited in sand units and decrease in fossils found in clay rich deposits. Porosity appears to play a role in the hypothetical transport of dissolved uranium flowing within ancient groundwater systems through porous geologic deposits.

The original source for the uranium is unknown but it is likely incorporated into the fossil mineral lattice structure through a process of chelation. Dentitions appear to have higher concentrations than other parts of the fossil. The presence of radioactivity appears to dissipate in the upper elevations (Tuana Gravel Formation) based on testing a camel fossil, pine species log, and a $CaCO_3$ layer. It also decreases in the lower elevations of the stratigraphy based on testing an unnamed basalt base at an elevation of 869 meters and minor numbers of fossils. The Shoestring basalt (Malde, 1962) base, located at an elevation of 975 meters, exhibits post-eruption secondary mineralization with FeO_2. Uranium was probably incorporated into this mineralization process from groundwater under the same conditions as the fossils.

SURVEY DATA

Elevations of fossil sites were derived from two different methods. Older surveys used a "Criterion" laser transit tied into benchmarks placed by the U.S. Bureau of Land Management Cadastral division in 1993 to calculate coordinates to an elevation accuracy of 0.3 meter (1 foot). The second method used a combination of horizontal coordinates from a Trimble Pro XR with corrected data to produce horizontal accuracy of about 1 meter. These points were plotted in ArcGIS 8 with five-foot contour line intervals that have a vertical

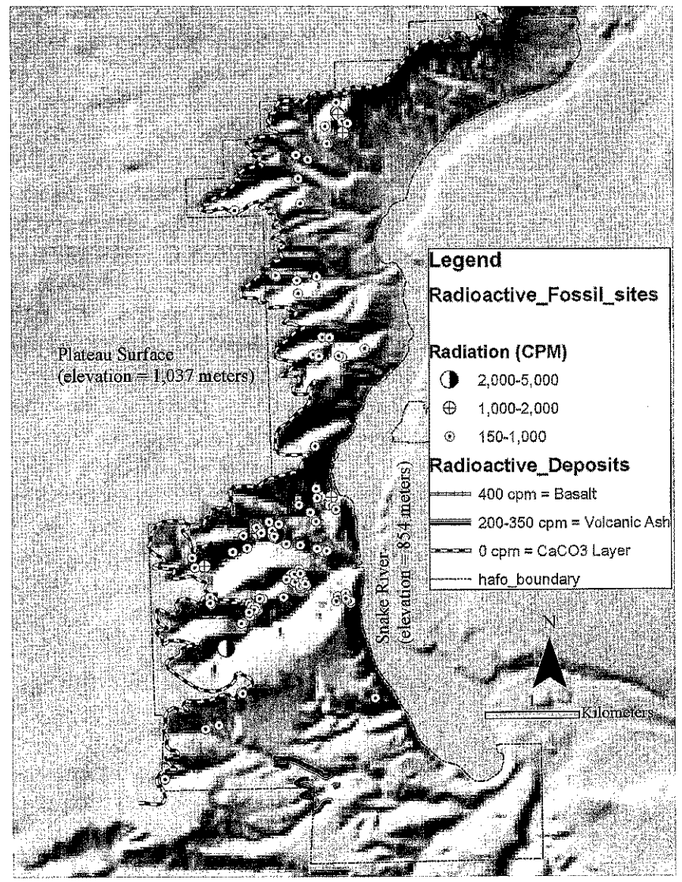


Figure 3. General location map showing horizontal distribution patterns of radioactive fossil sites.

accuracy of 0.10 meter. Fossil site elevations were interpolated based on these contour lines and GPS derived points thereby eliminating the use of GPS elevations which are notoriously inaccurate. Then all of the sites were grouped into 10 meter elevation zone categories shown in Figure 2 as the horizontal bar graphs.

MAPPING

A preliminary map (Figure 3) and vertical frequency distribution graph (Figure 2) were developed using GIS to aid this scoping investigation and park management with identifying the vertical and horizontal distribution of radioactivity. The circles denote radioactive fossil sites with different levels of radioactivity in cpm. The lack of sites in the northern and southern 25% of the Monument is due to less fossil exposure from erosion, more vegetation and ancient landslides. The sinuous dashed line on the left side of Figure 3 is a $CaCO_3$ layer that exhibits only ambient background levels of radioactivity. The $CaCO_3$ layer is located at the top of the formation at an elevation of 1,036 meters (3,400 feet). The black lines in the south area represent the Peter"s Gulch silicic volcanic ash which tested at 70 to 120 cpm. In the north area is the Shoestring basalt flow positioned at an elevation of 975 meters (3,200 feet), mid-level within the geologic section, noted with a black hachured line. The rubble iron oxide base (Figure 4) tested at 400 cpm while the massive part of the basalt above the rubble base is near ambient background levels.



Figure 4. Iron oxide rubble base of the mid-section basalt flow tested at 400 dpm.

The base of the lower unnamed basalt at an elevation of 869 meters (2,850 feet) also tested at ambient background levels and it is located at a low elevation in the formation. The vertical distribution (Figure 2) indicates most of the radioactive sites are located approximately between 900 (2,953 feet) and 1,000 meters (3,281 feet) elevation. The elevation of the Snake River is 854 meters (2,800 feet) and the top of the plateau is about 1,052 meters (3,450 feet). It is unknown why radioactive deposition appears to be concentrated between these elevations.

HUMAN HEALTH HAZARDS

Human health concerns have resulted from the presence of radioactivity. Exposure occurs from handling of specimens during preparation and inhalation of radon and its decay daughter products. Radon gas, a byproduct of uranium decay, has been documented inside fossil storage cabinets with a maximum of 544 and average of 436 pico-Curies per liter (pCi/L) noted in Figure 5 (McBride, 1996). Ambient radon gas concentrations in the fossil storage room have been recorded by National Park Service staff with a maximum typical value of 24 pCi/L. The U.S. Environmental Protection Agency recommends homes with radon gas concentrations of 4.0 pCi/L take action to reduce levels. The National Park Service is deficient implementing corrective protective actions as of 2006 (NPS, 2004); ten years after the initial radon tests documenting high concentrations.

In 2001, HAFO continued to allow children to handle radioactive fossils (Figure 6) at the "Hagerman Horse Quarry Site" during its "Camp Pliocene" summer programs (HAFO, 2001). There are benefits from the radioactive deposits such as using the presence, absence or level of radioactivity as a tracer to assist with mapping the distribution of geologic deposits and fossils on the Monument.

Usage of a Geiger-Muller counter during field work assisted Monument staff with the discovery of a recent Mastodon fossil tusk which was determined to be radioactive at 350 cpm. There is potential to use the radioactivity as a tracer to determine ancient sediment source areas and age dating.

CONCLUSIONS

Naturally occurring radioactivity is well documented at Hagerman Fossil Beds National Monument at highly elevated concentrations. The official "Idaho State Fossil" site is radioactive at 1,600 cpm. It is unknown why the spatial distribution of radioactive fossil sites occurs primarily between an elevation zone of 900 to 1,000 meters. They are most commonly found associated with ancient river channels filled with sand and fossils found in clay rich deposits do not exhibit discernable levels of radioactivity. Similarly, the basalt low in elevation exhibits ambient background levels while the upper basalt has higher levels. Radon is documented in fossil storage collection facilities at highly elevated concentrations up to 544 pCi/L. About 45% of 300 fossils tested with a Geiger-Muller instrument resulted in responses of 500 counts per minute or higher and 75% exhibited radioactivity at twice the ambient background or higher. Further detailed investigations are ongoing at this time.

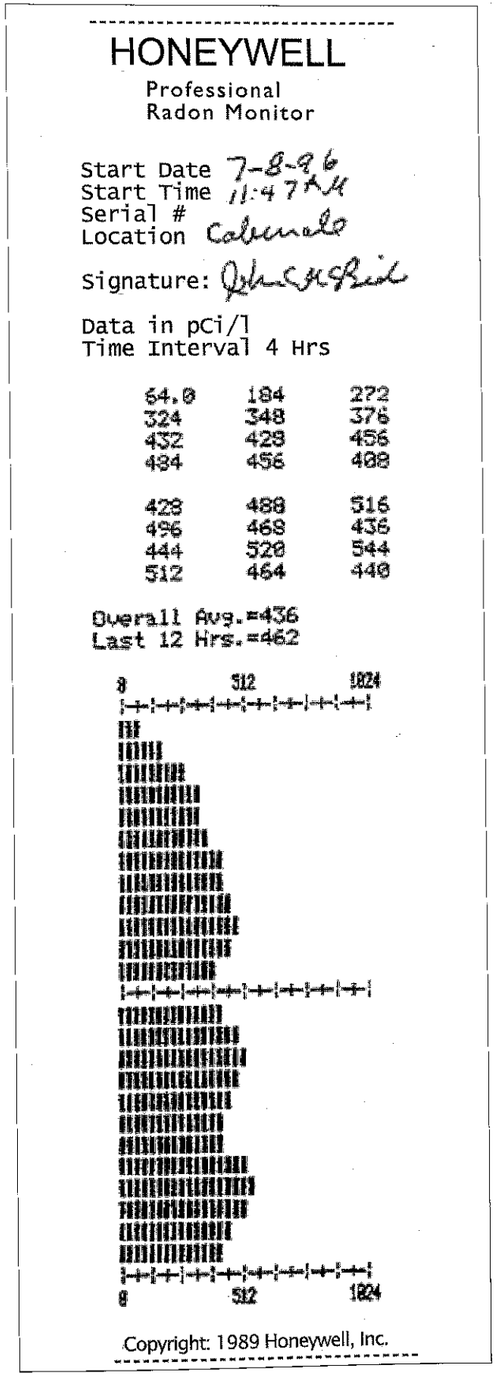


Figure 5. Radon concentration test inside fossil storage cabinet.

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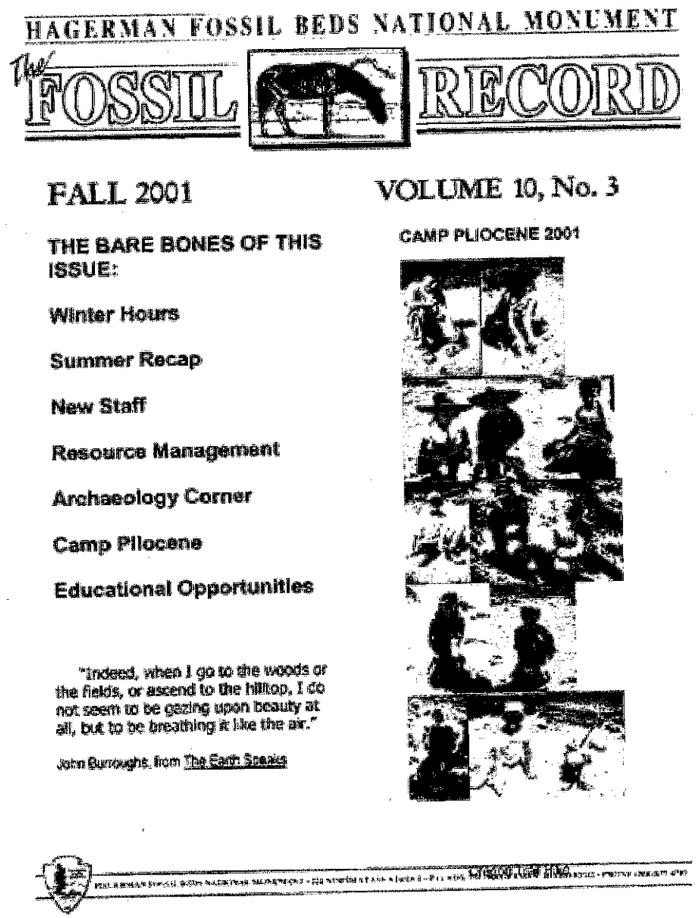
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ACKNOWLEDGEMENTS

I would like to thank Bob Willhite, former Park Ranger, for his support of this project from 1996 through 2001. I would like to thank the manuscript reviewers and Hagerman Fossil Beds staff for testing fossils for radioactivity.



HAGERMAN FOSSIL BEDS NATIONAL MONUMENT

The FOSSIL RECORD

FALL 2001 VOLUME 10, No. 3

THE BARE BONES OF THIS ISSUE:

Winter Hours

Summer Recap

New Staff

Resource Management

Archaeology Corner

Camp Pliocene

Educational Opportunities

"Indeed, when I go to the woods or the fields, or ascend to the hilltop, I do not seem to be gazing upon beauty at all, but to be breathing it like the air."

John Burroughs, from The Earth Speaks

CAMP PLIOCENE 2001

Figure 6. Children handling the radioactive "Hagerman Horse" Idaho State fossils.

Keynote Speakers



Lava Super-eruptions; Environmental and Landscape Effects

Stephen Self
Volcano Dynamics Group, Dept. of Earth Sciences,
The Open University, Milton Keynes, United Kingdom

How will the next volcanic super-eruption affect us? Stephen Self will begin by explaining how plains-type basaltic volcanism, defined from lava fields such as the Craters of the Moon and others in the western USA, occurs and changes the landscape. Drawing on information from similar historic events such as Laki (Iceland) in 1783-84 and Lanzerote (Canary Islands) in 1730-36, which both erupted approximately 10-15 cubic kilometers of magma, the formation of fissure vent systems (like the Great Rift), the output of lava from the vents, and the emplacement of the lava flow fields will be discussed. Magma degassing is an important aspect of such eruptions. The severity and style of atmospheric impact that may arise from volatile releases during a future plains-type eruption will be highlighted.

Self will then scale-up to lava super-eruptions, or the formation of flood basalt provinces, which have occurred spasmodically throughout Earth history. These huge lava provinces have volumes ranging from 100s to millions of cubic kilometers, such as the Columbia River Basalt and Deccan
(India) provinces. They were produced at extremely fast rates and are distinguished from all other basaltic volcanism by the repeated effusion of huge batches of magma. Self's studies of the Columbia River Basalt lava flows suggest that eruptions of this magnitude last in the order of a decade and are capable of emitting huge amounts of sulfur dioxide gas. The potential atmospheric impact of such large-scale, long-term events is being investigated, but even smaller ones, such as Laki, have had disastrous effects.

Stephen Self has studied volcanoes and volcanic rocks in almost every part of the world and has written over 140 articles in the scientific press and popular magazines. He has taught short courses for universities and industry, and has been a keynote speaker at international conferences. Self was previously a Professor in the Department of Geology and Geophysics at the University of Hawaii. He now holds the Chair in Volcanology at the Open University, UK, and heads the Volcano Dynamics Group in the Department of Earth Sciences. He is currently leader of the UK's Volcanic and Magmatic Studies Group and coauthor of the Geological Society's Working Group report on Super-eruptions. His research interests include large-scale basaltic volcanism, mechanisms and deposits of explosive volcanic eruptions, and the effects of eruptions on global climate and the environment.



Archaeology and Human History on Idaho's Snake River Plain

C. Melvin Aikens
Emeritus Professor, University of Oregon

People have lived on the Snake River Plain for perhaps 15,000 years, since the waning of the last ice age. Their cultures changed again and again over that time, always being shaped by the area's distinctive natural environment. Archaeological evidence, interpreted through the medium of Native American traditional knowledge, reveals the human story.

C. Melvin Aikens began his archaeological career in 1958 as an undergraduate field assistant on the Glen Canyon archaeological project in southeastern Utah. After several years work in the Southwest, he developed research interests in the broader intermontane western region, especially the Great Basin, which he continues to pursue. He served for a number of years as Head of the Department of Anthropology and currently serves as Director of the University of Oregon Museum of Natural History. He holds a B.A. degree in Anthropology from the University of

Utah (1960), and M.A. and Ph.D. degrees in Anthropology from the University of Chicago (1962, 1966). Aikens was elected a Fellow of the American Association for the Advancement of Science in 1983, and named the Oregon Academy of Science Outstanding Scientist for 1990. In 1995 he received the High Desert Museum's Earle A. Chiles Award, recognizing "accomplishments in promoting thoughtful management of the natural resources of the Intermountain West." Dr.. Aikens has directed the UO Archaeological Field School since joining the University of Oregon faculty in 1968-69. His research focuses on the archaeology of the Great Basin of North America and of Japan, with collateral interests in the archaeology of their encompassing regions. He is author or editor of fifteen books and many book chapters and journal articles.

The Sagebrush Ocean: A Naturalist's Vision of the Great Basin



Stephen Trimble
Writer and photographer

Come with Stephen Trimble to the Great Basin Desert. Enter sagebrush seas, climb island mountains, stand in the center of dry lake-beds and look to a horizon where mountains recede in a haze of mirage. Nowhere else in the West is there such a continuous sweep of undeveloped country filled with such silence. The Great Basin Desert —an ocean of sagebrush— sweeps from the Sierra to the Rockies, from the Snake River Plain to the Mojave Desert. "Biogeography" best sums up Trimble's focus on this land: what lives where, and why. He introduces concepts of desert ecology and discusses living communities of animals and plants that band Great Basin mountains —from the exhilarating emptiness of dry lake-beds to alpine regions at the summits of the 13,000-foot Basin ranges. In this fascinating slide show, Trimble will share stories and photographs from his books, The Sagebrush Ocean: A Natural History of the Great Basin, winner of The Sierra Club's Ansel Adams Award and The High Desert Museum's Chiles Award, and Earthtones: A Nevada Album, winner of the Shepperson Award from the Nevada Humanities Council.

As writer, editor, and photographer Stephen Trimble has published nineteen books. His bedrock focus is the land—western wildlands and natural history—including: The Geography of Childhood: Why Children Need Wild Places (with Gary Nabhan) • The Sagebrush Ocean: A

Natural History of the Great Basin • Earthtones: A Nevada Album (with Ann Ronald) • Blessed By Light: Visions of the Colorado Plateau • and • Words From the Land: Encounters with Natural History Writing. Trimble spent ten years listening to Southwest Indian people, and their stories fill his books: The People: Indians of the American Southwest • Talking With the Clay: the Art of Pueblo Pottery • and • Our Voices, Our Land. He has also contributed commentaries to local and national NPR shows, especially "The Savvy Traveler." Stephen Trimble was born in Denver, his family's base for roaming the West with his geologist father. After a liberal arts education at Colorado College, he worked as a park ranger in Colorado and Utah, earned a master's degree in ecology at the University of Arizona, and served as director of the Museum of Northern Arizona Press. He has been a full-time free-lance writer and photographer since 1981. Trimble makes his home in Salt Lake City and in the red-rock country of Torrey, Utah, with his wife and two children.

Stephen Trimble's presentation was made possible in part by a grant from the Idaho Humanities Council.

ISTA WORKSHOPS

(Listed alphabetically by name of the primary presenter)

Rick Alm, Science Chair, Bonneville High School, Idaho Falls, Idaho
NSBRI Space Physiology

NSBRI–National Space Biomedical Research Institute approved activities to relate space travel effects on human physiology. The microgravity environment is pretty tough on the human body. These activities illustrate some of these effects. Topics include bone density, balance and cardiovascular fluid shift. All topics include an activity to relate the concepts to students. Handouts and a CD of the presentation will be available.

Larry Barnes, Teacher, Wood River High School, Hailey, Idaho
Increase Student Participation with Quizdom Audience Response System

Quizdom is an audience response system that encourages student participation. You may insert questions into your powerpoints and check comprehension during your presentation. Students may use the Quizdom remotes to enter their test responses. There are many review games that are fun ways for students to review for tests. Teaches high school biology and been using Quizdom for two years.

Larry Barnes, Teacher, Wood River High School, Hailey, Idaho
Success with Tom Lord's Constructivism in High School Biology

Over several years I have attempted to adopt some of college professor Thomas Lord's ideas on constructivism in my compulsory biology classes. Ideally, students construct their own knowledge through inquiry-based activities; traditional notes are eliminated. While I still retain some notes, I have made my classes more interesting and fun by moving toward constructivism through team activities and open-ended problems. I will share the successes and pitfalls I have experiences during my shift from teacher-centered learning toward student-centered learning.

Larry Barnes, Teacher, Wood River High School, Hailey, Idaho
Using the Free Quizstar Website to Write Tests and Assess Students Online

Quizstar is a free online resource that teachers may use to test their students. The teacher enters a test and then makes it available to students who take the test in or outside of class depending on the teacher's desire. I began using Quizstar in 2004-05 and am continuing this school year. Grading is instantaneous and retesting can occur outside the classroom. Teachers may use images and sounds to make fun and challenging tests.

John Black, National Science Consultant, McDougal Littell
The McDougal Science Toolkit — A Unique Resource

Join us for this presentation of a binder filled with time-saving lesson plans, strategies, and transparencies that will enhance students' science skills. A unique teaching tool!

Mick Bowen, Aerospace Education Specialist, Oklahoma State University / NASA AMES Research Center, Bozeman, Montana
NASA Educational Resources for your Classroom Using World Wind (Virtual 3D Earth) and Celestia Exploration Activity (Real-Time Space Simulation Add-On to the Celestia Program)

World Wind lets you zoom from satellite altitude into any place on Earth. Leveraging Landsat satellite imagery and Shuttle Radar Topography Mission data, World Wind lets you experience Earth terrain in 3D. Look across the Andes, into the Grand Canyon, over the Alps, or along the African Sahara. Explore the solar system in real time or visit the past and or the future. See the moons of the planets or various spacecraft that may be orbiting a particular planet. NASA has free educational resources and materials related to science, technology, engineering and mathematics for grades K-12 teachers.

Kevin Collins, Science Coordinator, Idaho Department of Education, Boise, Idaho
Keeping the Focus on Quality Instruction: Teaching Science Better

As a result of the Spring 2005 field test of the Science ISAT, there is a renewed interest in teaching science across Idaho. As professional educators we must focus our instructional efforts on student learning of materials that will be significant to the lives of our students. Recent research gives us insights into instructional methods for science instruction that work and also boost reading and writing and math skills at the same time. This presentation will cover the organizational frameworks for the science ISAT and give insights into teaching strategies that support learning.

Kevin Collins, Science Coordinator, Idaho Department of Education, Boise, Idaho
Understanding Idaho's Science Achievement Test

To meet the requirements set forth by the federal law known as No Child Left Behind, Idaho is developing a science exam based on a subset of the science standards now know as the Science Power Standards. This presentation will discuss the history of how the Power Standards were identified, the focus of item writing and what can be done to help teachers foster learning of science in their classrooms.

Chris Corwin, Environmental Health Education Specialist, Idaho Department of Health and Welfare, Boise, Idaho
Integrating Environmental Health into your Existing Curriculum

This workshop will give teachers ideas on how to integrate environmental health issues into their already existing curriculum. Through demonstrations and environmental health lesson plans, teacher will be able to use environmental health to reinforce the concepts they have just learned in their science or health class. It will give them real world applications and help them become critical thinkers. This information can also be used in English, history or math classes. It's curriculum integration using environmental health.

Alexa Davis, University of Idaho, Moscow, Idaho
Voyage Through Time Curriculum Modules

This workshop will focus on Voyages Through Time (VTT) an integrated science curriculum based on the theme of evolution and delivered on CD-ROM. The curriculum is divided into six modules: Cosmic Evolution, Planetary Evolution, Origin of Life, Evolution of Life, Hominid Evolution, and Evolution of Technology. Individual modules can also be used in discipline-based science courses such as biology, earth science, geology, or astronomy. The over-arching goals for Voyages Through Time are for students to understand: 1) evolution as cumulative changes over time, 2) the various processes underlying these changes 3) the differing time scales and rates of change 4) the connections and relationships across these realms of change 5) science as a process for advancing our understanding of the natural world.

Jo Dodds, Earth Science Teacher, O'Leary JHS, Twin Falls, Idaho
Linda Selvig, Earth Science Teacher, Centennial HS, Meridian, Idaho
ASSET: Astrobiology Summer Science Experience for Teachers

Engage your students in hands-on, inquiry-based astrobiology activities. We will share the latest in astrobiology research on the origin of life on Earth, the extreme conditions in which life exists, Mars exploration, the formation of planetary systems around Sun-like stars, and the search for life in the universe. Voyages Through Time curriculum will be showcased in this session.

Jo Dodds, Earth Science Teacher, O'Leary JHS, Twin Falls, Idaho
REVEL (Research and Education: Volcanoes, Exploration and Life) Project

Have you thought about going on a seagoing research expedition and working with scientists? Can you fathom the life that exists on the ocean floor at hydrothermal vents? Teachers have the opportunity to participate in the REVEL project, to research, discover, and learn about the hydrothermal vent environment. While on ship, teachers interact with their students, engaging them in oceanographic challenges.

Jo Dodds, Earth Science Teacher, O'Leary JHS, Twin Falls, Idaho
Science with Handhelds
Students will be using Palm handheld units in conjunction with Vernier probes to go outside the classroom for their investigations. Students can use the handheld units to collect, display, graph, print, and analyze data. Come to this session to get experience using the Palm handheld units and probes with experiments and demonstrations formerly done with devices such as thermometers, pH strips and stopwatches.

Laura Eder, middle school science teacher, National Energy Foundation, Rigby, Idaho
Identifying Rocks and Minerals

Workshop participants will learn how to identify rocks and minerals. Topics to be addressed: the rock cycle, mineral identification and the classification of rocks. Teachers will receive many quality items for classroom use including a rock and mineral kit.

Marjorie Freeman, 8th Grade Science Teacher, Lewis and Clark Middle School, Caldwell, Idaho
A Patchwork of Ideas for the Science Classroom

Teachers will be introduced to the techniques of the use of student-produced quilts in the classroom. Various methods including natural dyes, appliqué, stamping and other methods will be taught. Teachers will be given handouts on methods and materials needed and will produce a patch using one of the methods demonstrated. Making quilt patches is a unique way to encourage students to investigate measuring, math, chemistry and their artistic abilities. This activity ties in with the Idaho State Standard of Technology in the classroom as well as the History of Science.

Bob Fuhrmann, Education Coordinator, Yellowstone National Park, Yellowstone NP, Wyoming
Yellowstone's Geysers, Earthquakes, and Supervolcanoes – Teaching Strategies

Explore unique ways of teaching about the geological events that shape the bow of the Great Rift Zone in Yellowstone National Park. Join Yellowstone's Education Coordinator to learn how to: make a caldera collapse, feel a caldera, and make a geyser. Learn about some of Yellowstone's educational opportunities both in your classroom and in the park. Expedition: Yellowstone!, a curriculum-based, residential program for grades 4-8, will be highlighted.

Timothy Gunderson, Teacher, Burley High School and College of Southern Idaho, Burley, Idaho
Visiting the Moon – Without Leaving Idaho

The volcanic features on the Snake River Plain are some of the best examples of plains-style volcanism found anywhere in the world. These features have been used to train geologists for many years. With the advance of space exploration in the mid-1900's, there was a need to train future space geologists. The Snake River Plain was the perfect laboratory. The main focus of this project is for students to train themselves how to identify volcanic features from images and descriptions of Snake River Plain volcanism. Students then view images of the Moon, Mars, and Venus and identify those same volcanic features. Participants would learn to differentiate between meteor craters and volcanic craters and identify flow fronts, lava tubes, lava channels, rilles, rifts, grabens, cinder cones, pancake domes, ash deposits, pressure ridges, and wrinkle ridges.

Virginia Jones, Science Teacher, MESSENGER Fellow, Bonneville High School, Idaho Falls, Idaho
MESSENGER Mission to Mercury for Elementary and Middle School Teachers

MESSENGER, our first mission to Mercury, blasted off in August 2004. In this workshop you will learn how to bring the magic of space travel into your classroom with inquiry-based lessons that are tied to Idaho State Standards. Science ISATs are here and the MESSENGER program can help you prepare your students for them.

Virginia Jones, Science Teacher, MESSENGER Fellow, Bonneville High School, Idaho Falls, Idaho
MESSENGER Mission to Mercury for High School and Middle School Science Teachers

The MESSENGER spacecraft is on its way to Mercury! Learn how to use inquiry lessons to teach Idaho Science Standards. This workshop will include challenging lessons appropriate for all high school science classes. You will also get a CD of all of the lessons as well as a beautiful poster.

Virginia Jones, Science Teacher, MESSENGER Fellow, Bonneville High School, Idaho Falls, Idaho
The Genetics of Addiction

Learn about the latest research on how genetics influences addiction. You will receive some great lessons that you can use in your biology and health classes.

Martha Kelley, Third Grade Teacher / ISAT Elementary Representative, Hope Elementary School, Hope, Idaho
Rhetta Anderson, First Grade Teacher, Hope Elementary, Hope, Idaho
BLAST OFF!!! Design, Build and Launch your own Rocket

Participants will experience a hands on workshop with bottle rockets. Every participant will be given a 2 liter bottle to design a rocket. They will have the experience of launching their rocket. Examples of journaling will be shared. Samples for journals and directions for launch boards will be provided at the end of the session.

Lee Leroy, teacher, St. Maries HS, St. Maries, Idaho
Mnemonics – Help Students Quickly Memorize Terms so You Can Get on to the Really Important Work

In the days before books were widely available, people relied almost entirely on their memories. All over the world, people developed similar systems for improving memory. These skills are largely lost in today's world of instant access to vast amounts of information. In this workshop, we will explore (and practice using) a variety of techniques to improve memory. Using examples from biology, participants will learn to use daisy chains, the peg method and numerical systems to help students quickly memorize even complicated technical terms and their meanings. Participants will then put together a set of mnemonics for their own classes.

Paul Link, Professor, Diana Boyack and Laura DeGrey, Instructors, Dept. of Geosciences, Idaho State University, Pocatello, Idaho
Digital Geology of Idaho: New Web-Based Vehicle to Teach Earth Science Standards

The Digital Geology of Idaho project accessible via (imnh.isu.edu/digitalatlas), provides geologic teaching units, Powerpoint slide presentations on Idaho geology, and lab exercises for high school and college students. Colorful geologic maps of Idaho counties are tied to photographs and text describing the various geologic provinces of Idaho. The workshop will familiarize teachers with this new resource, which contains information on all aspects of Idaho geology, from the Silver Valley to the Bonneville Flood and from the Yellowstone Hot Spot to the Accreted Terranes.

Carolynne Merrell, Contract Archaeologist specializing in rock art recording, Archaeographics, Moscow, Idaho
Rock Art Recording Methods and Educational Opportunities

This workshop will address methods used to record pictographs and petroglyphs and the way to approach and document rock art sites. Emphasis will be placed on how nonprofessionals can do their part to become good stewards of rock art sites. One focus will identify safe ways people, including children, can visit and record pictographs and petroglyphs. Two hands on activities will conclude the workshop. All rock art examples will be from sites in the region of the Great Rift.
Professional archaeologists, resource managers and educators will find value in the material presented during this workshop, which can be applied to their individual areas of rock art interest.

Teri Mitton, Science Teacher, Highland High School, Pocatello, Idaho
Jennifer Claypool, Graduate Student, Idaho State University, Dept. of Biological Sciences, Pocatello, Idaho
Outdoor Science: Using Science to Assess the Environmental Health of a Local Area

How do you get students to take part in the scientific process instead of doing the minimal requirements for a grade? How do you provide a meaningful lab experiences to students? How do you motivate students and pique their curiosity? This workshop will answer these questions and more. Come and learn how to have high school students do soil pH tests, invertebrate counts, plant density counts, and biodiversity estimates on the school campus and their own backyard. This presentation will address how to use biota as indicators and how to do basic data gathering.

Douglass Owen, Park Interpreter / Geologist, and Ted Stout, Chief of Interpretation, Craters of the Moon National Monument and Preserve, Arco, Idaho
Introduction to Using Craters of the Moon as an Outdoor Classroom

Craters of the Moon National Monument and Preserve protects ~750,000 acres (1,100 sq. miles) encompassing most of the Great Rift, the best example of a volcanic rift zone on the eastern Snake River Plain (ESRP). Of the eight geologically young lava fields on the ESRP, the Monument encompasses the three youngest and least altered. The Kings Bowl and Wapi lava fields and much of the Craters of the Moon lava field are only about 2,000 years old and their age, coupled with the desert climate, makes them phenomenal areas to observe geologic features associated with basaltic volcanism. Features include deep open-crack rift sets, spatter ramparts, cinder cones, spatter cones, pressure plateaus, tumuli, hornitos, volcanic bombs, and different kinds of lava. The Monument also protects vast areas of sagebrush steppe habitat and provides home to 58 mammals, 3 amphibians, 10 reptiles, 660 plants, and over 200 birds. The National Park Service (NPS) and Bureau of Land Management (BLM) provide a wide range of educational opportunities from elementary to college level. This workshop will provide an introduction to using this fantastic resource as an outdoor classroom.

Ralph Peterson, Teacher, North Gem High School, Bancroft, Idaho
Non-Confrontational Evolution

Once students understand the Nature of Science, the so-called controversy of evolution is diminished. This workshop will study the limits of science using a hands-on approach. This will be used to show why evolution is a good scientific theory.

Vana Richards, 5th grade teacher, Carberry Intermediate School, Emmett, Idaho
Drawing Them in and Making Family Science Nights Successful

Learn how to set up hands on science activities that will draw families in and leave them wanting more science nights. Try out and take home, quick easy activities, which teach basic science principles, to use in your classroom or at a family science night. This workshop will give teachers hands on science activities that can be used at family night, or in the classroom. Take activities such as make and take comets, blood, stomach acid, g-force suits, and NASA activities back to your classroom. The How To's of setting up a successful family night, from the initial planning to the actual night will be covered. Learn how to select themes for your family science nights and use passports to move families through your activities.

Vana Richards, 5th grade teacher, Carberry Intermediate School, Emmett, Idaho
From the Jelly Lab to Gummy Bears – Teaching Variables and Measurement

This workshop is a fun easy way to teach students how to make a hypothesis, use metric measurement, record data, and understand how variables affect outcomes in experiments. Using only jelly on bread students discover through experimenting and recording results how variables affect their predicted (hypothesis) outcome. Students will become familiar with scientific terms and how to record and graph results that lead to support for their hypothesis. The second part of this workshop uses gummy bears to teach the basics of mass, weight, volume, density. In a follow up to this lab, students will be predicting outcomes and reviewing how to find mass, weight, volume, and density, with some interesting results.

Eric Rude, Teacher, Pocatello High School, Pocatello, Idaho
The Perfect Crime: A Forensics Simulation for High School Students

The eerie glow of a blue light being used to find evidence, the swirling of a brush to develop latent fingerprints, hair samples being examined under the microscope: the beginning of a new episode of CSI? No, these are my students finishing their forensic science unit. After learning—and practicing—fingerprint identification, soil analysis, blood typing, and much more, my students are ready to solve a crime. So, I set up a simulated crime scene, we round up the usual teachers—er, suspects—gather evidence, and finally handcuff the killer. The students show me what they have learned, and enjoy the reward of a mystery solved. In this presentation, I will demonstrate some ways in which teachers can create their own forensics lab kits, ranging from the almost no-cost to the more expensive. Teachers will learn a variety of techniques, explore sources of equipment, and discover how to set up their own perfect crime—for their students to solve.

Steve Shropshire, Associate Professor, Idaho State University, Pocatello, Idaho
Make & Take Electromagnetic Toys

Participants will make electromagnets, simple motors, sound-bite speakers, and plastic cup speakers. Electromagnets will be made with nails and wire. Motors will be made from batteries, wire, refrigerator magnets, and paper clips. Sound-bite speakers will be made from hobby motors, speaker wire, and a craft stick. Plastic cup speakers will be made with magnet wire and refrigerator magnets. Discussion will focus on the use of these constructions to address state standards on Concepts of Physical Science, Scientific Inquiry, and on Unifying Concepts of Science for grades 3 and above. Teachers will take home all items they construct. Participants will also be provided with a list of related resources in print and on the web.

Steve Shropshire, Associate Professor, Idaho State University, Pocatello, Idaho
Waves and Sound Make & Take Activities
Participants will engage in an inquiry activity investigating sound transmission through yarn and metal spoons to illustrate implementation of the K-4 Content Standard on Science as Inquiry. Investigations into the relations between yarn tightness, weight, length and the pitch and volume of sound carried in the yarn will be encouraged. Participants will make soda straw reed pipes, film can crumhorns, and construct wave machines out of straws, tape and paper clips. Teachers will be instructed on how to guide their students through these constructions to teach Physical Science (Standard B) as outlined in the Content Standards for grades K-4, 5-8 and 9-12. The reed pipes, crumhorns, boomwhackers, and pvc poppers will be used to illustrate energy transmission through sound, the concept of resonance, and the Bernoulli effect. The wave machines will be used to illustrate energy transmission through vibration, the properties of waves on reflection and transmission, and the dependence of the speed of waves on stiffness and weight.

Rosemary J. Smith, Associate Professor of Biology, Idaho State University, Dept. of Biological Sciences, Pocatello, Idaho
Inquiry-based Lessons to Teach Biology Using Native Plants and Animals

This workshop will involve teachers in four inquiry-based science lessons that use organisms from the sage-steppe ecosystem to teach biological concepts. The basic principles of an inquiry-based approach will be followed, and teachers will receive materials and handouts for implementing the lessons in their own indoor and outdoor classrooms. The lessons were developed by Project BioLearn, a National Science Foundation-funded project, in collaboration with the ISU Dept. of Biological Sciences and College of Education. All of the lesson plans have a regional environment (the sage-steppe ecosystem) focus and are designed for middle and high school science students.

Joyce Sutter, representative, Harcourt School Publishers, Boise, Idaho
Elementary Science, They Love To Get Their Hands On It!

This elementary workshop is designed for teachers for grades 1-5. Participants will have an opportunity to do and take hands on science activities appropriate for those grades. Teachers will also have an opportunity to discuss successful teaching strategies for the elementary classroom.

Marv Tolman, Professor of Elementary Education, Brigham Young University, Provo, Utah
Using Inquiry Activities to Teach Science in the Elementary Classroom

We will do several hands-on activities related to the topics of air and water. These activities are easily adapted to various ages within the elementary grades.

Michael Wiedenfeld, Research/Technology Teacher, Treasure Valley Mathematics and Science Center, Kuna, Idaho
Dynamic Student Presentations through the Use of Movie-making Software

Ever want to give a news broadcast from Mars?? How about following a bite of a candy bar through the digestive system? Use Windows MovieMaker (free!), Visual Communicator (not free) and/or StudioDV (not free) to provide students with the opportunity to showcase their learning through movie-making. Movie-making provides an alternative to Powerpoint or other electronic presentations and engages students by allowing them to create newscasts that can even include green screen technology. Topics from science, social studies, historical figures and re-enactments, etc. are great ways to utilize movie making as a method to showcase student learning. More importantly . . . it's easy!!

Walter Woolbaugh, Region XV NSTA Rep., Manhattan School, Manhattan, Montana
The Magic of NSTA

The goals of this sectional are two fold. One is to acquaint the participants with many of the resources that NSTA provides. Some of these resources include scilinks, a web based series of content specific science topics. The four NSTA journals provide a wealth of content information, inquiry-based science activities, demonstrations, and a vast array of teaching strategies. The science store offers a large assortment of books on a variety of science topics. A second goal of this sectional is to demonstrate a variety of science activities that might be useful in the teaching of science lessons. Whether these are discrepant type events or inquiry-based problems, there should be something for all teachers in all grade levels. All of these activities will be presented using a variety of teaching strategies and a variety of formative assessment techniques.

Field Trips

Craters of the Moon: Outdoor Classroom
Leader: Douglass Owen, Geologist, Craters of the Moon Park

The Craters of the Moon Visitors Center will be the first stop on this tour. Then we will head out into the park to examine spatter cones, volcanic vents, cinder cones, Broken Top Loop, lava-tube caves, and many other world-class examples of rift volcanism. In addition to geology, this tour will provide opportunities to study plant and animal adaptation in an extreme volcanic desert environment. Teachers will gain insight into learning opportunities at Craters of the Moon National Monument and the Great Rift. This bus tour includes waypoint stops and several short hikes.

Geology of the South Great Rift Volcanic Zone
Leaders: Mel Kuntz and Duane Champion, U.S. Geological Survey

The northern part of the Great Rift (at Craters of the Moon National Monument) receives much attention, but the southern port of the Great Rift has amazing and perhaps equally remarkable volcanic features. Recent geologic mapping, paleomagnetic studies, and argon-argon dating

provide a new perspective on the geologic evolution of the southern part of the Great Rift volcanic rift zone. Led by two of the premier scientific investigators of Great Rift geology, this tour interprets various volcanic processes and how they produced the remarkable and unique volcanic features of the Great Rift. Visit Creon's Cave, King's Bowl, Cottrell's Blowout, Inferno Chasm, and the Wapi lava field, among other features. This van/Suburban tour includes waypoint stops, short hikes, and includes a printed field guide.

King's Bowl/South Grotto/Pillar Butte/Wapi Lava Field
Leaders: Scott Hughes, Professor and Chair, Geosciences, Idaho State University, and David Freiberg, Outdoor Recreation Planner, Bureau of Land Management

Hike on a lava lake, discover a steam-blast explosion crater, peer into the Great Rift eruptive fissure system, climb one of the world's largest spatter cones, and hike across the Wapi lava field to Pillar Butte eruptive center on this tour of some of Craters of the Moon National Monument's most spectacular and accessible geologic features. This van/Suburban vehicle tour and lava hike takes place in the southern part of the Monument. In addition to several short walks, the hike to Pillar Butte covers three miles round-trip over open lava and can be moderately strenuous. Includes printed field guide.

Lava Tube Cave Tour
Leaders: Silver Sage Grotto (National Speleological Society) of Twin Falls

Venture into the underground wilderness. Learn about the primary mechanism of lava transport and volcanic genesis through a tour of Government Cave, a public land lava-tube. This one-day tour will provide an in-depth look at lava-tube formation, caving practices, volunteer cave management, cave conservation and ecosystems, cave education opportunities and learning environments. This van/Suburban vehicle tour includes waypoint stops, a cave hike, and other short hikes. Helmets, headlamps and knee pads will be provided.

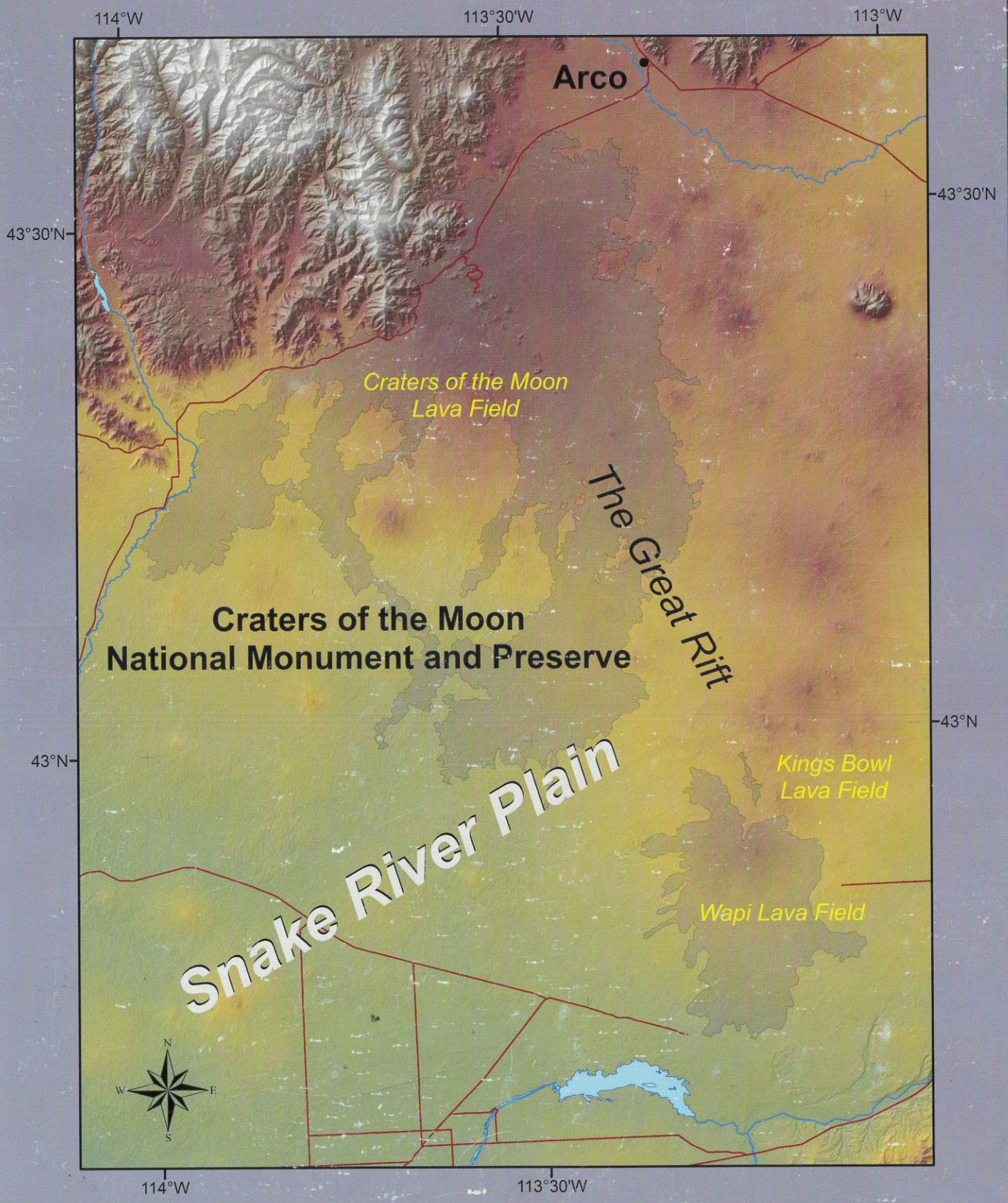
It was beautiful out there.
It was nice as you'd ever see a place:
having the wind
and the sun scarlet on the flows
the waves coming in
garlanded with paintbrush
and meadowlark riffs.

And raising your arms
you savored the wind with your arms
as if you had hawk's blood
as if this were the sea.

- Will Peterson



Photo by Roger Boe



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