C406

Volcanic Geology of Craters of the Moon National Monument

Background Information

Compiled by David Clark, Park Interpreter, 1984

OUTLINE

I. Regional Setting/Pacific Northwest
- A. Cascade Range
- B. Columbia Plateau
- C. Snake River Plain
- D. Basin and Range Province
- E. Craters of the Moon/The Great rift

II. History of Eruptions at Craters of the Moon
- A. Past Volcanic History/Eruptive Sequence
- B. Fissure Eruptions

III. Silica Levels

IV. Formations, Features and Characteristics
- A. Cinder Cones
- B. Spatter Cones
- C. Pahoehoe Lava
- D. AA Lava
- E. Blocky Lava
- F. Lava Tubes
- G. Cinders and Bombs
- H. Tree Molds and Lava Trees
- I. Coloration
- J. Lava Depth
- K. Formation of Aa Lava From Pahoehoe Lava
- L. Minerals
- M. Bedrock Composition
- N. Vesicles
- O. Joints in Lava Flows
- P. Xenoliths

V. Future and Conclusions
- A. Prediction of Future Eruptions
- B. Warning Signs

I. Regional Setting/Pacific Northwest

A. Cascade Range

Bingham--Bio #4--Mount St. Helens is just one of 15 majestic volcanic peaks capping the rugged coastal Cascade Range from southern British Columbia to northern California. The chain of volcanoes is the surface manifestation of an ongoing collision between two crustal plates -- the North American plant and the tiny Gorda plate (see National Geographic on which plate this is) that lies offshore. At the boundary between the Gorda and pacific plates, the Juan de Fuca rift zone adds about one inch of new crust each year to both plates. The growing Pacific plate moves away in a northwest direction, but the new sea floor added to the little Gorda plate moves on a collision course toward the coast of Washington and Oregon where it plunges beneath the westward marching North American Plate. It then bends downward into the earth's mantle beneath the Cascade volcanic chain. The friction between these 60-mile-thick slabs sliding past each other supplies the heat necessary to melt the crust and generate molten rock, or magma. Mount St. Helens, as well as the other volcanoes in the Cascade chain, are localized spots where this magma pokes through and spills onto the surface.......

The Pacific Northwest has a long history of volcanic activity, indicating that the area has long been a plate boundary. The earliest volcanism in the Cascades occurred some 250 million years ago, though the bulk of the volcanic rocks are about 50 million years old. The range is punctuated by the eroded roots of old volcanoes.

Findley--Bio #5--Mount St. Helens and other towering young volcanoes of the Cascade Range have been built up by the submergence of the Juan de Fuca plate beneath North America. Creeping under the coast at more than an inch a year, the small oceanic plate melts rock into pockets of magma that work their way up some 60 miles to the surface.

B. Columbia Plateau

Christiansen--Largest Cenozoic basalt field in North America. The basaltic flows are relatively thick (20 m or more) and very widespread, some occurring tens or even hundreds of kilometers from their linear fissure vents.

McKee--Bio #7--Columbia Plateau....First great outpourings of basalt lava built one of the world's most impressive piles. Later, gigantic floods of water raced across the plateau and produced one of the world's most intricately channeled surfaces. Nowhere today can we see flooding of either water or lava on this scale.

A "typical" flow of the Columbia River basalt was approximately 100 feet thick, although some flows were more than 200 feet thick, and others had a thickness of just a few feet. The eruptions were not from a single vent but from very long cracks or fissures, each of which was many miles long. An individual eruption was probably fed by many fissures erupting simultaneously.

The flows spread out almost like water for great distances. One member has been traced.....over an area of approximately 20,000 square miles.

Bullard--Bio #6--Columbia Plateau....Here, covering most of Oregon, and parts of Washington and Idaho with an area of 200,000 square miles, are basaltic lavas reaching a thickness of 3,000 feet and representing hundreds of flows superimposed one upon another.

Greely--Bio #16--Flood basalts form extensive, often thick flows erupted at very high rates from fissure vents and produce vast basalt plateaus.

Kuntz--Bio #8--Columbia Plateau....Age between 14 and 16 million years ago. It looks like the Western Snake River Plain has in it basalt that is Columbia River in age. Columbia River basalts are found in the deeper parts of the western Plain and are also exposed at various points around its edges. So it appears that it was an extension of the CR basaltic province, back 14 to 16 million years ago. In fact, some of the faults that occur along the edges of the Western SRP, look as if they may actually be extensions of the same kind of system (deep crust cracks) that formed the CRP fissures. But the CRP basalts ended 14 million years ago and that was it. The SRP has these same basalts but continued to erupt into more recent geologic times.

C. Snake River Plain

Bullard--Bio #6--The Snake River Plain is commonly described as an eastward extension of the Columbia River Plateau..., But structurally is is different from the CRP and, in addition to being younger (mainly Quaternary), the lavas are chemically distinct.

Greeley--Bio #16--Snake River Plain...(Has differentiated Snake River Plain as a "Basaltic Plain". Different from the CRP because of average flow thickness of only 10m, and the presence of lava tubes, channels and shield volcanoes. The SRP contains characteristics of both flood basalts and shield volcanoes. Lava flows erupted from both central vents that produced low shields and short fissures that formed thin sheet flows; the combined flows in the SRP locally exceeds 1,500 m. As with shield volcanoes, flow features such as lava tubes and lava flow channels are relatively common and are important in emplacing lava flows in the low-lying areas between the low shields.)......the SRP represents a style of volcanism between flood basalt volcanism and Hawaiian volcanism. Basaltic plains volcanism combines both elements of shields and flood basalt plateaus; the plains involve multiple, thin flow units erupted from central vents commonly aligned along fissures.

Mabey--Bio #3--The Snake River Plain, which extends in a 600 kilometer arc across southern Idaho, is the most prominent Cenozoic feature in the state.

Although the regional surface geology of the SRP in Idaho is well known and many shallow and a few deep holes have been drilled on the plain, major uncertainties remain concerning the structure of the plain. Seismic refraction profiles have revealed that under the plain a thin upper crust overlies a lower crust which is thicker than that under the Basin and Range province to the south.

Kuntz--Bio #8--The SRP went through its own very unique geologic history and the style of volcanism was very different from the CRP. There were intermittent eruptions from very short lengths of fissures. Instead of fissures being measured in tens of miles like occurred on the CRP, the fissures were only a few kilometers in length. Large broad shield volcanoes were common in this area. Last eruptions in the WSRP were probably from 500,000 to a few million years old, but there are no verified dates at this time.

(Evidence that this very hot magma does exist beneath the plain is demonstrated by the fact that) if you look at a map of Idaho and look at the location of the epicenters of all of the earthquakes that have occurred, you will find that only the SRP is totally blank. This indicates that the area, instead of being composed of rock that is fairly cool and and deformed by fracture (faulting) when seismic energy is released, is an area where the rocks are hot and plastic and deformed by flow. When these rocks are subjected to stress, they tend to flow rather than fracture. So the best explanation of why there are no earthquakes beneath the SRP is that the crust here is still very hot......

The Columbia Plateau was formed above oceanic crusts where basalt has little difficulty reaching the surface. The Western Snake River Plain , however, is located partly above continental crust. The continental crust acts as a barrier in allowing basalt magma to the surface, because it reprsents a density barrier to the rise of dense basalt magma. So what happens is that only small volumes are erupted. This is very sporadic because evidently the magma is continuously wedging its way upward, but most of it is being blocked by the density barrier and is congealing deep in the continental crust.

Eastern Snake River Plain--Theories on the origin of the SRP are involved and currently a combination of the plume theory and the flaw theory has the best acceptance. To start with, around the margins of the ESRP, rhyolitic rock has been located in several areas where it extends from under the basaltic lavas on the surface of the SRP. These rhyolites have been dated and the corresponding ages have been recorded. Twin Falls 15-18 million years ago, Pocatello 10-12 million years ago, Arco and Idaho Falls 4-6 million years ago and Yellowstone .6-2 million years ago. There is a progression to the northeastfrom young to old. (Recent research has indicated that it is not this simple--the progression may be young-old-young-old-etc.--but in general the progression is from youngest to oldest to the northeast).

Thinking now is that these rhyolitic sheets come from massive calderas. The calderas are formed when a large amount of rhyolitic magma in chambers in the crust that are 20 to 40 across rises to the surface. The cap on these chambers may collapse or explode due to the tremendous amount of gas in the rhyolite magma that expands once it is no longer under pressure. Some of the material is blown into the air , but much of it moves out laterally in its own unique type of lava flow--it rides along on a cushion of heated air and flows for great distances. The material deposited is known as welded tuff.

Why do these calderas form? Well, calderas form when large masses of melted, crustal material (rhyolite magma) form and then rises gravitationally (buoyantly) toward the surface. Rhyolite magma forms at the base of the crust where the mantle is so hot that it is melting the crust. How does the base of the crust get so hot? This is where the mantle plume theory comes in.

Mabey--Bio #3--The eastern SRP is basically a downwarp containing numerous calderas. Extension normal to the plain is a possible explanation for the thinned upper crust under the plain and the high thermal anomaly now centered under Yellowstone National Park that moved northeastward across southern Idaho producing a complex of calderas that are now largely obscured by the younger basalt flows on the SRP. Such a thermal event can be used to explain the formation of the eastern SRP only if some mechanism for the development of a large positive mass anomaly under the plain is also involved. The current tectonics of the eastern plain appear to be extension parallel to the axis of the plain.

Kuntz--Bio #8--A mantle plume is still not fully understood but the general idea is that the plume is a very hot spot that is fixed, does not move. Then as a plate (in this case the North American plate that is rotating on the earth in a southwest direction at a rate of about 3 cm a year), slides over the plume, its base is melted, creating rhyolitic magma. This would produce tracks across the earth's surface and the theory is that this is seen on the SRP. If the ages of the rhyolite flows are compared with the distances between source vents on the SRP, the movement of the NA plate from Twin Falls to Yellowstone figures to be 3 cm. Coincidence? There is nothing wrong with this theory except that it is really very simple. There are other theories being developed.

One is Basin-Range extension that produces heat not through a plume but rather frictional heating. Since the NA plate has overridden the East Pacific Rise, several different forces are at work in the western US. The EPR is spreading out in a more or less west and east direction and as the continent moves to the southwest: thus there must be a tremendous amount of friction at the base of the crust. This friction causes heat.

These are the same forces that are creating the Basin and Range structure in the western US. The SRP is located at a boundary between a stable part of the continent (Idaho Batholith--a granitic intrusion) and a spreading part of the Basin and Range. It becomes a frictional boundary and heating may be occurring at this particular location. We know that the eastern boundary of the Basin and Range is moving off to the east as more and more country is being affected by Basin and Range extension. This may explain the progression of calderas at this frictional boundary between a non-extending and extending crust. The progression of calderas simply follows the northeast trend of basin and range expansion.

Mabey--Bio #3--Active volcanism, open fissures and evidence of continued subsidence show that the SRP is an active structure that continues to develop. A suggestion exists in the magnetic data that the eastern plain may be part of a northeast trend reflected in Precambrian rocks to the northeast, but no evidence has been reported to suggest that the plain existed before Miocene time. Several lines of evidence do suggest that the development of the plain may coincide with the large-scale extension of the Basin and Range province to the south, which began about 17 million years ago.

The apparent relationship between the rifts on the eastern SRP and the basin and rage faults to the north and south suggests they represent different responses to extension of the crust approximately parallel to the axis of the plain. Normal faults south of the plain, and presumably those north of the plain, appear to be controlled by old structures, many related to overthrusting; many of the normal faults flatten at depth to merge with major thrust faults. Although the belt of overthrusting probably initially extended across the area of the SRP, subsequent igneous activity along the plain and perhaps extension normal to the plain have disrupted the thrust faults.

Kuntz--Bio #8--Another theory is called the "flaw theory". The flaw theory states that there is a basic southwest, northeast trending structure in the crust that is being used by the magma to get to the surface. This flaw would be seen only if we could strip off all of the thin, superficial cover of igneous rock to get down to Precambrian rock. Where nearby Precambrian rocks are exposed (Grand Tetons, etc.), there is what is called a structural grain to the Precambrian rocks of this area. That grain trends southwest-northeast. This would mean that in Precambrian time, uniform structural trend was imposed on the Precambrian rocks at that time and with subsequent movement of the continental plate, this particular trend is oriented parallel to the SRP. What could possibly be happening is that whatever process is producing magma seems to be taking advantage of the structural trend and the flaw in the crust to allow magma to move to the surface. Activity may take place along the entire length of the flaw, but magma is only produced on the surface in areas where there is still crustal rock which can be melted. As the continental plate moves over the hot spot, more rock can be subject to melting and this may result in the progression of young to old lava flows on the SRP.

Geophysical evidence indicates that the structural trend is very extensive. It covers all of the Eastern SRP and goes into Nevada where it is known as the Humboldt Trend. Its placement has all been determined through the analysis of aeromagnetic data.

Tomorrow there will be another theory and then another. The truth may be a combination of these theories or something totally different. All we can do is say, "Here is a theory" and its test for the present is whether it is consistent with the current data available concerning geology, history, geophysics, petrology and other related geologic sciences.

D. Basin and Range Structures

Press--Bio #13--West of the Rocky Mountains is the Basin and Range province, a region of many smaller chains of mountains alternating with elongated basins. This is the area that some see as a potential huge rift valley that may someday separate the continent into two parts.

One might have expected the structurally high Basin and Range province, with its average elevation of about one kilometer, to have a slightly thicken crust to go along with its negative anomaly. Actually, many geophysicists thought this to be the case until experiments with seismic waves revealed the thin crust. ...... The low density mantle (in this area) seems to go with a tectonic setting that includes recent volcanism, high heat flow, and low seismic velocities--which implies, perhaps a partially molten mantle directly below the Moho. Some geologists suggest that these features, as they occur in the

Basin and Range province , indicate that tension-producing forces, perhaps due to a spreading or divergence zone, are active within a continent.

Crone--1984--The Lost River Range , and the Lemhi and Beaverhead Ranges to the northeast , form typical basin-range topography north of the Snake River Plain and east of the Idaho Batholith. The ranges are composed of Paleozoic and Precambrian sedimentary rocks that were complexly folded and thrust faulted into imbricate sheets during the Mesozoic. Cenozoic normal faults bound one or both flanks of the intervening valleys.

Kuntz--Bio #15--Many volcanic rift zones in the central and eastern SRP appear to be extensions onto the plain of northwest-trending range-front faults that bound basin-range, block-fault mountains along the margins of the plain. In contrast, the Great Rift does not lie on an extension of a range-front fault, but it may be a southeastward extension of a basement structure in older rocks that extends northwest from the margin of the plain.

When the relative position of the Beaverhead, Lemhi and Lost River Ranges (Basin and Range mountains) and their associated fault systems are charted, a regular pattern of spacing between these structural features becomes apparent. If an extension is made to the west to include the Great Rift, the regular pattern of spacing is still apparent, but there are no basin-range mountians to the north of the Great Rift to complete a perfect match up. Between each range and its boundary fault is a separation of approximately 25 to 30 miles. In several areas, the boundary faults for these ranges can be followed onto the Snake River Plain and the extensions coincide with volcanic rift zones.

But this may be because the area north of the Great Rift is structurally different because of the presence of the Idaho Batholith (The Idaho batholith is a series of intrusions ranging from 120 my old to about 50 - 70 my old), an immense intrusion that spans most of central Idaho. And since the Idaho Batholith is a granitic intrusion, while the typical basin-range landform consists of sedimentary rock, extentional forces at work in this area may have been expressed differently.

Within the Idaho Batholith, directly north of the Great Rift, is another series of much smaller intrusions or plutons that trend NW-SE, parallel to Basin and Range mountains and to their boundary faults. The alignment of the plutons would indicate the presence of a basement structure that would be a flaw in the earth's crust that allowed for their implacement. From this information it could be extrapolated that this basement fault represents the effect of basin-range extension into the batholith.

In summary, at the present time, there is no definite evidence that the Great Rift is a typical basin and range associated fault, but location of the Great Rift and the intrusions directly north of the Rift may indicate that extentional forces related to basin-range formation may indeed have been responsible for the original formation and location of the Great Rift.

Smith--Bio #23--However, not all areas of continential intraplate volcanism fit into either the rift or uplift category. Such an area is the Cenozoic volcanic province of the western USA which, although studied in great detail, is not fully understood. Volcanism in this area falls into two episodes. An earlier phase ranging over a period of from about 70 to 20 Ma ago was characterized by dominating calc-alkaline volcanism of intermediate to silica-rich composition. This was probably related to subduction along the Pacific margin to the west. After only a brief interlude between 20 and 17 Ma ago most of the area was subjected to pronounced regional extension. For example cumulative tectonic extension exceeded 100 km in the Great Basin. Except in the extreme west, volcanism now changed to either basaltic or alternations of basaltic and rhyolitic in composition. The entire igneous province which extends for about 2000 km north to south and about 1000 km east to west encompasses several major and distinct areas, including the block-faulted Basin and Range province (characterized by high heat flow and a lithosphere only 60 km thick), the Rio Granderift, the Colorado plateau and, to the north , the Snake River plain, the Yellowstone plateau and the Columbia River flood basalt plateau.

E. Craters of the Moon/The Great Rift

LeFebvre--Bio #9--In the CRMO area the interpretable history is very short because the rock ages are younger than 20,000 years -- less than an instant of geologic time....A lack of erosion to have exposed the deeper, older layers....means that deciphering the exact sequence of eruptions along the Great Rift is difficult and the story may remain incomplete.

Since the Great Rift is parallel to the basin-and-range structures in southern Idaho, this theory for the origin of the rifting that produced the Craters of the Moon lavas is strongly supported. On the other hand, the hotspot theory (areas that inflate over hot spots like the one proposed under the Hawaiian Islands) for the formation of the entire line of successively younger volcanoes that extend southwest of Yellowstone is still a favorite of many geologists. The theory proposes that a plate moving over a hot spot -- the source of which is unknown -- leaves a trail of successively older volcanoes in positions the hot spot once occupied.

Since lava tends to rise along rifts, it follows that, on the surface, volcanic eruptions occur in alignment with the trace of the rift. In fact, it is often true , that only by connecting eruption centers (vents, cones) with straight lines, can geologists locate the position of the rift.

Rift systems, one of the most common geologic processes on the surface of the Earth, occur in areas of extension producing vent features along the rift and lava fields off to each side of the rift. The Great Rift, because of its youth, magnitude and large vent systems and lava fields, is probably the best example of a rift system in the conterminous United States. Others do occur: there are many in the SRP of southern Idaho and they can be found throughout the western United States.

Kuntz--Bio #15--The Great Rift consists of volcanic vents, eruptive fissures, and non-eruptive fissures that extend approximately 85 km from the southern Pioneer Mountains southeastward through CRMO to Pillar Butte in the Wapi lava field, located about 30 km northwest of American Falls, Idaho.

CRMO lava field is a composite of more than 40 lava flows erupted from more than 25 cinder cones and eruptive fissures, most of which are located in CRMONM......The field covers an area of 1,600 km2, contains more than 30 km3 of lava, and is the largest basaltic lava field of dominantly Holocene age in the conterminous US.

II. History of Eruptions at CRMO

A. Past volcanic history/Eruptive sequence

Kuntz--Bio #15--The CRMO lava field formed during at least eight periods of eruptive activity, each of which was about 1000 years or less duration and separated by intervals of quiescence lasting from a few hundred years to more than two thousand years.

Lava flows and groups of flows that are believed to have similar ages, based on field, radiometric and paleomagnetic data, can be grouped into what we term "eruptive periods." Eight eruptive periods are presently recognized in the CRMO lava field. The duration of each eruptive period is uncertain, but paleomagnetic studies show that the durations of most of the younger eruptive periods were probably less than a few hundred years. The intervals between eruptive periods may have been times of volcanic quiescence or sporadic volcanic activity.

The oldest lava flows of the CRMO lava field flowed away from the general location of the Great Rift. This relationship suggests that the Great Rift was a locus of source vents for even the earliest of flows, and that these early flows are covered by younger flows.

The definition, components and extent of each eruptive period is contained in "The Great Rift and the Evolution of the Craters of the Moon Lava Field"--Kuntz

B. Fissure eruptions

Kuntz--Bio #15--Basaltic volcanism has occurred as fissure eruptions within volcanic rift zones in many parts of the world, including Hawaii, Iceland and the eastern SRP, especially along the Great Rift. Based on well-documented Hawaiian eruptions, we believe that the typical eruption along the Great Rift consisted of distinct, though gradational, stages. The stages described below represent a generalized gradational sequence during a prolonged basaltic eruptive cycle: individual eruptions may have included only some of the phases described.

Eruptions generally began with a long line of lava fountains that extended for hundreds of meters and locally for a few kilometers along a single fissure or a series of en echelon fissures. Voluminous outwelling of fluid lava long nearly the entire fissure accompanied fountaining. The basaltic lava in the early eruptive stages was extremely fluid and heavily charged with dissolved gases. The early stages of such eruptions led to the development of spatter ramparts and downwind blankets of fine-grained tephra.

After several hours or days, the eruption generally diminished and lava fountains became localized along short segments of fissures. Spatter ramparts were succeeded by spatter or cinder cones which built up around the lava fountains.

After several hours, days or weeks, a decrease in magma pressure and in the amount of dissolved gas in the magma produced a corresponding decrease in the height of lava fountains and thus to a change in the types of volcanic processes and landforms. During historic, long-lived Hawaiian activity and, by inference, during prehistoric activity along the Great Rift, fountaining diminished and was followed by quiet but voluminous outpourings of lava over or through the existing spatter or cinder cones. A prolonged period of overflow of lava in most places produced a lava cone composed largely of sheets of pahoehoe lava that mantled the older cone structure. Lava-cone summits are typically indented by an elongated crater. The elongation of the crater is generally parallel to the underlying fissure or rift, which served as the channelway for magma to the vent. Large craters were formed by collapse of the crater walls, accompanied by repeated crater filling and draining.

Where eruption of fluid basaltic lava extended over periods of months and possibly years at a single vent, large lava cones or shield volcanoes were produced (shield volcanoes have been identified outside of the monument and Blue Dragon may also qualify as a shield volcanoe if further research verifies this). These broad, low.rounded, shield-shaped landforms grew by the continued buildup of thin, far-spreading pahoehoe and, to a lesser extent, aa lava flows. Little explosive activity was involved in the shield-building stage.

Kuntz--Bio #8--Big Craters is probably the best example at CRMO of how an eruptive fissure will finally center down to erupting from one pipe-like conduit. The eruptive fissure the Big Craters and Blue Dragon flows probably extended from the spatter cones on the south to the northwest corner of North Crater. Along this fissure, eruptions would occur at one end and then the other end or at one end then the middle and then at the other end. Each eruption successively starting up and then died down. Each pulse of a fountain ends up with a circular accumulation of cinders and ash around it. Very powerful eruptions would tend to blow out materials laid down in previous eruptions. It would go on like this with the eruptions switching back and forth until it centered on just one point of eruption. Continued eruptions from the single spot or from a short length of fissure would form a cinder cone or elongated complex, respectively.

this occurs in a time span of every few weeks to every few years. At CRMO, magma accumulates at a much slower rate with probable storage deep in the crust (40-60 km) with periodic release every 2,000 +/- 1,000 years. So the intervals between eruptions is very long at CRMO, but very short in Hawaii. Also volumes (long term) are small at CRMO and large at Hawaii.

III. Silica Levels

Macdonald--Bio #19--The explosiveness of an eruption depends largely on two factors: the fluidity or viscosity, of the lavas, and their gas content. Three factors govern the viscosity of a lava, its chemical composition, its temperature, and the amount of gas it contains. In general, the higher the silica content of the lava the more viscous it is, and the higher the temperature and gas content, the lower the viscosity. Low viscosity fluid lava allows moderate amounts of gas to bubble out with little more than minor spattering; but in very viscous lava it is difficult for the gas to work its way upward and break through the surface of the liquid, and it accumulate until the pressure is sufficiently high to allow it to burst free. With high enough gas pressure, a large amount of gas, and viscous enough lava, a major explosion or series of explosions may result.

Kuntz--Bio #8--We do know that silica levels vary throughout the monument, tend to be higher in the northern section of the Rift and what the results will be on the surface as the silica level changes. What we do not know is exactly why these variances in the silica level occur. One possibility is that as the basalt begins to collect, it pools in a pocket at depth and builds up enough heat to begin the melting of crustal rock. The magma becomes a mixture of basalt and rhyolite that results in higher silica levels than pure basalt. There could also be a preferential absorption of certain elements such as silica.

Whatever the process is that changes the composition of basalt and leads to higher silica levels has progressively increased the silica content of basalts of the more recent eruptions. The higher silica levels indicate that eruptions will be more explosive in the future. In a typical eruption, however, the silica rich lava is erupted first and then followed by eruptions of low silica lava.

Silica levels also have an effect on the type of lava flows that develop. Pahoehoe flows at CRMO typically have a silica level of 52% or lower. AA flows that are completely aa (even at the source vent) have a silica composition of 51% or higher. Blocky lava flows are even higher in silica content. Of course temperature, gas content, and other conditions may also play a role in determining the type of lava flow that will develop at any given place.

Volcanic Geology of Craters of the Moon National Monument--Part 2

Background Information

Compiled by David Clark, Park Interpreter, 1984

IV. Formations, Features and Characteristics

A. Cinder cones

LeFebvre--Bio #9--Lava which is richer in silica will be more viscous and therefore more explosive......the higher the silica content, the larger the cone will form.......the presence of ground water and the resulting steam can also cause an explosive eruption and produce rather large cones.

A cinder cone hundreds of feet high can be deposited in a matter of hours or days. Big Cinder Butte, the tallest cone at CRMO, stands about 700 feet above the land surface and could have been built in as little as a few days or weeks.

If the wind is strong during the formation of a cinder cone, the cone will not develop the normal circular shape, but will elongate in the direction the wind is blowing. Dominant winds in this area are from the west to east and many cones such as Grassy, Sunset, Paisley and Inferno Cone are elongated to the east.

Kuntz--Bio #15--Cinder cones are widely scattered throughout the eastern SRP but they are best developed in size, shape and number along the Great Rift. The cinder cones are composed of agglutinated and non-agglutinated tephra layers interbedded with thin lava flows. Composite cones such as Sunset and Big Craters were formed by overlapping accumulations of ejecta from several contemporaneous or nearly contemporaneous lava fountains. The composite cones may have elongated crater walls aligned along the eruptive fissure. Many of the cones are breached on the northwest and/or southeast flanks. The breaches probably formed by a number of mechanisms; by burrowing of lava flows erupted along a feeder fissure beneath the cones after they formed, by burrowing of lava flows through, and erosion of, the walls of the cinder cone, or by removal of ejecta by a lava stream that flowed from the feeder fissure during the formation of the cones. Some cinder cones have a multi-stage history. Younger lava erupted from vents in North Crater, the Watchman and Sheep Trail Butte cinder cones as volcanic activity in and near them was rejuvenated.

There are basically two reasons why there is a greater predominance of cinder cones on the northern most section of the Great Rift. One is that there has simply been more eruptions on this end of the Rift than there has been in the middle or southern part. The other concerns the composition of the lavas -- the lavas from the northern end of the Rift tend to have a higher silica level and the thicker lavas produce more explosive eruptions where the formation of cinder cones is more likely.

Cinder cones can form in very short periods of time. Any cinder cone at CRMO could have formed in a matter of a few days or a few weeks. In fact the only cones that appear to have been formed by more than one eruptive event are the Watchman and Sheeptrail Butte.

Macdonald--Bio #10--One of the most familiar of all volcanic structures is the cinder cone -- a cone-shaped hill or small mountain nearly always with a truncated top in which is a bowl-shaped crater. It results from the heaping up around a more or less circular vent of cinder thrown into the air during moderately explosive eruptions. The conical form of the hill results from the fact that the largest fragments and the largest proportion of fragments of all sizes fall closest to the vent, so the hill is highest close to the vent and decreases in height away from it. The angle of the slope is close to the angle of rest for piled-up loose irregular fragments and is generally about 30 degrees.

The crater at the top of the cone is most typically rather smoothly bowl shaped or funnel shaped . The sides are the result of loose fragments rolling and sliding down toward the vent until they obtain equilibrium. The crater may consist of a single depression, indicating a single vent active at the end of an eruption, or it may be multiple with several depressions, each surrounding a former vent. Most typically, multiple craters are aligned, as a result of the arrangement of the vents along a fissure. Where multiple craters are present during early stages of the eruption, they may be buried and replaced during later stages by a single crater as all but one of the vents becomes inactive. ...Sometimes later collapse is very extensive due to the lowering of the magma level in the conduit removing some support and allowing the overlying material to sink in and the loose material of the crater walls to slide to a new position of rest.

Rarely, a diminution in the strength of ejections toward the end of the eruption results in filling of the crater and formation of a round-topped craterless cone. Most commonly, however, craterless cones are the result of later erosion that has destroyed the crater rim.

B. Spatter cones

Macdonald--Bio #10--With a decrease in the explosiveness of eruption, or an increase in the fluidity of the magma, or both, cinder cones grade into spatter cones. Sometimes layers that are wholly spatter alternate with others that are largely or wholly cinders.

A still further decrease in the proportion of cinder leads to the formation of purely spatter cones. Typically, they are smaller than cinder cones, rarely reaching a height as great as

100 feet, and most of them less than 50 feet. Their slopes tend to be steeper of those of cinder cones, because the fragments stick together and the slopes are no longer dependent on the angle of rest of the loose material. Welded spatter can stand in a bank that is essentially vertical....Occasionally a pipe-like or fissure-like conduit may remain open to a depth of several tens of feet below the bottom of the crater (this occurs at CRMO). Where the eruptive vent was a fissure (main spatter cone chain at CRMO), the spatter cones may be very elongate (at CRMO--Vermillion Chasim), or a series of partly coalescing (yes) spatter cones may be formed.

"Rootless" spatter cones, also called "hornitoes" (also found at CRMO) commonly form on the surface of lava flows, particularly pahoehoe flows, by the escape of still-fluid gas-charged lava from the central part of the flow upward through breaks in the crust. The are generally small from less than a foot to 10 or 15 feet high, and are sometimes referred to as "driblet cones." Very steep sided ones have been called "driblet spires." They are types of hornitos.

Macdonald--Bio #19--Because Hawaiian-type eruptions commonly occur along extensive fissures, the heap of ejected material often is very long and narrow, and is called a spatter rampart.

C. Pahoehoe lava

LeFebvre--Bio #9--Of the three major types of lava flows -- pahoehoe, aa, and block lava -- pahoehoe is the most common in the CRMO lava field.

An example of a large volume eruption at CRMO is the 2100 year old event which produced Big Craters and the Big Craters and Blue Dragon lava flows. These flows covered an area of almost 300 km2.

Kuntz--Bio #15--Most flows of the CRMO lava field are pahoehoe; they have hummocky, billowy, ropy and wrinkled surfaces that reflect the fluid nature of the lava. The upper centimeter of many fresh, unweathered flows consists of vesicular to dense glass that has a striking blue to green iridescence (eg. Blue dragon lavas). The pahoehoe flows were typically fed through lava tubes and tube systems. Pressure ridges and pressure plateaus are common large-scale features of the surfaces of the pahoehoe flows.

Decker--Bio #12--Pahoehoe has a smooth, billowy surface, often wrinkled or ropy appearance where a "skin" has started to form and has been dragged along by the more fluid lava underneath. These are rapidly moving flows, which sometimes divide to surround an obstruction leaving an island -- or kipuka -- of vegetation in the middle of a flow.

Most flows emerge from the vent as pahoehoe and somewhere downslope change to aa. Change in the other direction doesn't happen, though sometimes pahoehoe will flow through a tunnel under an aa flow and emerge looking like a continuation of the aa flow. The chemical composition of both kinds of lava maybe the same; the change occurs when a pahoehoe flow starts to cool and loses some of its gas content. The number of internal crystals increases and the flow starts to break up unto jagged blocks in much the same way that a batch of fudge will start to sugar and quickly become chunky.

Macdonald--Bio #19--The great fluidity of Hawaiian lava results in rapid movement of the flows. In the main feeding channels, speeds as great as 55 kilometers an hour have been observed, but the flow as a whole advances much more slowly because the narrow feeding river, seldom more than 15 meters wide, must supply an advancing flow front that may be a kilometer or more across. Common rates in Hawaiian eruptions are a few tens to a few hundreds of meters per hour.

The ropy surface of pahoehoe is the result of dragging and wrinkling of the solidifying but still plastic crust by moving liquid beneath. Because the moving of the liquid stream is fastest in the center, the ropy-looking wrinkles are curved with their convexity pointing in the direction of the flow.

D. AA lava

Kuntz--Bio #15--Other CRMO lava field flows are of aa lava that has a rough, jagged, clinkery surface. Large areas of the surface of aa flows consist of irregular blocks of broken lava, some of which are broken slabs of pahoehoe.

Decker--Bio #12--An aa flow advances in a different way. Commonly there is a central river of molten rock five to ten meters across, flowing at speeds of 5 to 50 km per hour depending on the slope. The flow then oozes out on all sides from this central system and forms slowly-advancing dark lobes of cooling lava rubble riding on a molten but unseen core.

The lava blocks tumble down the steep front of the advancing flow, sometimes giving a glimpse of the glowing interior, and are slowly overridden.

The growing edges and fronts of the flow look like giant slow-motion bulldozer treads moving out, down, and under as the mass spreads forward. As a result the surface is a layer of angular jagged fragments, each covered with tiny sharp spines.

E. Blocky lava

Kuntz--Bio #15--A few flows, such as the Highway flow, consist of block lava that is characterized by irregular blocks of dense, glassy lava with smooth surfaces.

Kuntz--Bio #8--Block lava is a variety of aa lava. Instead of having spiny projections of aa, the block lava consists of irregular blocks. This is extremely thick lava because of a very high silica content. The highest silica lava at CRMO are the block lavas at 64 to 66% levels. The Highway Flow is the best example of a blocky lava flow at CRMO.

If we further increased the amount of silica to 75 to 77% we would have an incredibly viscous lava. This is what produces obsidian--a material that is so thick it is not a liquid and will not allow crystals to grow in it. Thus, glassy material is formed. No deposits of obsidian occur at CRMO, but it is found around Big Southern Butte, but in association with rhyolite lavas.

Macdonald--Bio #10--Block lava flows may be basaltic in composition, but typically they are more siliceous. The greater richness in silica correlates with the greater viscosity.

Macdonald--Bio #@9--Aa flows grade into another type known as block lava flows, which have much the same structure as that of aa flows, but the upper and lower fragmental parts of the flow, instead of consisting of very irregular jagged pieces of clinker, are made up of blocks with relatively smooth sides. Block lava is formed by more viscous magma than that which forms aa, and consequently the flow tends to be thicker and to move more slowly.

F. Lava tubes

LeFebvre--Bio #9--Large eruptions that produce lava flows also produce complex plumbing systems in order to move this great volume of lava from the vent past earlier formed products. The lava tube systems in the Blue Dragon flow were all formed as a plumbing system to feed the Blue Dragon flow to the east.

Decker--Bio #12--The rivers of pahoehoe quickly crust over and leave streams of lava moving in tunnels under the crust. When the supply of lava feeding the stream stops, the lava drains out leaving an empty tunnel or lava tube.

Greeley--Bio #16--Lava tubes form only in basaltic lava flows and are common in many young basalts of the western US. As molten basalt flows away from its source, the upper surface cools and forms a solid crust while flow of molten lava continues beneath the crust. Eventually, active flow is restricted to a conduit within the basalt flow that feeds the advancing flow front. Cessation of the eruption at the source limits the lava supply and fluid material drains from the conduit by gravity, leaving a hollow void, or lava tube.

The single most important factor in tube formation is low viscosity, which is directly related to temperature, chemistry and the amount of gas dissolved in the lava. The lava flow is more fluid and less viscous at higher temperatures and/or with a higher gas content. As the lava cools, loses gases, and crystallizes, it becomes more viscous. Basalt is the only volcanic material fluid enough to permit development of tubes, but even some basalt flows are too viscous for tube formation.

Tubes are so common in pahoehoe flows that they are evidently the primary means of flow advance. Small distributary tubes branch from the main lava tube to feed the flow front. These feeder tubes usually do not drain and are seldom preserved. If drainage does occur, feeder tubes often fill with lava from later flows.

G. Cinders and Bombs

Macdonald--Bio #10--Fragments of rock thrown out by volcanic explosions are called ejecta, and accumulations of such fragments are known as pyroclastic rocks.....(the term tephra may also be used). (These materials are further classified by size as bombs, lapilli or ash).

The cinder fragments range from a fraction of an inch to several feet in diameter, but most of them are between 1/4 inch and a foot. Within individual layers the size of the fragments generally decreases upward, because in general in any one explosion the larger fragments are thrown less high, fall faster, and strike the ground sooner than the smaller ones. The size of the fragments depends in part on the strength of the explosion, more violent expansion of the gas tending to tear the magma into smaller shreads. Commonly, individual cinder cones are characterized throughout by a more or less uniform size of fragments resulting form fairly uniform explosiveness of the entire eruption. However, it is also common to find a systematic increase in the size of fragments in the uppermost layers resulting from a decrease in gas content of the magma and explosiveness toward the end of the eruption. It is also common to find occasional large bombs imbedded in a haphazard manner in finer cinder.

Fusiform and spherical bombs often are associated with cinder, though generally, in very minor proportion, and in some cones they are lacking. Commonly, they are most abundant in the outer portion of the cone, and this also seems to result from a decrease in the gas content of the erupting magma and, consequently, in the explosiveness of the last stages of eruption.

Bullard--Bio #6--Volcanic bombs are masses of new lava blown from the crater and solidified during flight, becoming rounded or spindle-shaped as they are hurled through the air.

H. Tree molds and Lava Trees

Bullard--Bio #6--A tree mold , or lava tree, is formed when fluid lava encases the trunk of a tree. Commonly the tree burns, but some portions may be converted to charcoal, especially the root system in the soil zone beneath the flow. In some cases the tree may be pushed over by the advancing flow, and the resulting tree mold will be more or less horizontal. When the tree remains upright, the depth of the tree mold well is determined by the thickness of the enclosing flow. Spatter from nearby lava fountains may accumulate on and round the tree so that a whole "lava tree" is formed. The volatiles released as the trunk of the tree burns make the lava in contact with the tree more fluid, so that minute details in the structure of the bark or wood (now in the form of charcoal) may be preserved.

(The charcoal excavated from the bottom of some of the tree molds at CRMO was dated by using C14 methods. This enabled Bullard to measure the age of some of the flows in this area)

Macdonald--Bio #10--Tree molds are formed where fluid lava surrounds the trunk of a tree and is chilled against it resulting in a cylinder of solidified lava encasing the tree. The tree is burned and when the charcoal is removed (weathering/rotting) a well-like opening is left. In forming, the charcoal on the outer part of the trunk often develops a pattern of shrinkage cracks, and the liquid lava invades these cracks and preserves the pattern.

Kuntz--Bio #8--Lava trees can be formed by either of two methods. The first is where trees are coated with spatter from a nearby eruption and then the spatter congeals and hardens around the tree. Another way that lava trees are formed is when a flow moves around a tree and later is deflated as gas escapes or lava flows out from underneath the crust. A coating that will eventually harden is left on the tree as the lava flow recedes.

I. Coloration

Kuntz--Bio #8--The redish color of the cinders is due to oxidation of the iron contained in the basalt. Most of this oxidation takes place at the time that the cinders are deposited and not later on. If a clot of lava is erupted at 1000 C, it comes out of the throat of a volcano and is thrown a couple of hundred meters into the air. By the time it falls to the ground, it has cooled to about 900 C, but in the time it has cooled down only 100 C it has already congealed. On the ground, it is surrounded by other pieces of lava also at 900 C. It continues to cool, but it may take days or weeks to cool another 100 C because it is surrounded by other hot material and is also very well insulated. It is during this time when most oxidation takes place. If the material is exposed to steam during this period, the oxygen in the steam will further accelerate the oxidation and the cinders may turn red in a matter of only days or weeks.

The coloration of the lavas themselves is much more complicated. The reason for the blue color of the Blue Dragon lavas is very complex. Theory has it that it involves the ratio between ferrous and ferric iron and has something to do with titanium as well. Suffice to say that it is due to a unique chemical composition.

This blue coloration occurs only in the top couple of millimeter of the crust and under this you find the normal color of the rock. And the deeper you go into the rock, the darker the color becomes. Evidently as you get deeper into the rock there is a difference in not only temperature, but also the ratio of ferrous and ferris iron and possibly the state of oxidation. There may be even more oxygen trapped in the form of gas in the lavas than in the outside atmosphere. Red coloration on the inside of the rock are the result of oxidation that takes place on cooling.

Miller--Bio #21--The unusual color of the "Blue Dragon" lava is due to intense blue light being reflected from clusters of tiny titanian magnetite crystals, which, together with crystallites of plagioclase and olivine are dispersed throughout an outer layer of clear brown glass.......The blue dragon lava seems to be unique in that its outer oxidized layer is strikingly blue in reflected light, but rich brown in transmitted light. Blue light, which reflects from the surface of small, partly oxidized, titanian magnetite particles, and which is caused by electron transfer between Fe^{2+} -- Fe^{3+}, and probably Fe^{2+} -- Ti^{4+} pairs, may account for this phenomenon.

Lefebvre--Bio #22--Iridescence in cinders......The iridescence is caused by microscopically thin veneer of glass which forms as the exploding cinders hit the cool air. The thickness of the glass is just one-quarter of the wavelength of the light reflecting form it. For example, normal sunlight that hits a veneer of glass just one-quarter the wavelength of blue light, will be reflected back (and reinforced) as blue light. If the veneer of glass becomes thicker or thinner than visible wavelengths of light, the iridescence will disappear. This glass contains no special minerals and is the same composition as the rest of the lavas.

J. Lava Depth

Kuntz--Bio #8--An exploratory well at INEL went through about a kilometer of basalt and then through almost 2 kilometers of rhyolite. Elsewhere on the SRP, studies have indicated that the basalt is anywhere from a half kilometer to about one and one half kilometers in depth. You can only guess at the depths of the lavas at CRMO. Since it is on the northern extremity of the SRP it would probably not be as deep as if measured farther out on the plain and 150 to 300 meters in depth would probably be a good guess.

K. Formation of aa lava from pahoehoe lava

Kuntz--Bio #8--Whether lava flows are of the aa or pahoehoe type can be determined initially by silica content--high silica results in thick flows leaning towards aa in character and vice versa for pahoehoe flows. But after eruption a pahoehoe flow can turn into an aa flow if it becomes thicker because of a lowering of its temperature or loss of gases.

Temperature loss occurs with the exposure of the lava to the atmosphere. A pahoehoe flow, as long as it is being fed lava for a sufficient period of time, will gradually loose enough heat to become thicker or more viscous and change into an aa type flow. The spreading out of the flow or travel down a steep slope can also increase the surface of the flow and increase the rate of temperature drop. Pahoehoe lavas are usually erupted at a temperature of about 2,000 F and a drop of less than 300 degrees can be enough to change it to aa.

As pahoehoe is erupted gases are constantly rising through the lava to be dissipated into the atmosphere. As a crust develops over the surface of the flow, gases may be trapped until the surface of the flow is broken, but the action of flowing over a cliff or down a steep slope may be enough to break up this crust and again allow the gas to escape. As the gas escapes the billowy and fluid crust becomes thicker and stiffer until it becomes aa.

Since these processes cannot be reversed it would be correct to say that aa can never turn into pahoehoe. It would not be correct, however, to say that aa can never produce pahoehoe because pahoehoe is sometimes dispelled from the interior core of an aa flow when it slows or stops.

Macdonald--Bio #19--Most flows emerge from the vent as pahoehoe, changing to aa as they advance downslope. The reverse change, from aa to pahoehoe, does not occur, although rarely pahoehoe will burrow under and aa flow and emerge at its lower margin giving the false appearance of a flow changing from aa to pahoehoe.

Chemical analysis of congealed fragments of both types of lava show that there is no consistent difference in composition between them. Whether one or the other forms depends on the physical state of the liquid lava and on the amount of stirring it undergoes. The more viscous the lava, the greater is its tendency to change to aa. Likewise, the more stirring it undergoes, the greater is the tendency for this change. The latter is illustrated by the fact that parts of the same pahoehoe flow continuing down a smooth slope in one area and tumbling over a cliff in another remains pahoehoe on the smooth slope but changes to aa immediately to aa where it goes down the cliff. In some instances aa issues directly from the vent, apparently as the result of vigorous stirring of the liquid by unusually violent lava fountaining.

L. Minerals

Leeman--Bio #2--Craters of the Moon Lava Field .... Contaminated and differentiated lavas ranging from ferrobasalt to ferrolatite (44 to 63 % SIO2). Some flows contain common xenoliths of granitic to gneissic crystalline rocks, silicic volcanic clasts, and alkali feldspar and quartz xenocrysts.

Evolved and hybrid lavas from the SRP are widely dispersed in space and time, yet they display surprisingly systematic compositional relations to one another. Some may have originated by high-pressure crystallization of olivine tholeiitic magmas, although details of this process are obscure. Subsequently, mafic variants of these lavas (ferrobasalts) evolved further via lower pressure crystallization to produce ferrolatite magmas. The most extreme ferrolatite differentiates at Craters of the Moon lava field may reflect 90% or more crystallization of an olivine tholeiite parental magma.

Karlo--Bio #17--Extensive deposits of various sulfate minerals have been found in a number of Holocene lava fields within the Snake River Plain basalt province in Idaho. The sulfate minerals (gypsum, mirablite, bassanite, thenardite, bleodite, epsomite and jarosite) were found in various combinations in sheltered areas in the flows, mostly in vent craters and lava tubes.

A compromise hypothesis seems most likely; an original series of deposits were fumarolic in origin, and the Jarosite powders and gypsum + bassanite crusts are the only remaining examples of this primary deposition. More soluble minerals were affected by groundwater and underwent solution, leaching, transport and redeposition to varying degrees and in various combinations.

M. Bedrock Composition

Kuntz--Bio #8-- Under CRMO the bedrock composition directly beneath the lavas is mostly Challis Volcanics and high-grade metemorphic rocks such as granulites--as evidenced by inclusions in the basalts. Possibly, also the Paleozoic sedimentary rocks and granitic rocks that are exposed in the mountains north of CRMO, but they have not been seen as inclusions.

As for the rest of the Plain, mostly rhyolite ash flow tuffs and rhyolite lava flows at shallow depths, then deeper crustal rocks, probably granulites--also identified from inclusions in the basalts. Probably not the Paleozoic rock in the mountains outside the Plain, except very close to the boundary.

Mabey--Bio #3--Only one deep hole has been drilled on the eastern SRP. This hole, which is on the Idaho National Engineering Laboratory about 30 km east of Arco, was 3,155 meters deep and was bottomed in a rhyodacite porphyry. The rock in the lower part of the hole, which has been dated at 11.2 million years, may be an ash-flow tuff or a high-level intrusive rock. Doherty suggest that this hole was drilled into a caldera. Drillings and resistivity soundings suggest that Quaternary basalt is generally less than 1 km thick on the eastern plain, although in part of the area it may be thicker.

What rock and structures underlie the SRP at great depths remains unknown. One of the deep drill holes on the western plain apparently bottomed in granite, which could be part of an extensive Cretaceous mass of granite that makes up the Idaho Batholith north of the plain....The upper crust of the eastern plain is composed of more magnetic units than in adjoining areas, indicating a greater abundance of igneous rocks in the crust under the plain. The response of the eastern plain to the regional stress is very different form areas to the north and south. This suggests that the structure and perhaps lithology are different. The average density of the upper crust under the eastern plain is probably not greatly different from the adjoining areas, but intense igneous activity in Cenozoic time has probably produced major changes in the lithology and destroyed most of the older structures.

N. Vesicles

Macdonald--Bio #19--Vesicles in pahoehoe generally have fairly regular spheroidal shapes, whereas vesicles in aa tend to have twisted, irregular shapes. This apparently occurs because the high fluidity of the pahoehoe lava allows the gas bubbles to retain their spheroidal shapes, but the gas bubbles in the more viscous aa lava are easily deformed.

Identification of the type of flow from the shape of the vesicles is not entirely infallible, because sometimes some of the bubbles in pahoehoe become deformed and sometimes aa bubbles retain their regular shape. It probably is accurate 7 or 8 times out of 10.

O. Joints in Lava Flows

Macdonald--Bio #19--All types of lava flows are usually broken by cracking into innumerable polygonal blocks. The cracks are known as joints....Most of the joints in lava flows result from the stresses that arise in the rock during cooling. As the rock cools, it shrinks. The rock literally pull itself apart. The principally cracks develop approximately perpendicular to the cooling surface---in the case of a lava flow, the top and bottom surfaces of the flow. The cracking is analogous to that of mud in a dried-up puddle. In the mud the cracks open at right angles to the drying surface, and the intersection of the cracks ideally forms short columns that tend to be six sided. In lava flows, also, there is a tendency to form six-sided columns...although five- or seven-sided columns are also common.

P. Xenoliths

Macdonald--Bio #19--Fragments of older solid rock enclosed in the magma, and eventually left frozen into solidified igneous rock, are known as xenoliths, or simply inclusions. Some of them may be picked up from the ground surface over which lava is flowing, but most are acquired as the magma rises toward the surface. Some are torn from the walls of the conduit; others are lossend from the roof of the magma chamber and sink into the magma. Xenoliths may be fragments of older lava similar to that in which they are found, or they may be pieces of intrusive rock. In other parts of the world, they may also be pieces of sedimentary rock.

Leeman--Bio #20--Xenoliths from CRMO.....analysis indicates....an affinity between the xenoliths and many exposed granulite-facies metamorphic terranes (from intermediate crustal depths)....to establish the presence of early Archean crust beneath south-central Idaho. These samples record the presence of a deep Archean basement complex at least several hundred kilometers west of other known outcrops in the northern Rocky Mountains.

V. Future and Conclusion

A. Prediction of future eruptions

Lefebvre--Bio #9--There is no evidence to support the idea that the Great Rift is extinct. The fact that it has been an active eruptive fissure for at least 13,000 years and that its time of repose, 2,000 y.b.p., is much shorter than the length of its eruptive history is good reason to call it an active volcanic rift zone that is presently in a dormant state. The Great Rift's approximate 2,000 year periodicity is also reason why we can expect an eruption anytime from the present through the next few hundred years to at most one thousand years.

Kuntz--Bio #18--Although it is speculative to predict the time and character of future eruptions based on the past history of a volcano or volcanic rift zone, the data (now available) suggest that reasonable forecasts for future volcanism along the Great Rift can now be formulated. Because it has been more than 2,000 years since the last eruption, we are near the end of a normal repose interval and it seems reasonable to expect another eruption in the next 500 years. The steady state nature of the volcanism and constancy of the most recent output rate suggest that 5 to 6 km3 of lava will be erupted in the next eruptive period.

In the past, successive eruptions have generally shifted to parts of the Craters of the Moon segment of the Great Rift that have experienced the longest repose interval. This factor suggests that the next eruptive period will begin on the central part of the Craters of the Moon segment, but may well propagate to the northern part of the Craters of the Moon segment of the Great Rift. The SiO_2 vs. time relationship suggests that noncontaminated lava flows with SiO_2 contents as high as 54% will be erupted first and will be followed by flows with decreasing SiO_2 contents. These eruptions would be relatively nonexplosive and would likely produce large volume pahoehoe flows.

Eruptions from potential vents on the northern part of Craters of the Moon segment of the Great Rift may produce lava flows of the contaminated magma type with SiO_2 contents as high as 66%. The eruption of lavas of this composition may be comparatively explosive and be accompanied by more than normal amounts of tephra, destruction of cinder cones by collapse and explosions, and emplacement of domes.

B. Warning signs

Decker--Bio #12--(The prediction of imminent volcanic activity based on:) Earthquakes. As molten rock accumulates within a volcano it exerts pressures that can crack solid rock, causing earthquakes. Swarms of hundreds or even thousands of small, mostly unfelt quakes are recorded on the seismographs of the Hawaiian Volcano Observatory during the month or weeks before an eruption. The number, size and location of the earthquakes are all important in interpreting their meaning with regard to a potential eruption.

Tremor. A peculiar type of ground vibration detected by the seismographs is called harmonic tremor. This unfelt but continuous shaking of the ground produces a broad, wiggling record on the seismograph that may last for a few minutes or many days. Tremor is always recorded during an eruption, and its intensity varies with the rate at which lava is being poured out. Tremor indicates that molten rock is on the move, and its occurrence when an eruption is not in progress suggests that molten lava is moving rapidly in underground conduits.

Bibliography

1. The Style of Basaltic Volcanism in the Eastern Snake River Plain, Idaho , Ronald Greeley, 1982.

2. Evolved and Hybrid Lavas from the Snake River Plain, Idaho , William P. Leeman, 1982.

3. Geophysics and Tectonics of the Snake River Plain, Idaho , Don R. Mabey, 1982.

4. Discover , Bingham, 1980.

5. The Eruption of Mount St. Helens, National Geographic , Rowe Findley, January, 1981.

6. Volcanoes of the Earth , Fred M. Bullard, 1976.

7. Cascadia . Bates McKee, 1972.

8. Taped Interview, Mel kuntz, USGS, July, 1984.

9. Draft, The Geologic Story of Craters of the Moon National Monument , Richard Lefebvre, 1984.

10. Volcanoes , Gordon A. MacDonald, 1972.

11. Volcanoes , Peter Francis, 1976.

12. Volcanoe Watching , Robert and Barbara Decker, 1980.

13. Earth , Frank Press and Raymond Siever, 1974.

14. Basaltic "Plains" Volcanism , Ronald Greeley, 1977.

15. Holocene Basaltic volcanism Along the Great Rift, Central and Eastern Snake River Plain, Idaho , Mel A. Kuntz et al, May, 1983.

The Great Rift and the Evolution of the Craters of the Moon Lava Field, Idaho , Mel A. Kuntz et al, 1982.

Time, Volume, and Whole-rock Composition Relations of Holocene and late Pleistocene Basalt Volcanism Along the Great Rift, Idaho , Mel A. Kuntz, 1982.

16. The Snake River Plain, Idaho: Representative of a New Category of Volcanism , Ronald Greeley, 1982.

17. Sulfate Minerals in Snake River Plain Volcanoes , John F. Karlo et al, 1980.

18. Contrasting Magma Types and Steady Rate, Volume-Predictable, Basaltic Volcanism Along the Great Rift, Idaho , Mel A. Kuntz, et al, 1984.

19. Volcanoes in the Sea: The Geology of Hawaii , Gordon A. Macdonald et al, 1983.

20. Primitive Lead in Deep Crustal Xenoliths from the Snake River Plain, Idaho , William P. Leeman, 1979.

21. "Blue Dragon" Basalt from Craters of the Moon National Monument, Idaho: Origin of Color , Roy M. Miller, 1973.

22. Personel communication, Richard Lefebvre, 1979.

23. The Cambridge Encyclopedia of Earth Sciences , David Smith et al, 1981.