Forum Article

Speculations about the Effects of Fire and Lava Flows on Human Evolution

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ABSTRACT

Recent research argues that an association with fire, stretching back millions of years, played a central role in human evolution resulting in many modern human adaptations. Others argue that hominin evolution was driven by the roughness of topographic features that resulted from tectonic activity in the African Rift valley. I combine these hypotheses to propose that, for millions of years, active lava flows in the African Rift provided consistent but isolated sources of fire, providing very specific adaptive pressures and opportunities to small isolated groups of hominins. This allowed these groups of early hominins to develop many fire specific adaptations such as bipedalism, smaller teeth and mouths, shorter intestines, larger brains, and perhaps a host of social adaptations. By about 1.8 million years ago, *Homo erectus* emerged as a fire adapted species and mastered the technology necessary to make fire itself. This technology allowed them to move into the rest of the world, taking a new kind of fire with them that would change ecosystems everywhere they went. This hypothesis is supported by recent geologic work that describes a large lava flow occurring in the region of the Olduvai Gorge during the 200 000 year time period we believe *Homo erectus* emerged in the area.

Keywords: fire, human evolution, lava flows

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INTRODUCTION

This paper evolved from a talk I gave in Savanna, Georgia, at the opening plenary of the 4th International Fire Ecology and Management Congress in 2009. The theme of the congress was "Fire as a Global Process." At this conference, researchers and land managers were meeting to discuss fire ecology and the role of anthropogenic fire in many parts of the world. However, my goal was to set an even broader context for the conference by delving far deeper into humanities' journey with fire.

This talk was an opportunity to publicly discuss some interesting recent anthropological hypotheses about fire's role in human evolution, as well as introduce thoughts I have been having for years about our ancestors and fire. My intention was to suggest that, while our use of fire has had tremendous power in shaping the planet's biota, that same relationship may have also shaped many of the things that make us who we are in the animal kingdom. I also proposed that lava flows in the African Rift, occurring over millions of years, provided consistent and isolated sources of fire, perhaps creating specific adaptive pressures and opportunities for small isolated groups of hominins, and possibly leading to a set of adaptations that contributed to the evolution of modern humans. In the last century, science has begun to unravel the role of fire in many terrestrial ecosystems. However, this paper is not a scientific presentation of hypotheses that have been extensively tested in the field. Rather, it is a playful exercise in speculation and even "just so stories" about human evolution and fire.

After all, we are the fire animal. We are the only creature that can start fires, allowing us to thrive in almost every climate on Earth. We use combustion to cook our food and heat our homes. Today, we even use the energy from combustion to refrigerate our foods, cool our buildings, and travel into space. We use fire and its heat in many agricultural and manufacturing processes, and we have moved fire and its atomic surrogates into the engines and boilers that power our world. Combined with our languages and cultures, our power to ignite is perhaps our most important tool for truly reshaping the world around us. For millennia before we even began using steam power or internal combustion engines, our fires reshaped ecosystems almost everywhere humans lived. Many landscapes have literally coevolved with humanity's fires for a very long time, a process that has been best expounded upon in the extensive writings of Stephen Pyne (e.g., Pyne 1995, 2001).

I propose that we consider the additional possibility that, like the other systems and species we study, humans are also highly fire adapted. Every year we learn more about other species' evolutionary adaptations to fire. Fire changes things. Therefore, it seems reasonable to ask how fire might have changed us as a species. When I first started thinking about this a decade ago, I was surprised that only a few other people seemed to be asking the same sorts of questions. However, two recent books have proposed that many of the unique features of humanity are the result of specific evolutionary adaptations to consistent exposure to fire (Burton 2009, Wrangham 2009).

In this paper, I start with the somewhat controversial works of these researchers who propose that an association with fire, stretching back millions of years, played a central role in human evolution, resulting in many modern human adaptations and our own chain of speciation (Burton 2009, Wrangham 2009). I also describe a new mechanism for that speciation. Specifically, I propose that, for millions of years, active lava flows in the African Rift provided consistent, long term, but spatially isolated sources of fire. These burning islands in the African pyroscape provided small areas that would create very specific adaptive pressures and opportunities for very small isolated groups of hominins. Some of these episodes of isolation may have extended for hundreds of thousands of years, allowing these isolated groups of early hominins to develop adaptations that can be argued to be the result of living in proximity to fire, such as bipedalism, precision hand grips, smaller teeth and mouths, shorter intestines, larger brains, and perhaps a host of social adaptations.

Long before we achieved control of fire, lava flows may have provided our ancestors' first continuous exposure to fire in a way that propelled the evolution of many hominin species, including ourselves. Then later, some of these adaptations may have given us the necessary physical and intellectual tools to make fire rather than simply tend it, allowing our forbearers to spread around the globe. This admittedly tenuous string of hypotheses is supported by recent geologic work that describes a large lava flow occurring in the region of the Olduvai Gorge during the 200 000 year time period we believe *Homo erectus* emerged in the area.

HOMININ EVOLUTION

Over the last decade, the term "hominin" has come to refer to all the bipedal species in the tribe *Hominini.* This tribe includes all of the *Homo* species, the Australopithecines, and other ancient species that appeared after a separation with the chimpanzee lineage and were related to *Homo sapiens.* The more traditional term "hominid" is the family level *(hominidae)* and is now taken to refer to all the great apes (NRC 2010). But the question remains: what drove these evolutionary splits? I believe we should consider the evidence that some hominin ancestors developed unique relationships with fire that may have been some of the driving factors in a host of adaptations, possibly even setting off the separation from the chimp lineage and leading to many of the unique features of the hominins.

For decades, the dominant model of human evolution held that tree dwelling apes transitioned into ground dwelling bipedal human predecessors. Variations of this hypothesis usually hold that these hominins moved from forests and onto the African savannah as changing climates reduced the sizes of the forests (King and Bailey 2006). This transition was also thought to be accompanied by a shift from herbivory to a more omnivorous and meat centered diet. However, other recent research has indicated that the climatological story during this evolutionary period was far more complicated than previously believed. Some researchers now argue that the constantly shifting climate scenarios in eastern Africa were themselves a major driver in the evolution of hominins (NRC 2010). However, there have been literally dozens of competing hypotheses intended to explain such basic human adaptations as hairlessness and bipedalism (Niemitz 2010). For example, one hypothesis from the 1980s that was never well accepted in the anthropological community proposed that we had aquatic ape progenitors leading to hairlessness and many other adaptations (Morgan 1982). While recently, others have proposed that wading and aquatic foods led to bipedalism while providing essential nutrients for human brain evolution (Cunnane 2005, Wrangham *et al.* 2009).

HOMININ EVOLUTION AND FIRE

The strongest evidence for hominin use of fire dates to *circa* 400 000 BP, or pre-modern *Homo sapiens*, with various degrees of suggestive evidence stretching back to about 1.7 million years (James 1989, Burton 2009). Detangling evidence of early hominin use of fire from naturally occurring fire is very difficult as much of the evidence burns away. Nevertheless, two scholars have written recent books suggesting that fire played a central role in the evolutionary development of some of our earliest ancestors (Burton 2009, Wrangham 2009). Both authors argue that fire has been overlooked as a primary driver in the story of human evolution. However, Wrangham (2009) emphasizes the impact of cooked food on physiology and behavior, while Burton (2009) focuses on the changes that may have resulted from fire light allowing activities in the dark of night.

In any case, for millions of years, hominins were developing a host of adaptations that may make more sense, taken as a group, if we consider the possibility that many individuals may have been living in close proximity to fire for some of those millions of years (Figure 1). Otherwise, we are forced to imagine small toothed, short intestined, tool using bipeds moving out of Africa about 1.8 million years ago, or even earlier, without fire. These possibly hairless *Homo erectus* would have been living in diverse climates on several continents, for perhaps a million years, all without fire. Thus, these creatures would certainly have trouble staying warm and protecting themselves from predators in these new climates. However, there are other competing hypotheses involving technological and social

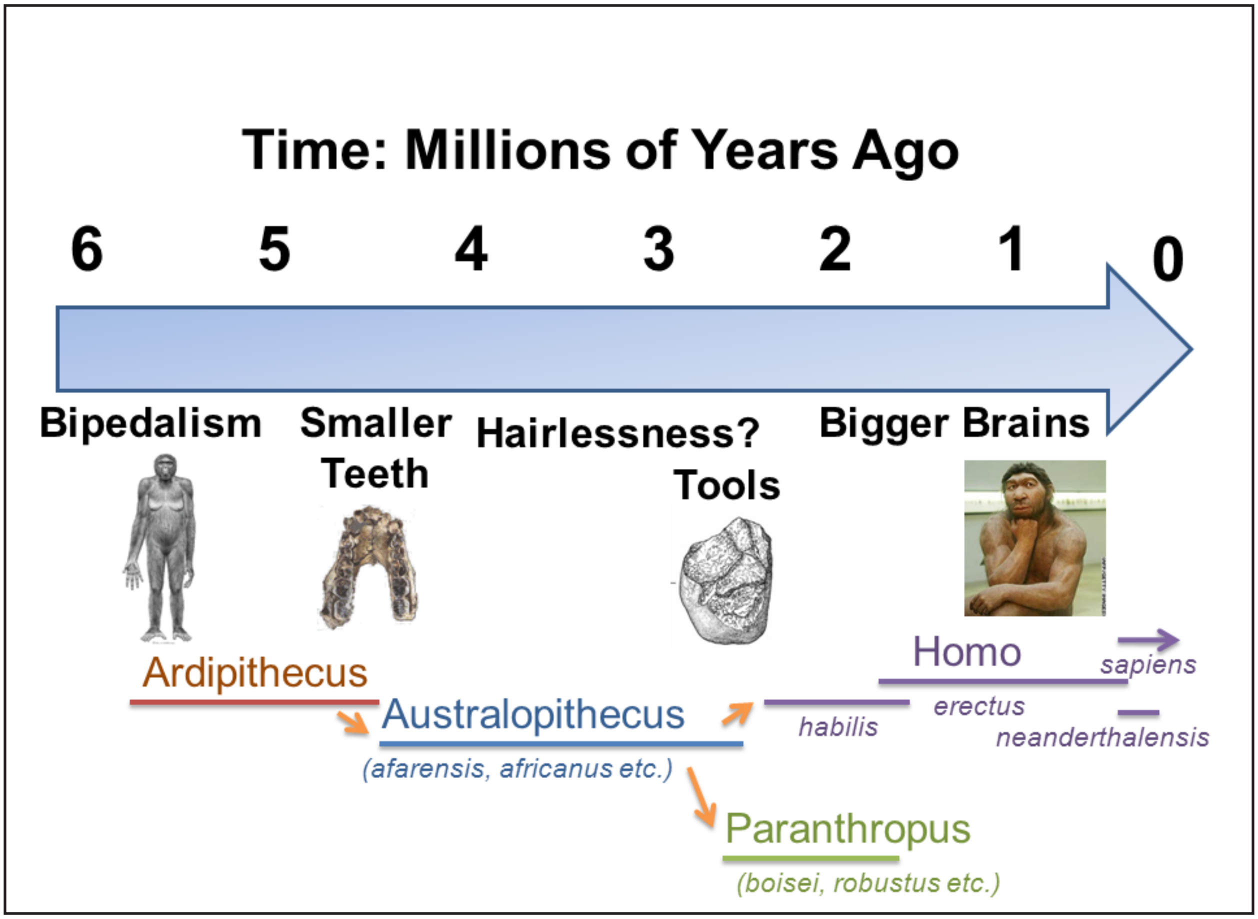

Figure 1. This timeline shows a rough outline of some hominin adaptations that may be associated with fire. The simplified phylogenetic tree at the bottom shows the time span of several significant hominin species. Throughout this entire timeline, active lava flows were occurring in the African Rift.

developments that are intended to explain this success without fire. But I believe a far more compelling argument for hominin adaptation to fire is Wrangham's (2009) argument that, without fire, these small toothed, short intestined creatures would simply have trouble chewing and digesting enough uncooked food to sustain themselves (Carmody and Wrangham 2009, Wrangham 2009).

This "pyrogenesis hypothesis" of human evolution holds that many modern human adaptations resulted from interaction with fire. Though I had been thinking about fire and human evolution since the 1990s, I borrow heavily from both of these books for many of the ideas in this piece. I concur with these authors that it is worth considering that our progenitors may have begun our unique relationship with fire several millions of years ago, and that this relationship may have shaped many of the things that make us unique in the animal kingdom.

In his book *Catching Fire: How Cooking Made Us Human*, Wrangham (2009) argues strongly that many of the physical traits that separate species in the genus *Homo* from other species are the results of several million years of interaction with fire. He argues specifically that our consumption of cooked foods provided more efficient digestion, leading to shorter intestines, smaller mouths, smaller teeth, and ultimately freeing caloric resources to support increased brain sizes. He proposes that, around two million years ago, a group of Australopithecines achieved a level of control of fire that allowed them to start eating cooked foods. These foods provided easier access to calories and also freed time previously needed for chewing. Wrangham (2009) argues that eating cooked food not only drove a host of physical adaptations, but also many social developments including pair bonding and a gender division of labor. Many of Wrangham's (2009) ideas are not clearly accepted in the anthropological world, and there is very little direct evidence supporting some of his assumptions and proposals, particularly his ideas about hominin behavior. However, speculation is at the core of this type of hypothetical thinking.

In the other book, *Fire: the Spark that Ignited Human Evolution*, Burton (2009) argues similarly that much of our unique evolutionary history is a result of several million years of association with fire. Burton (2009) argues that, for perhaps as long as six million years, hominins' relationship with fire led to exposure to nighttime light, producing changes in circadian rhythms and diurnal activity patterns, which in turn led to hormonal changes and many physical and social adaptations, ranging from bipedalism to language.

Both of these books offer compelling arguments and extensive literature citations for anyone interested in diving deeply into this emerging hypothesis of human evolution. Though Wrangham's cooked food hypothesis was first proposed in 1999, this pyrogenesis hypothesis is still in its infancy and is far from widely accepted (Wrangham *et al*. 1999). However, it is quickly gaining traction, and other subsequent research is beginning to provide more evidence supporting many of the key arguments of his cooked food hypothesis (Carmody and Wrangham 2009).

SPECULATIONS AND JUST SO STORIES

In the spirit of speculation, I propose that we consider the possibility that many hominin adaptations could have been influenced by selective pressures resulting from fuel gathering, fire management, cooked food, and living in close proximity to flames for as long as perhaps six million years in the African Rift region. A few example adaptations include bipedalism, changed digestion systems, brain size, tool use, and hairlessness.

Bipedalism

Bipedalism developed at least 4.4 million years ago in *Ardipithecus ramidus*, popularly known as Ardi, and perhaps millions of years earlier than that (White *et al*. 2009). Perhaps this new form of locomotion freed up powerful arms and restructured hands for fuel gathering. Bringing dry wood and food to an existing fire would be a powerful new ability for a hominin living with fire. Looking at J.H. Matternes' artistic rendering of Ardi, (Figure 2), it is easy to imagine her being particularly helpful in both climbing into trees and moving dead branches to an already burning fire.

Figure 2. On the left is Matternes' interpretation of a 4.4 million year old female Ardipithecus adapted from Lovejoy *et al.* (2009). On the right the author demonstrates the utility of bipedalism and grasping hands for fuel gathering, as well as modern yard cleaning.

Digestion and the Brain

Over the following few million years, we may be seeing evidence of early cooked food as many species of hominins' teeth and mouths shrink, rib cages constrict to contain shorter intestines, and brains slowly expand (Wrangham 2009). We also see the hominin species in our direct lineage lose the sagittal crest along the top of the skull, while significant sagittal crests occur in some of the *Paranthropus* species not in our direct lineage (Figure 1). This crest is the bony ridge at the top of the scull that is so obvious in many other primates. It is the attachment point for the huge jaw muscles necessary for chewing and eating dense uncooked fibrous vegetation.

Tool Use

By about 2.6 million years ago, we also see the first evidence of stone tools (Semaw 2003). Though these tools are often described as meat cutting implements, they may well have also been fuel cutting tools. Sharp stones are quite useful for cutting branches and making fine fuels for tinder. By 1.7 million years ago, we also see the introduction of the more sophisticated Acheulean hand axe, which was the primary hominin tool for about a million years. These large hand axes have puzzled many researchers as they seem too large for effective meat cutting (Figure 3). However, we intuitively call them axes, and they could be effective tools for chopping fuels into more efficient sizes.

Figure 3. The author's rather large hand illustrates the size of a replica of an Acheulean hand axe found in the Smithsonian Institute. This large axe seems inconvenient for meat cutting but quite practical for fuel cutting.

Hair Loss

Hair does not fossilize well, so we are unsure just when hominins may have become hairless. However, hairlessness was proposed as an adaptation to fire as early as 1978 by Claire Russell (1978). Researchers have estimated when hairlessness might have first occurred in our lineage using the DNA associated with skin color to argue that hairlessness arose at least 1.2 million years ago (Rogers *et al*. 2004). Others have theorized that hairlessness arose in response to parasites (Pagel and Bodmer 2003). Regardless, hairlessness is a clear candidate as a fire adaptation for anyone who has spent evenings sitting close to a popping and crackling campfire. Sparks landing on furry individuals could result in large enough burns to cause serious infectious wounds, while hairless creatures are likely to be much faster to recognize and remove a burning ember on their skin. Perhaps more importantly, hairlessness could also allow fire to serve as an artificial heat source on cool nights. This would facilitate better body cooling during the day, allowing individuals to be more efficient long distance bipedal travelers during the heat of the day, leading to more effective hunting and gathering (Wheeler 1984, 1992; Jablonski 2006).

DISCUSSION

This game of "explain the fire adaptation" can go on almost indefinitely, to which my wife, children, and campfire friends will all attest. For example, perhaps, the whites of our eyes developed to communicate emotions at night around a fire. Perhaps, as any smoker will attest to, inhaling smoke provides a sense of calm, harkening back to millions of years of security found near fire. Perhaps, as both Burton (2009) and Wrangham (2009) propose, large numbers of our social behaviors developed as a result of our association with fire. Obviously, though, any single explanation may be fraught with personal or cultural baggage, or be dismissed as another 'just so story.' Along those personal projection lines, my personal favorite fire adaptation proposal is that male pattern baldness developed as a response to fire. Perhaps our species' fitness was enhanced in groups in which at least one individual was able to hold their hairless head down near a fire while tending it without their head bursting into flames. And who better for that task than an older gentleman who has studied the nature of fire for his whole life? However, despite my arguably fire adapted personal hair style, I must admit that my long haired wife builds most of the fires at our home.

Admittedly, many of these adaptations can be explained by some other hypothesis, but if we accept for a moment Wrangham's (2009) and Burton's (2009) arguments that a long association with fire drove many facets of our evolution, then another question remains: what was the source of that flame for millions of years? If fire helped drive our evolution to the point that we developed the extraordinary mental capabilities and physical attributes that allowed us to begin making our own fire, then where did we get fire before that occurred? In short, many adaptations in the hominin fossil record can be attributed to adaptation to a life with fire, but until hominins began to make their own fire, these adaptations would require a fairly consistent source of flame for perhaps millions of years.

After years of living outside with various types of fire in a range of forested and arid environments, I personally find Burton's (2009) and Wrangham's (2009) proposed sources of this ongoing flame access unsatisfying. They both mention a suite of possible sources ranging from lightning and sparks from rock falls, to spontaneous peat ignition and naturally occurring burning gas vents. Admittedly, annual grassfires are common in the savannah today, and they may seem like a reasonable flame source, even if only seasonally. However, these areas were undergoing profound climate variations, and the savannah we see today was not always the environment in which early hominins developed (NRC 2010). Perhaps, instead of the savannah driving human evolution, some of these savannah landscapes are in fact ancient evidence of hominin fire spreading practices going back millions of years.

Wrangham (2009), Burton (2009), and even Pyne (1995, 2001) all briefly mention volcanism as another possible source of early hominin interaction with flame. However, they seem to dismiss it as too explosive and episodic. I propose here, that for these evolutionary processes to play out over millions of years, a more stable source of fire is required. Therefore, I propose that we should consider the possibility that the long term, less explosive lava flows occurring in the African Rift may have provided millennia of continuous heat and flame.

THE ROLE OF VOLCANISM

In an award winning paper appearing in the journal *Antiquity,* Geoffrey King and Geoff Bailey (2006) proposed yet another new model for the origins of humans and our evolutionary adaptations. They argued that the evolutionary stimulus that led to our lineage was generated by the roughness of tectonic and volcanic landforms in the African Rift region (King and Bailey 2006). Their paper provides an excellent overview of the many competing hypotheses about the environmental drivers that may have propelled our evolution. However, these authors were compelled by the remarkable geographic coincidence of active volcanism and tectonic processes in close proximity to many of the most significant finds in hominin evolution. They present a persuasive map illustrating the spatial patterns of volcanism and hominin fossils in the African Rift (Figure 4).

In the African Rift, large sections of the earth's crust are dropping down as massive continental plates are slowly spreading apart. This tectonic activity is spread over thousands of kilometers and is accompanied by chains of volcanoes and lava flows. As on the island of Hawaii today, many of these lava flows are slowly expanding magma intrusions. Though the African Rift does have composite volcanoes and the associated explosive eruptions and ash falls, many much slower lava flows have poured into internal basins for millions of years (Figure 5). Many of these flows lasted many thousands of years. During that time, sources of warmth and flame would have been available almost continuously as the flows would radiate considerable warmth and often ignite vegetation. Hominins may have learned quite early to stay near these fires and add fuel to the fires. Perhaps they even learned to move burning materials. They may have even learned to light fuels directly on lava and carry the burning materials to a safe location (Figure 6)

As a geographer, I am predisposed to the spatial persuasiveness of King and Bailey's (2006) paper. They argue that there must be something about the tectonics of the African Rift that drove hominin evolution. However, I propose that we combine their very strong spa-

Figure 4. Strong geographic evidence that hominin evolution is somehow related to tectonic activities and volcanism. (adapted from King and Bailey [2006]). (Cartography by Allyson Hayes and Alyssa Weatherford.)

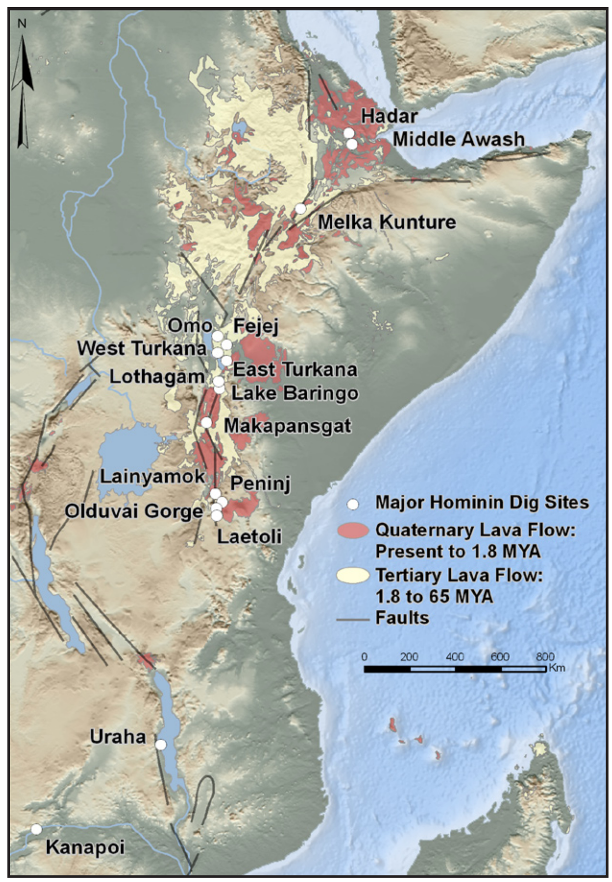

Figure 5. Lava flows in the African Rift. Many of the most significant finds in hominin evolution are located in close proximity to these lava flows. (Cartography by Allyson Hayes and Alyssa Weatherford.)

Figure 6. A modern example of a hominin lighting a stick by placing it on an active lava flow (photo by Dan Donato).

tial arguments about the role of tectonic landforms with the strongest elements of Wrangham's (2009) and Burton's (2009) pyrogenesis hypothesis. The result is my proposal here that, for millions of years, active lava flows in the African Rift provided consistent but isolated sources of fire, providing very specific adaptive pressures and opportunities to small isolated groups of hominins. This allowed these groups of early hominins to develop many of the adaptations mentioned above. Eventually, large brained, bipedal, cooked-food eating, tool using, *Homo erectus* emerged and mastered the quintessential human technology when they learned to make fire itself. This technology allowed them to move out into the rest of the world, taking a new kind of fire with them that would change the ecosystems everywhere they went.

Admittedly, this is all a rather imposing proposition, requiring several leaps of faith given the paucity of archeological data and the multitude of competing ideas. However, a good test of any hypothesis is how well it allows us to predict. Therefore, when I first started really thinking about this hypothesis, I realized that there should be spatial and temporal correlations between some of the most noteworthy developments in hominin adaptation and extensive lava flows (Figure 5). As King and Bailey (2006) point out, a large number of hominin fossils, and even footprints, are found in the vicinity of active volcanism. But the fossils and footprints themselves are often found in tufts created by volcanic ash falling from explosive eruptions. This does show that these individuals lived in the vicinity of volcanism, but the predominance of these findings could well represent only the fact that this particular set of circumstances preserves fossils well and distributes them in environments that are easy for us to find and examine today. What is needed is to demonstrate that particular instances of documented hominin development, or even speciation, occurred very near active lava flows.

Therefore, I decided to examine the emergence of *Homo erectus* in the Olduvai Gorge area that occurred about 1.8 million years ago. This is one of the most interesting and studied transitions in the hominin record, and it represents one of the most profound developments in human evolution as many consider *Homo erectus* to be the first true member of our own genus (Wood and Collard 1999). Even Wrangham (2009) focuses on the emergence of *Homo erectus*. He proposes that a population of Australopithecines achieved control of fire and were consistently eating cooked food by about 1.9 million years ago, leading to the emergence of *Homo erectus* (Wrangham 2009). If Wrangham is correct, and I am correct, then we should expect to see extensive lava flows pouring into internal basins in the Olduvai Gorge region at the time of this transition.

I was pleasantly surprised when, in 2009, a research paper was published describing lava flows in the Olduvai area. The paper describes extensive flows that began roughly two million years ago and lasted until 1.8 million years ago (Mollel *et al*. 2009). This large lava flow provided 200 000 years of continuing access to fire for small isolated groups of hominins that may well have eventually become *Homo erectus*, mastered ignition, and colonized Europe and Asia. As they traveled, they would have changed ecosystems everywhere they brought their fire.

CONCLUSION

Over the last century, we have embraced fire as a variable in the ecology of many natural systems and organisms. We no longer consider all fires to be disturbances in otherwise fire free systems. Instead, we are beginning to see a world of ecosystems and organisms that have evolved with fire. It is now considered very reasonable to suggest that some features in organisms may represent adaptations to fire. As our species and its progenitors have been living closely with fire for many millennia, if not millions of years, it seems reasonable to suggest that this association has influenced our development as a species. The ideas that I have proposed here are not intended to replace other hypotheses of human evolution, but simply to suggest that we consider the role of fire when we speculate about human origins.

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