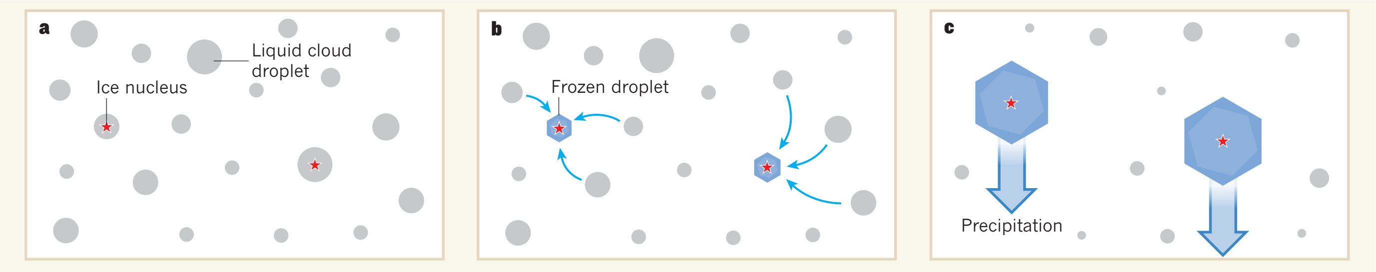

Figure 1 | Ice formation and precipitation. **a**, **b**, Aerosol particles known as ice nuclei catalyse the formation of a few frozen cloud droplets (typically several micrometres in diameter) from supercooled droplets of liquid water. These ice crystals grow at the expense of the remaining majority of liquid droplets, through transfer of water vapour (blue arrows). **c**, The resulting large ice particles (often several tens to more than 100 micrometres in diameter) have higher fall velocities than the small liquid droplets, and may initiate precipitation. Atkinson *et al.*[1] report that feldspar particles are the most effective mineral ice nuclei.

details of aerosol composition. Rarer still are studies that, as well as estimating the fraction of aerosols that is composed of minerals, also analyse what the different minerals are. Similarly, because of the expense of simulating the effects of many types of minerals and the lack of comprehensive data, the incredible variability of mineral aerosol composition is ignored in climate models. Instead, mineral aerosols are usually modelled together, as a bulk dust. Any atmospheric processing of mineral aerosols that would modify their chemical and physical properties is also commonly ignored in models.

Atkinson and co-workers' findings demonstrate the need for more observations of the mineralogical composition of mineral aerosols; currently, such observations are few and far between (see the Supplementary Information of the paper[1]). More information about the effects of acids on mineral aerosols is also required to gauge the role of these reactions in the atmospheric processing of minerals. For example, do acids convert feldspar into less-effective ice nuclei, such as clays? We also need a better understanding of the distribution of minerals in areas of soil that act as sources of dust. In addition, we must learn more about how humans and climate have changed, and will change, desert dust (and feldspar dust in particular) over time. The limited evidence available suggests that the mass of dust worldwide doubled over the twentieth century[9].

Finally, Atkinson and colleagues' work requires us to rethink how aerosols and aerosol–cloud interactions are modelled: multiple types of minerals, as well as their chemical reactions with compounds such as sulphates or organic acids in the atmosphere, must be considered. This means that substantial increases in the complexity and computational expense of models are needed. Scientists should consider whether we can use a proxy for the potential of different mineral compositions to nucleate ice — instead of the effects of specific minerals — to reduce the complexity of the problem such that mineral aerosols can be included in computationally expensive climate models more correctly.

In retrospect, the finding that a specific mineral is responsible for most ice-nucleation events in mixed-phase clouds is perhaps not that surprising, because the chemical and physical properties of different mineral aerosols are so disparate. For instance, earlier studies have highlighted the importance of aerosol mineralogy in the interactions of atmospheric dust with light[10] and in ocean biogeochemistry[11]. Nevertheless, Atkinson and colleagues' discovery is extremely important: when it comes to ice nucleation, not all dust is created equal. ■

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BEHAVIOURAL BIOLOGY

Archaeology meets primate technology

A study of wild capuchin monkeys that crack nuts using stone hammers reveals temporal and spatial patterning of the relics of their technological efforts, confirming that such behaviours can be studied from an archaeological perspective.

ANDREW WHITEN

Our ancestors have been fashioning and using stone tools for at least 2.5 million years[1]. Bronze blades began to replace lithic axes a mere few thousand years ago, so percussive stone tools — hammers and axes that function through targeted force — have characterized more than 99.9% of human technological evolution[2]. The discovery of stone-tool use in other primates has offered exciting opportunities to examine such behaviour in living species. West African chimpanzees have provided the focus for this research for 30 years, but it was revealed a decade ago[3] that bearded capuchin monkeys (*Sapajus libidinosus*) also use hammer stones to crack nuts (Fig. 1a). Writing in the *Journal of Archaeological Science*, Visalberghi *et al.*[4] present the fruits of an interdisciplinary project[5] that emerged from this discovery. Their study goes beyond behavioural observations to log the archaeological signatures of percussive tool use by capuchins.

This research represents one of the first comprehensive empirical examples of the new discipline of primate archaeology[6–8]. Working in the monkeys' open, savannah-like woodland habitat in Brazil, the authors located 58 active nut-cracking anvil sites, which they identified by the presence of hammer stones, pits on the stone or wooden-log anvils, and nut remains. Each month for three years, the scene at each anvil was inspected and photographed,

A, ELISABETTA VISALBERGHI; B, MICHAEL D. GUMERT; C, PRIMATE RESEARCH INST. OF KYOTO UNIV.; D, DIETRICH STOUT

Figure 1 | Use of percussive stone tools in primates. **a**, A male capuchin monkey weighing just over 4 kilograms uses a 3.5-kg stone to crack a highly resistant piassava nut. Hammer stones typically weigh around 1 kg. **b**, A long-tailed macaque raises a stone to crack an intertidal snail. **c**, A common chimpanzee cracking nuts using a stone hammer and anvil. **d**, People knapping stone tools on Irian Jaya, Indonesia.

the nuts were cleared, the hammers replaced and the array was re-photographed to track material changes at the site.

The authors found a median usage per anvil of 35% of months, and a maximal use of a single anvil in 30 out of 36 months. Hammer transport was a relatively rare occurrence, with just 40 cases of hammers being shifted farther than 3 metres in 1,872 visits. However, on seven of these occasions, the hammer was moved up to 10 m away to a boulder that had not previously been used as an anvil. Moreover, in four cases, viable new hammer stones, which are quite rare at the site, appeared at the inspected anvils. And a hammer disappeared from the site on 17 occasions, in two cases being returned 1 and 5 months later.

Putting these and previous observations[9] together, it seems likely that rare but more extended transport between anvils may also occur; the researchers are planning longer-term recordings, and it will be interesting to see what these reveal. Alongside other elements in this study, such as records of the weathering of nut-case remains, the observations begin to delineate the material effects of a non-human primate's technological activities on the landscape in both space and time, as well as indirectly charting large-scale patterns in the monkeys' tool-related behaviour.

Parallel studies on chimpanzees are under way[10]. Do studies such as these merit the 'archaeology' epithet their authors promote? Dictionary definitions suggest not, referring instead to studies of "man's past" and "ancient cultures". Indeed, we tend to think of archaeologists as digging deep to find crucial remains. It is true that the remains examined by Visalberghi and colleagues are far from ancient, although, in the case of chimpanzee nut-cracking, evidence of a history back to 4,300 years has been excavated[11]. However, such definitional quibbles can be seen as pedantic. Extending the scope of human-focused disciplines to other species has yielded insight in several domains of evolutionarily focused enquiry, culture itself being one of them[2].

A key question that must be addressed by such studies is thus whether capuchin technology is culturally transmitted, through observational learning. Controlled experiments have demonstrated that alternative foraging techniques that are seeded in different captive groups of capuchins spread through social learning to become traditions[12]. Such experiments are hard to emulate in the wild, but Visalberghi and co-workers' findings offer a variety of circumstantial evidence for cultural transmission, which the authors believe is supported by the correlated presence at anvils of arrays of key materials[13]. These findings are complemented by field experiments[14] that elegantly demonstrate a sophisticated understanding of optimal tool properties, such as mass and size, in capuchin monkeys.

Humans and capuchins are separated from their common ancestor by about 35 million years. So, can studying these monkeys influence our understanding of the lithic technology that pervaded so much of our own evolutionary history[2,15]? I believe so. We know that the long-tailed macaque also uses stone hammers to process hard-shelled foods, such as oysters and sea snails, on rocky shorelines (Fig. 1b)[16]. The shells acquire different wear patterns as a result of the monkeys' use of different tools for these various targets. Macaques are Old World monkeys, the group of primate species that are today found in Africa and Asia, as opposed to the capuchins, which belong to the New World monkeys of Central and South America. Together, these studies suggest that using stone hammers to access embedded foods may be a widespread but often latent capability among monkeys as well as apes, which finds expression in response to the co-occurrence of a small set of facilitating circumstances. The convergence on these behaviours by such diverse species of primate offers opportunities to identify ecological and other factors that support the emergence of percussive stone technology. For example, intriguing findings are already emerging in the capuchin studies that contradict a popular hypothesis that percussive tool use functions to overcome seasonal food scarcity[17].

The form that percussive, lithic technology takes in the chimpanzee — the species with whom we shared our most recent common ancestor — may have further significance. Whereas a capuchin generally needs to rear bipedally to use a stone to crack nuts (Fig. 1a), chimpanzees typically sit, truncally erect, and may use one hand to wield the hammer and the other to manipulate the target (Fig. 1c). In a common ancestor, this configuration would have provided a preadaptation to the approach used by modern human stone knappers[18] (Fig. 1d). ■

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HIV

Integration triggers death

That HIV cripples the immune system by killing CD4$^+$ T cells has long been known. It now emerges that the protein DNA–PK, activated by viral integration into the host-cell genome, is the agent of this death response. **See Letter p.376**

ANNA MARIE SKALKA

Retroviruses, the class of virus that includes HIV, do not ordinarily destroy the cells that they infect. Instead, they are propagated essentially as genetic parasites: after a DNA copy of the retrovirus's own RNA genome has been integrated into the DNA of a host cell, the cell is exploited to express viral molecules, and progeny viruses are released even as the host cell continues to thrive. But infection of human white blood cells known as activated CD4$^+$ T cells is a marked exception. In fact, it is the en masse killing of these cells by HIV that gives rise to the severe immunodeficiency that is AIDS. In this issue, Cooper *et al.*[1] (page 376) report that this death is the T cells' response to the attack on its genome by the viral integration machinery. Furthermore, the authors reveal that the main player in this response is DNA-dependent protein kinase, an enzyme normally associated not with cell death, but with the repair of DNA damage*.

Retroviruses enter their host cells fully equipped to carry out the first essential steps of viral replication. The viral enzyme reverse transcriptase ensures rapid synthesis of a double-stranded DNA copy of the viral RNA genome. Another virus-associated enzyme, integrase, then binds to and processes the ends of this viral DNA molecule as soon as they are formed. A protein complex containing the viral DNA, integrase and other viral and host proteins is subsequently transported to the cell's nucleus, where integrase catalyses a concerted cleavage and joining reaction in which the 3′ ends of the viral DNA are joined to the 5′ ends of a double-stranded cut in the host DNA. The remaining gaps and overhangs at this integration site are probably repaired by the cell within 26 hours of infection, when expression of viral capsid proteins can be detected[2].

Cooper and colleagues studied this process in human CD4$^+$ T cells infected with HIV *in vitro*. They observed that the cells express viral DNA and HIV-encoded proteins within 36 hours, but that this expression ceases by the second day, concomitant with massive cell death. This time frame is consistent with the estimated half-life of infected activated CD4$^+$ T cells in patients with AIDS[3], but the trigger for the death of these cells had not previously been identified. Cooper *et al.* found that both death and loss of HIV-protein expression in these cells could be prevented by the addition of inhibitors of viral reverse transcriptase or integrase (the authors used efavirenz and raltegravir, respectively) before infection. Furthermore, raltegravir treatment of activated CD4$^+$ T cells isolated from infected individuals (before therapy with antiretroviral drugs) rescued some of these cells from virus-induced death.

The authors also demonstrate that an increase in the prevalence of free viral DNA ends, which occurs when integration is blocked, does not, as has been suggested previously[4], promote cell killing. And they found that the expression of viral genes following integration into the host genome also does not promote cell death. These and other results from their study strongly support the conclusion that it is the viral-integration step that promotes killing of HIV-infected T cells.

This proposal is consistent with the notion that integration of virus-derived DNA is perceived by the cell as a DNA-damaging event[5]. Mammalian cells have evolved intricate and partially overlapping mechanisms for responding to DNA damage, and three members of the phosphatidylinositol-3-kinase-like protein family — ATM, ATR and DNA-dependent protein kinase (DNA-PK) — are central to this response[6]. Both ATM and DNA-PK are known to be recruited to and activated by double-stranded DNA breaks, and previous studies have implicated these enzymes in

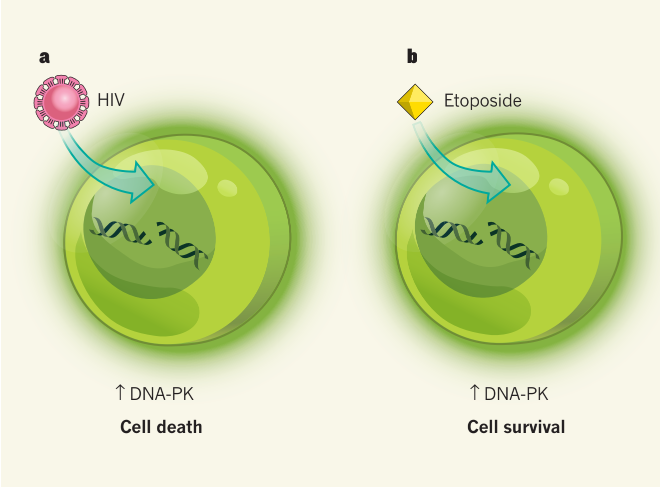

Figure 1 | Opposing responses to DNA damage. a, When a cell is infected with HIV, the virus's integrase enzyme induces double-stranded breaks in the cell's DNA and inserts a DNA copy of its RNA genome. Some cells survive this process, but activated CD4$^+$ T cells do not. Cooper *et al.*[1] reveal that this is because, in these cells, subsequent activation of DNA-PK leads to p53-mediated apoptotic cell death. **b,** Treatment of activated CD4$^+$ T cells with the agent etoposide also leads to double-stranded DNA breaks, by interacting with the DNA-unwinding protein topoisomerase II and preventing the rejoining of DNA breaks that occur during normal cell replication. In this case, however, DNA-PK activation promotes DNA repair, allowing the cells to survive.

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*This article and the paper under discussion[1] were published online on 5 June 2013.