removal, as well as that occurring in the wake of an infection, is carried out in vertebrates by phagocytes ('cells that eat'), and particularly by white blood cells termed macrophages ('big eaters'). Cells that are undergoing apoptotic cell death expose surface markers ('eat me' signals) that alert nearby phagocytes to engulf and dispose of the cell corpse. But, in contrast to receptors that directly bind cells displaying these markers, TAM receptors use adaptor proteins, or ligands, that bind both the marker on the cell to be removed and the TAM receptor on the phagocyte. These adaptors are called growth-arrest-specific protein 6 (Gas6) and protein S.

Fourgeaud *et al.* examined the function of TAM receptors in brain microglia — cells whose origin and competencies are only now becoming clear. Microglia are derived from primitive macrophages that enter the embryo from the yolk sac early in development, become distributed throughout the embryo as resident macrophages, and guide organ development. In the embryonic brain, which is populated by microglia from day 10 of gestation in mice and from gestational week 4.5 in humans[4], exuberant production of redundant cells keeps microglia busy clearing corpses[5]. The brain forms normally without TAM receptors, and Fourgeaud and colleagues wondered what the molecules' roles might be in adult life.

The study initially focused on two brain regions in which neurons are continuously being born and that are therefore designated neurogenic niches[6]. One of these niches produces neurons to replenish olfactory neurons, which support the sense of smell. Neurons from the second niche become integrated into regions associated with memory and learning. As with many generative tissues, the neurogenic niches produce an excess of progenitor cells (which have the potential to develop into neurons), most of which die. Speculation held that microglia cleared these cell corpses, and it seemed plausible that neurogenesis would fail if corpse removal was impaired[7]. Previous research[8] using mice that lacked all three TAM receptors in all tissues suggested an alternative idea: that neurogenesis is suppressed as a result of excessive inflammatory reactions by microglia with deficient TAM signalling. However, the state of the neurogenic niches without microglial TAM receptors remained unresolved.

Fourgeaud and colleagues' investigation of mice that lacked both *Mer* and *Axl* initially confirmed the predicted phagocytic defect: neuron progenitors showing markers of apoptotic death accumulated to a striking degree, whereas these dying cells were not seen in wild-type mice, nor were they seen in regions other than the niches. But the authors' analysis of neurogenesis yielded a shock: new neurons in the olfactory region increased by 70% in the mice lacking *Mer* and *Axl*.

An explanation for this result came from another study[9], which showed that microglia in regions of the mouse brain damaged by stroke engulfed viable neurons that displayed 'eat me' signals because of stress, not cell death. This study also found that if the uptake of these neurons by phagocytes was blocked, and thus their death by 'phagoptosis' prevented, the severity of stroke was reduced. Fourgeaud and colleagues' interpretation of these combined data is that phagoptosis can be observed in the healthy brain during neurogenesis (Fig. 1). Future work to determine the effects of augmented neurogenesis will be informative.

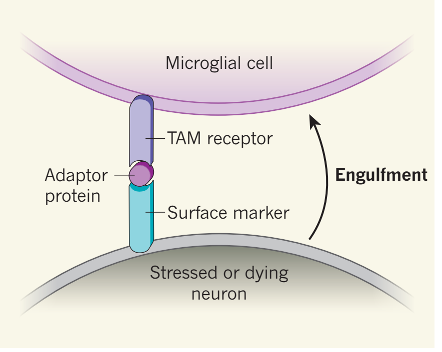

Figure 1 | Neuron clearance. Fourgeaud *et al.*[1] show that TAM-receptor proteins are required for microglial cells in the brain to remove neural cells that exhibit surface markers indicative of stress or apoptotic cell death. TAM-receptor binding, which occurs through an adaptor protein, leads to the engulfment of the stressed or dying cell by the microglial cell.

The *Mer*- and *Axl*-deficient microglia showed other changes as well. Microglia are noted for their delicate, branched processes, which are continually in motion, monitoring synapses (connections between nerve cells)[10]. Fourgeaud *et al.* show that TAM receptors are essential for the processes to be fully motile. Would lack of one or more of these receptors change microglial cells' ability to carry out their manifold tasks in aid of synaptic networks? Further revelations are likely as the TAM-receptor story unfolds and is integrated with findings from other microglial signalling systems. ■

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GEOCHEMISTRY

How rain affects rock and rivers

An analysis of the evolution of river channels on Hawaii's Big Island shows that a key factor is the effect of local rainfall on bedrock strength — rather than its effect on river discharge, as is often assumed. **See Letter p.223**

ALISON M. ANDERS

On page 223 of this issue, Murphy *et al.*[1] report that rainfall has a marked tendency to weaken rock through chemical weathering, so that increases in rainfall raise local rates of river erosion. This finding is valuable because it helps to provide a basis for quantifying the relationship between chemical weathering, which consumes atmospheric carbon dioxide, and erosion by rivers, which sets the pace of landscape-wide erosion in unglaciated mountain ranges.

The global carbon cycle is influenced by a range of processes that occur over geological timescales of tens of millions of years[2]. For example, large quantities of carbon can be stored underground in coal, oil and limestone as sedimentary basins evolve, and atmospheric CO_2 is absorbed when mountain building exposes silicate minerals to chemical-weathering reactions (Fig. 1). On the other side of the balance sheet, carbon stored in the deep Earth is reintroduced to the atmosphere by volcanism and metamorphism (changes in the mineral content and structure of rocks that occur at moderate pressures and temperatures, excluding melting).

Potential feedbacks in this long-term carbon cycle are embodied in the relationships between the rates of: mountain building; chemical and physical erosion of mountainous topography; drawdown of atmospheric CO_2; and changes in global climate. Some of these relationships have been debated[3–5] as potential explanations for the co-occurrence over the past 50 million years of profound global cooling, the rapid growth of mountain ranges, increasing dominance of glacial erosion in shaping mountain ranges and (until the Industrial Revolution) declining atmospheric CO_2 levels. An understanding of the impact of climate on erosion rates is central to unravelling these complex relationships. However, developing this understanding has proved difficult[6,7].

To address this problem, Murphy *et al.* measured the variability in strength and chemical composition of basalt (the most common volcanic rock) along river valleys that cross gradients in mean annual precipitation on the Big Island of Hawaii. The topography of the Big Island before any erosion took place is known, because the island formed from a 'shield' volcano, and shield volcanoes have predictable geometries. The topographic profiles along rivers on the Big Island can therefore be used to derive average rates of river incision into rock over the well constrained age of the basaltic lava flows that formed the island.

The authors compared these river-incision rates with modern mean annual precipitation and rock strength. On the dry side of the island, they found that rock strength decreases as modern mean annual precipitation increases. This pattern reveals the decreasing strength of basalt as it undergoes progressive chemical weathering. But a different relationship holds on the wet side of the island: rock strength is lower than on the dry side and increases with increasing river-incision rate. This is because chemical weathering has generally progressed to a more advanced stage than on the dry side, and the exposure of fresh rock by river incision increases rock strength where incision rates are large.

Murphy *et al.* then developed a predictive model of river incision that included the effect of local precipitation on bedrock strength, and show that it reproduces the observed river-channel topography. The model cannot reproduce the observations when this effect is neglected, even when the spatial variability in precipitation is accounted for in simulations of river discharge (rate of flow). The model suggests that chemical weathering becomes a substantial modulator of physical erosion rates where such erosion rates are modest, but that the impact of chemical weathering on overall erosion is much less where physical erosion is rapid.

Although the complementary nature of chemical weathering and physical erosion has long been recognized conceptually, this work quantifies it in the context of landscape evolution — something that has seldom been done[8]. But Murphy and co-workers' study also highlights a subtle, crucial and frequently overlooked assumption that has hindered our understanding of the connection between climate and erosion: the idea that the effect of spatial variability in precipitation is dominated by the influence of precipitation on river discharge. Instead, the authors show that the main effect of precipitation is its role in driving chemical weathering. Spatial variability in precipitation does strongly influence spatial patterns of resistance to erosion observed in river-channel topography. But the impact of precipitation gradients on river discharge is much less pronounced, because discharge depends only on the average precipitation across the whole drainage area of the river.

The finding that the major influence of spatial variability in precipitation on river erosion is through chemical weathering also suggests other ways in which precipitation might influence local erosion rates. For example, precipitation controls the type of vegetation that can grow, which in turn influences chemical-weathering rates and physical resistance to erosion.

Although the authors' work to quantify the influence of precipitation on chemical weathering and rock hardness is admirable, much uncertainty remains. Precipitation patterns were probably stable over the several hundreds of thousands of years during which the river channels evolved, but we have few constraints on estimates of the absolute amount of precipitation at times other than the past century. Moreover, for most of this time period, the global climate was cooler than it is now, suggesting that modern mean annual precipitation rates in Hawaii are probably higher than the average of such rates over the lifetime of the channels[9]. This implies that the reported sensitivity to precipitation may be an underestimate, and highlights the need for caution in applying the observed relationship more broadly.

Nevertheless, Murphy and colleagues' study is an invaluable contribution to our growing understanding of interactions between global climate, rock weathering, mountain erosion and the long-term carbon cycle. Tropical volcanic islands will probably contribute disproportionately to global chemical-weathering fluxes because of their warm and wet climates and their supply of fresh, easily weathered basalt[10]. To determine the impact of climate on weathering and erosion globally, however, we also need to understand bedrock-weathering processes in glaciated mountains and cold climates, because these processes are more characteristic of those that occurred over large areas of continental crust in Earth's recent geological history. ■

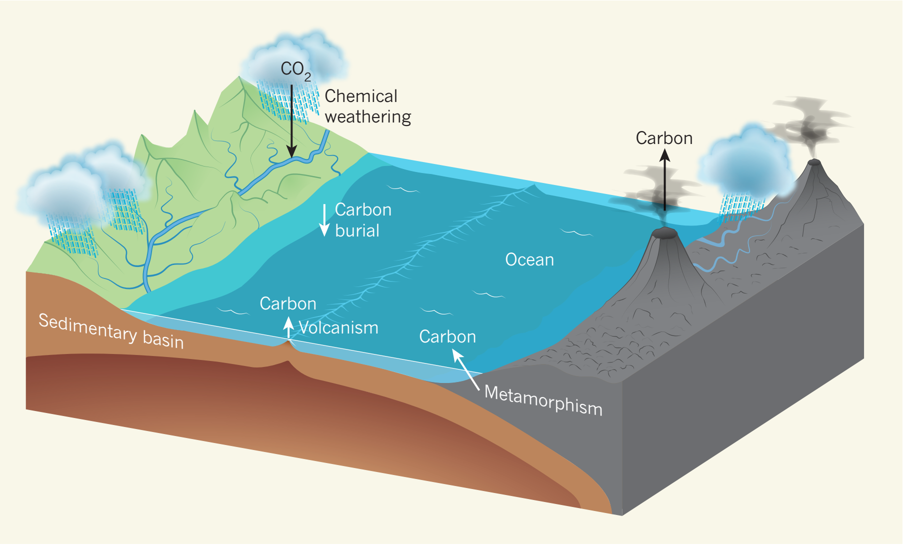

Figure 1 | The geological carbon cycle. On timescales of tens to hundreds of millions of years, carbon cycles between the atmosphere and the deep Earth. Chemical-weathering processes associated with rainfall consume atmospheric carbon dioxide, and carbon also becomes buried in sedimentary basins. Volcanism and metamorphic processes (by which minerals change form without melting) release deep-Earth carbon back into the atmosphere. Murphy *et al.*[1] studied the evolution of river channels on Hawaii's Big Island, and find that local precipitation affects bedrock strength and chemical weathering — improving our understanding of the relationships between the processes that affect the long-term carbon cycle.

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