tion, however, all the enclosed rhinos could be dehorned, predators of rhino calves removed from the sanctuaries, and information and education campaigns mounted to inform poachers of the dehorning so that reprisal killings[8] are avoided. Tourists, too, would need to accept that hornless rhinos are better than no rhinos.

One other problem remains to be solved. The horns of the Damaraland rhinos have only been sawn off and filed down[1], and so will regrow within two to three years. If initial dehorning experiments prove successful and rhinos are not to be exposed to the risks of repeated immobilization, cauterization of the horn bases should be experimented with. An analagous operation, albeit with horns of a somewhat different structure, is carried out routinely to poll horned breeds of cows and is permanent[9]. Conservationists can only hope that Namibia's courageous move will play a constructive role in a final stand to save Africa's rhinos over the next decade. □

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GEOLOGY

Fluid flow through fault zones

Andrew M. McCaig

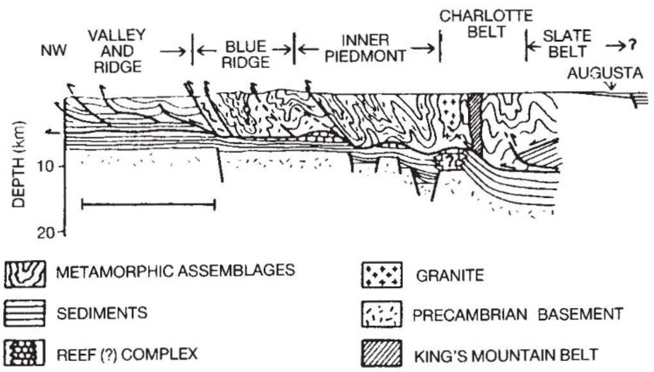
NEW work in Virginia[1] emphasizes the importance of fault zones as major conduits for fluid flow through the middle crust, and may provide a useful new tool for gold exploration. Gates and Gundersen[1] have found significantly enhanced concentrations of radon gas in soils overlying the Brookneal fault zone in West Virginia, relating this to uranium concentrations of 7–8 parts per million (p.p.m.) contrasted with the 1–2 p.p.m. found in nearby undeformed granite. There is also a rough correlation between the shear strain in the zone and the uranium and thorium content, suggesting a progressive increase in uranium enrichment with deformation.

It has been known for many years that mylonitic rocks in ductile shear zones are frequently very different in composition to the rocks they cut[2–5]. These chemical changes are generally ascribed to the passage of large volumes of hydrous fluid through the zones. Shear zones are by definition much more strongly deformed than surrounding rocks and are typically produced when volumes of rock metamorphosed or intruded at high temperatures are reworked under lower-temperature conditions. There is almost certainly a complex feedback mechanism between fluid flow, chemical alteration and strain concentration[5], but it is very hard to separate cause from effect. Nevertheless, it is clear that the only permeable pathways through large volumes of the continental crust must be shear zones, and that in many cases these will be effective fluid conduits only during active deformation.

It is interesting to speculate on the source of fluid and the driving force for fluid movement in shear zones. In the Appalachians, large blocks of highly metamorphosed basement rock such as the Blue Ridge and Piedmont belts (see figure) have been thrust for tens or even hundreds of kilometres over relatively unmetamorphosed sediments[6]. It is possible that the fluid moving through the Brookneal and similar zones was squeezed out from such sediments owing to the enormous weight of thrust sheets above them[4]. But the Brookneal Zone shows mainly strike-slip motion and was probably active before the main Alleghenian collisional event[7], which placed the Piedmont Belt over continental margin sediments. In these circumstances, fluid may have entered the shear zone as a result of seismic pumping[8], either directly or via an underlying decollement[9]. Seismic pumping occurs because of the development of microcracks in highly stressed rocks immediately before earthquake rupture. This increase in pore volume (dilatancy) leads to pressure differentials and sucking of fluid into the stressed rock. When rupture occurs, the microcracks close up, forcing out fluid and leading to greatly increased spring discharges[8].

Fluid movement through fault and shear zones is an important subject of study for both environmental and economic reasons. As pointed out by Gates and Gundersen[1], radon gas is a major and insidious environmental health problem in any area where uranium is concentrated in underlying rocks. Clearly, shear zones should be included in the list of potentially hazardous sites. Equally important is the question of waste disposal; there is hardly any area of crust which does not contain either ancient or currently active fault zones. It is vital to assess the role of seismic pumping if waste is to be buried in seismically active areas such as California, and the long-term permeability of fault and shear zones must be established even in stable regions. A matter of current concern in waste disposal is the presence of corrosive hypersaline brines as groundwaters in crystalline rocks[10]. One possible source for such groundwaters is leaching of ancient fluid inclusions[11]. Recent work in Leeds (S. Tempest, personal communication) shows that fluid inclusions from altered shear zones can contain up to 40 per cent by weight equivalent of NaCl. The possibility that shear zones may contain anomalous concentrations of ancient, corrosive fluids has implications for many engineering projects.

Finally, fault and shear zones are prime targets for gold exploration in many parts of the world. Mineralization is commonly associated with specific geometrical features such as bends and intersections of zones[12]. Often the location and geometry of shear zones are concealed by superficial deposits so that soil sampling for radon may prove a powerful exploration tool. □



Cross-section through the southern Appalachians based on a COCORP seismic reflection profile. The Piedmont belt, containing the Brookneal shear zone studied by Gates and Gundersen[1], is interpreted to overlie unmetamorphosed continental margin sediments. (From ref. 6.).

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