whole answer. Because they offer no mechanism for the static friction of the fault to be low, if they were the solution to this paradox we would observe huge stress drops of the order 100 MPa during an earthquake, whereas observed stress drops are only of order 10 MPa. Given this fact, the static friction of the fault must be low, and there are other observations that suggest this is true for the San Andreas fault[10], but not for less developed faults, which appear to have ordinary friction coefficients[11,12]. But if static friction on the fault is low, solution of the heat-flow paradox does not require any dynamic weakening mechanism.

The most prevalent class of models to explain the low static strength of the fault is that the fault core contains fluid at nearly lithostatic pressures, which lowers the effective perpendicular stress across the fault and hence the frictional resistance[13,14]. As I pointed out in an earlier News and Views article[15], however, this explanation contains its own enigma. To maintain near-lithostatic fluid pressures within the fault core, there must be a dynamically impermeable seal between the fault core and the surrounding rock, and because at the seal itself the fluid pressure will exceed the compressive stress in some directions, the seal must also be impenetrable by hydrofracturing. There is no known or imagined geological material with those properties.

In the 25-year history of the San Andreas heat-flow paradox, no solution has appeared that is plausible and does not contain a fatal flaw or lead to another enigma. As in all such cases, either we are missing something very simple or the Earth works in ways very different from the way we think it does; or perhaps there is something wrong with the paradox itself. One possibility is that fluid flow in the crust disperses the frictional heat[16], so that it does not produce an anomaly. □

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OBITUARY

Julius Marmur (1926–96)

With the death of Julius Marmur on 20 May, molecular and microbial biology has lost one of its leading practitioners. In particular, he had a great influence on studies of DNA following the discovery of its structure in 1953.

Marmur was one of those many outstanding talents acquired by North American science before the Second World War. He was born in Poland, but with his family emigrated to Canada shortly thereafter; he took undergraduate and master's degrees at McGill University, Montréal, before moving to Iowa State University where he received his PhD. In the early 1950s, following hard on Oswald Avery's discovery that DNA was the genetic material, with Rollin Hotchkiss of Rockefeller University he demonstrated that pneumococcal DNA carried the information for a specific enzyme and that the coding for two enzymes could be carried on a single piece of DNA.

With a firm grounding in bacteriology, Marmur arrived in my laboratory at Harvard in 1957. This was a time when we were exhausting what could be done with the crude preparations of mammalian DNA of those early times. We had shown that DNA in solution undergoes a dramatic change in viscosity, sedimentation rate and ultraviolet absorbance when heated above a narrow temperature range, indicating the collapse or melting of a one-dimensional crystal — the double helix. Sensing that the rapid brownian motion within the single-stranded, flexible, nucleotide chain could allow the exploration of many interchain contacts, a tiny fraction of which might correspond to the original in-register pairing that would allow the double helix to reform, we searched for this phenomenon by slowly cooling the denatured form. However, little change was found in the short times we observed. It was only with the availability of bacterial DNA, which Marmur prepared with great dexterity, that we met with success: the much lower complexity of the bacterial DNA allowed the helix to reform in reasonable times, optimally at 25 °C below the melting temperature.

With Marmur in the lead, joined by Carl Schildkraut and others, it was possible to establish that the renatured DNA regained its biological (transforming) activity, that mixtures of normal and density-labelled

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DNA formed true hybrids of intermediate density, and that limited hybridization occurred between strands of related bacteriophages and bacteria. Thus, renaturation was set to become a primary means of manipulating DNA, later playing an essential role in developing recombinant DNA, DNA sequencing and amplification by the polymerase chain reaction. Moreover, with the variety of bacterial DNAs available, Marmur and others were able to show the striking dependence of melting temperature and buoyant density on the DNA composition — that is, the guanine + cytosine content.

All in all, Marmur co-authored 21 papers in this period. His own paper on the preparation of bacterial DNA elicited more than 5,000 reprint requests.

After three years at Brandeis University in Massachusetts, during which he continued to collaborate closely with my laboratory, Marmur moved to Albert Einstein College of Medicine, New York, as professor of biochemistry and molecular genetics. Of the highlights of his three decades of work there, two stand out. With his students he brought the yeast *Saccharomyces cerevisiae* into the molecular biological research arena, developing the standard method for the isolation of its DNA and demonstrating that its mitochondrial DNA was sharply altered, and sometimes absent, in *petite* mutants.

More recently, Marmur turned to exploring carbohydrate metabolism in yeast. This work unravelled the complex *MAL6* (maltose) locus, with its linked permease and regulatory genes, and promises insights into the evolutionary relationships hidden in its alternative carbohydrate metabolic pathways.

Marmur, however, was much more than a scientific pioneer: he was a remarkably generous and responsible man, who touched deeply all those who came within his broad ambit. His constant presence in the laboratory, his teaching by example and by questioning, and his excellence in writing and editorial work, as well as his voracious appetite for the literature (often benefiting his colleagues), made him an ideal mentor. As a result, Marmur's laboratory and his wider circle of friends became the seed bed for dozens of people who matured into highly trained, motivated and imaginative researchers, and who accepted the obligations of good citizenship in the scientific community as a privilege. Paul Doty

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