Obituary

Harmon Craig (1926–2003)

SCRIPPS INST. OCEANOGR.

Pioneer in isotope geochemistry

After the Second World War, weary of their part in the development of the atomic bomb, faculty at the University of Chicago turned to more esoteric matters. With mass spectrometers in place for making isotope measurements, Harold C. Urey and colleagues began studies in geochemistry and cosmochemistry. It was into this hotbed that Harmon Craig was propelled without waiting to finish his undergraduate degree. Craig, who died on 14 March, one day short of his seventy-seventh birthday, was to contribute hugely to these fields over the ensuing half-century.

One of the aims of the Urey group was to determine the temperatures of the ancient oceans. This depended on analysing carbon dioxide released from calcium carbonate fossils, and measuring the relative masses of the isotopes ^{18}O and ^{16}O. The constancy of the carbon isotopes was tacitly assumed. For his thesis, however, Craig measured the natural variability that occurs in the ratio of $^{13}C/^{12}C$. The independent discovery of natural radioactive ^{14}C by W. F. Libby at the University of Chicago immediately led to dating applications in archaeology and geology. Craig's analysis permitted the proper determination of radiocarbon ages — later to be corrected to calendar years by accommodating the variations in initial $^{14}C/^{12}C$. His thesis remains the primary citation for work that involves $^{13}C/^{12}C$ variation in natural materials — from studies of food chains to identifying sources of ancient marbles.

In cosmochemistry, the quest for the best measure of the early composition of the Solar System centres on meteorites called chondrites. It was commonly assumed that they have a uniform composition. Working with Urey, however, Craig first established 'quality certification' to reject meteorite samples modified by weathering, then showed that chondrites fall into at least two major groups. The Solar System, it emerged, was not so uniform after all, a discovery that with later work provided a new view of how and from what materials planets formed.

In 1955 came Craig's move to the institution where he remained for the rest of his career — the Scripps Institution of Oceanography in San Diego. The eastern universities in the United States were not yet ready to accept the strange world of geochemistry. In the west, however, the California Institute of Technology hired a bevy of geochemists from Chicago, while Scripps, mainly through the foresight of Roger Revelle, its director, brought in Harmon Craig.

Back then, instruments were not built in a day. As Craig was tooling up, he tackled the question of what happens to CO_2 in the atmosphere and the oceans. His theoretical solutions are valid to this day, and anticipated the programme for measuring atmospheric CO_2 begun at Scripps by C. D. Keeling in 1957 at Revelle's instigation.

Craig decided that somebody should work out how oxygen and hydrogen isotopes are distributed in the hydrological cycle, especially if these isotopes were going to be used for palaeoenvironmental reconstructions. In two elegant papers that resulted from his presentation to an appreciative Italian audience at Spoleto in 1965, he laid out the framework for investigating kinetics and equilibrium in determining the isotopic composition of the hydrosphere, including the oceans. These 'Spoleto' papers remain fundamental documents in light-isotope geochemistry.

In 1967 came another turning point. At a meeting at the Woods Hole Oceanographic Institution, Henry Stommel proposed that a systematic study of the geochemistry and oceanography of all the oceans should be undertaken. With the new tracers and chronometers then available, it was the right moment to embark on this daunting enterprise. In due course it became clear that the leaders of this Geochemical Ocean Sections Study (GEOSECS), split among different institutions, should be Wallace Broecker, Derek Spencer and Craig. This programme did not self-destruct, as some people thought (or maybe hoped) it would; it accomplished its main goals and spawned continuing projects. Craig himself was interested in the rate of turnover of the oceans. Here, the starting point was the idea that ^{226}Ra, with a half-life of 1,620 years, might be a good tracer of circulation, being introduced at the ocean bottom from sediments and making its way up to the surface, decaying along the way. The ^{226}Ra daughter, ^{210}Pb, was proposed as a surrogate that could be measured. But when Craig and colleagues pursued this path, they discovered that ^{210}Pb reacted with particles and was removed from the ocean by settling. This provided the basis for understanding the behaviour of particle-reactive elements in the ocean.

Another fruitful project concerned helium isotopes. The talented Brian Clarke developed a technique for measuring the ratio of ^{3}He to ^{4}He. When this was applied to an ocean water 'profile' collected by Craig, the astounding result was that, relative to atmospherically derived gases, there was an excess of ^{3}He, not ^{4}He as had been expected. The implication was that Earth's interior is still releasing a gas that was trapped when the planet was formed. The consequences lay not only in understanding ocean circulation but also in deciphering the way in which Earth's mantle behaves at ocean spreading centres and in ocean-island basalts.

In one of his last papers, Craig made sense of the cosmogenic ^{32}Si measurements made on GEOSECS. To some, this was a hopelessly flawed set of data when tested with a simple model of the silica cycle. Craig and his co-authors responded with a paper, "Paradox lost: ^{32}Si and the global ocean silica cycle", in which the mixing of two sources of silica explained the results. So here was a man whose eye for high-quality measurements first showed up in studies on meteorites, but who decades later was instrumental in deciphering a major problem in marine geochemistry.

Harmon Craig influenced so many fields because he combined the strengths of a brilliant field observer with those of a meticulous measurer and a profound theorist. Yet this seeming one-man army was not acting alone. In everything he did he was aided and encouraged by his wife, Valerie. It was her patience with Craig's perennially searching mind that made the Craig enterprise such a success.

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