

radiobiology, is the relationship between energy deposition, molecular damage to cellular components, and biological 'end-point'.

K.F. BAVERSTOCK  
R.B. CUNDALL

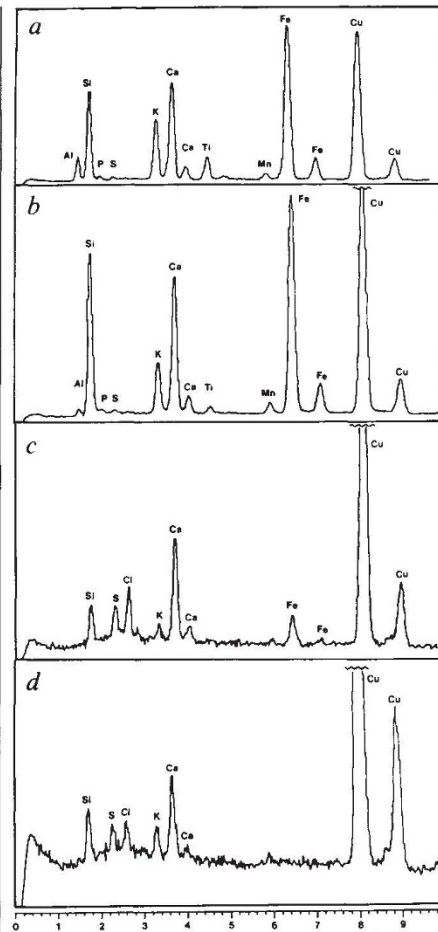
MRC Radiobiology Unit,  
Chilton, Oxon, UK

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## Wood treatment used in Cremonese instruments

SIR—There has long been speculation about the methods and materials used by the seventeenth and eighteenth century schools of Italian violin makers of whom Antonio Stradivari of Cremona is the most celebrated. In particular, the wood treatment and varnish are vital to the outstanding appearance of his instruments and possibly also to their acoustic quality. Chipura<sup>1</sup> has argued persuasively that a wood treatment likely to have been used by the Cremonese craftsmen would have involved the application of Roman hydraulic cement, a material that would have been familiar to them. This cement is made by interacting lime with the locally available pozzolana volcanic ash<sup>2</sup> and imparts a hard and durable surface.

To test this theory experimentally, we used scanning electron microscopy (SEM) coupled with elemental analysis by energy-dispersive X-ray spectroscopy (EDAX)<sup>3</sup>. Examination of a sample of red



**Fig. 1** EDAX spectra of typical particles from *a*, red pozzolana, *b*, Stradivarius wood surface, *c*, varnish and *d*, wood interior from a Link Systems energy dispersive X-ray emission spectrometer attached to a JEOL JEM 200 CX transmission electron microscope. Accelerator voltage, 200 keV. Samples (held in a graphite single tilt holder) are tilted by 45° so their upper surfaces face the spectrometer. Spectra recorded over 100-s lifetime at a resolution of 20 eV per channel. Electron beam focused to spot sizes from 2  $\mu\text{m}$  upwards to analyse single particles or groups of particles supported on thin holey carbon films on copper grids.

pozzolana from Valentana by EDAX showed the heterogeneity of the mineral; although the proportions of the elements varied, most particles contained Al, Si, P,

S, K, Ca, Ti, Mn and Fe; Fig. 1*a* shows a typical spectrum (the copper peaks result from the copper grid on which the particles were supported). A sample of yellow pozzolana from Bologna yielded similar spectra but with higher proportions of sulphur.

Generous contributors have provided fragments of authenticated Cremonese instruments. An SEM section (Fig. 2) of a rib from a 1711 Stradivarius cello (from W.E. Hill and Sons) shows a dense particulate material (P) between the varnish layer (V) and the wood (W). A typical EDAX spectrum of the particulate material (Fig 1*b*) indicates the presence of Al, Si, P, S, K, Ca, Ti, Mn and Fe; there is a clear resemblance to the pozzolana spectrum in Fig. 1*a*. By comparison, particles dispersed in the varnish layer contained only Si, S, Cl, K, Ca and Fe (Fig. 1*c*), with a much lower proportion of iron than in pozzolana. Particles taken from the wood interior (Fig. 1*d*) contained only Si, S, Cl, K and Ca.

It has been suggested that this analysis could point equally to another material of volcanic origin, pumice, which was, and still is, used as a fine abrasive. There are two arguments against this interpretation. First, it seems improbable that this use of pumice would build up the observed particle thickness on the wood surface (Fig. 2). Second, an EDAX spectrum of a powdered pumice sample showed Al, Si, S, K, Ca, Ti and Fe, with much more silicon and much less iron than in Figs 1*a* or 1*b*.

Although these findings indicate that the range and proportions of elements present on the wood surface of this Stradivari instrument are compatible with the presence of pozzolana ash, Chipura's suggestion that the pozzolana was applied in the form of Roman cement cannot be verified; in such a case the surface particles should show a greatly enhanced calcium content. We are extending these investigations to other fragments from instruments of the period hoping not only to be able to define the nature of the wood surface treatment more precisely but also to reveal the methodology of the Cremonese craftsmen.

CLAIRE Y. BARLOW

Department of Materials Science  
and Metallurgy, Pembroke Street,  
Cambridge CB2 3QZ, UK

PETER P. EDWARDS\*

G. ROBERT MILLWARD

RALPH A. RAPHAEL

DAVID J. RUBIO

University Chemical Laboratory,  
Lensfield Road,  
Cambridge CB2 1EW, UK.

\*To whom correspondence should be addressed.

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**Fig. 2** SEM showing part of a through-thickness fracture surface running normal to the surface of the instrument. V, varnish layer, the outside of the instrument, containing few obvious inclusions and 5-10  $\mu\text{m}$  thick. P, particulate region, up to 100  $\mu\text{m}$  thick with most particles under 4  $\mu\text{m}$  in diameter, mainly 0.5-2  $\mu\text{m}$ . Most are rough in shape, some very nearly spherical, and in general aspect ratios are around unity. There is some visible porosity, with cracks and voids up to 1  $\mu\text{m}$ . W, (maple) wood penetrated by particles to a depth of up to 30  $\mu\text{m}$ .

