SCANDIUM/IRON AND COBALT/IRON RATIOS AS INDICATORS OF THE SOURCES OF STRATOSPHERIC DUST PARTICLES. D. J. Lindstrom, Code SN2 NASA/Johnson Space Center, Houston, TX 77058.

Particles of dust collected in the stratosphere by high-flying aircraft include a wide variety of materials. The Cosmic Dust Catalogs produced at JSC provide preliminary classifications based on particle morphology and energy dispersive X-ray analyses (EDX) done with a scanning electron microscope. Detailed criteria are given in the catalogs for the identification of the particles as C (Cosmic Dust), TCA (Terrestrial Contamination, Artificial), TCN (Terrestrial Contamination, Natural), AOS (Aluminum Oxide Sphere), or "?". While the chemical signatures of chondritic C particles and AOS particles are quite distinct, identification of the others is difficult. Most research has focused on particles of C type, but there is the possibility that by so doing, important samples of extraterrestrial materials of different composition may have been ignored.

We have been doing analyses of dust particles by high-sensitivity Instrumental Neutron Activation Analyses (INAA) [1] for several years [2-4]. The results are quite precise, considering that the samples are about 1000 times smaller than normally done by INAA (weights $10^{-9}-10^{-7}$ g), but interpretations have been hampered by contamination by as yet unexplained processes from unknown sources [5]. Another problem is that only relative abundances are obtained because the samples are too small to weigh. Weights are best obtained by comparing Fe values by INAA with those measured on microtomed surfaces of the particles with the electron microprobe. Here I use INAA results for three of the best-determined elements (Sc, Co, and Fe, typically having relative analytical uncertainties of 1-5%) to show the likely sources of many of the particles we have analyzed.

Fig. 1 shows the values of the Sc/Fe and Co/Fe weight ratios in a number of potential sources, including averages for the various chondrite classes and suites of igneous rocks from all of the solar system that we have sampled to date. Note that 1) Sc/Fe ratios show little variation (except for the lowest SNC point, which is Chassigny, an olivine cumulate); 2) Chondrites cluster rather tightly and have lower Sc/Fe ratios and higher Co/Fe ratios (each by about a factor of ten) than the igneous rocks; and 3) Eucrites are depleted compared to other basaltic rocks, also by a factor of 10. Igneous differentiation apparently has little effect on Sc/Fe because at the scale of Fig. 1 Sc$^{3+}$ behaves much like ferrous and/or ferric iron in magmatic systems. On the other hand, differentiation in metal-rich systems cannot seriously alter the Co/Fe ratio (the bracket in the lower right gives the range in iron meteorites, and the arrow gives the position of the strongly peaked distribution [6]).

Fig. 2 compares the results of INAA analyses of 49 stratospheric dust particles [2-4,7] to the fields delineated in Fig. 1. Easily half of the points fall within the customary factor of 3 of CI chondritic values, and a few more could be considered "chondritic" if uncertainties were considered. Of the remainder, 10 are uncatalogued spheres that have not yet been microtomed and analyzed further, so little is known of their mineralogy. The five spheres in the lower left corner are almost certainly TCAs, their severe depletions in Sc and substantial Co depletions being typical of man-made materials such as steels. Only two particles (U2015E10 [2] and L2007-1 [3]) and one uncatalogued sphere resemble igneous rocks. The points falling below the chondrite field include at least one sulfide-rich particle (L2005 V13) and two spheres that will be studied further. Catalogued spheres often have EDX spectra dominated by FeS, so it would not be surprising if these, too, were sulfide-rich. Since sulfides strongly exclude Sc and weakly exclude Co, chondritic sulfides are expected to fall below and perhaps to the left of the chondrite field on this plot.

Sc/Fe ratios alone can explain the provenance of most dust particles: values $<10^{-6}$ are TCAs, those between $10^{-5}$ and $10^{-4}$ are chondritic, and those $10^{-4}$-$10^{-3}$ are "igneous," probably TCNs. (A fourth category, not yet observed, consists of refractory inclusions which have Sc/Fe $>10^{-3}$.) Consideration of Co/Fe allows eucrites to be identified and helps sharpen the distinctions in many cases. These ratios are the best chemical criteria yet developed for nondestructively determining the provenance of dust particles.
SC/FE AND CO/FE IN STRATOSPHERIC DUST: Lindstrom D.J.

Fig. 1. Weight ratios of transition elements in chondrites and igneous rocks. Terrestrial igneous suites are represented by data from the reference suite of Keweenawan rocks [8] (circles). Also shown are averages of lunar basalts (open triangles), eucrites, and SNC meteorites (filled triangles). The heavy dashed line connects Chassigny, an olivine cumulate, to the other SNCs.

Fig. 2. Results of INAA analyses of stratospheric spheres (circles) and other particles (squares). Fields are from Fig. 1, above. Downward-pointing arrows denote that the points are two sigma upper limits. The dotted ellipse represents differences of a factor of three from CI composition. The range of Co/Fe ratios in iron meteorites is shown in the lower right, with the mean marked by the upward-pointing arrow. The light dashed line connects two pieces of L2005-M1, a TCA particle rich in Ca and Si.

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