SNC METEORITES: EVIDENCE AGAINST AN ASTEROIDAL ORIGIN.

L. D. Ashwal, J. L. Warner, and C. A. Wood, Lunar & Planetary Institute and NASA-Johnson Space Center, Houston, TX 77058.

The 1.3 b.y. formation ages for the 9 SNC (Shergottites, Nakhilites and Chassignites) meteorites distinguish them from all other meteorites which apparently formed >3 b.y. earlier. Three distinct suggestions in the recent literature address the origin of young SNC meteorites: (a) Martian igneous rocks, (b) asteroidal impact melts, and (c) asteroidal igneous rocks. In an earlier paper (1) we have advocated the proposal that SNC meteorites are ejected from Mars by a later impact. This proposal is attractive petrologically, geochemically, and geophysically, however, there are dynamical difficulties with unmelted ejecta escaping Mars. In this contribution we consider the two asteroid models that are dynamically reasonable. We discuss geochemical, petrologic and isotopic observations that strongly argue against SNC meteorites being impact melts from asteroids (or anywhere else) and less strongly argue against the asteroidal igneous rock proposal.

ARE SNCs ASTEROIDAL IMPACT MELTS?

Singer and Melosh (2) have proposed that SNC meteorites are impact melts formed during the excavation of moderately large craters (>25 km) on one or more asteroids. In their model a large enough sheet of melt is created so that 10^4 to 10^5 years are required for crystallization, during which time the cumulate texture characteristic of SNCs is postulated to develop. Subsequent impacts dislodge fragments of this young melt rock which ultimately hit the Earth.

There is an impressive array of petrographic, geochemical, and isotopic evidence from terrestrial, lunar, and meteoritical impact melts to refute this theory: Textures: Thousands of hand specimens and thin sections of impact melts from various planetary bodies have been examined and all contain obvious lithic and mineral clasts: Manicouagan Crater (3), Clearwater Lakes Craters (4), Apollo 16 (5), Apollo 17 (6), lunar granulites (7), and mesosiderites (8). By contrast we have found no clasts (nor any feature to suggest the former presence of clasts) in our petrographic examination of Shergotty, Zagami, EETA-79001, ALHA-77005, and Nakhla. Likewise, none have been reported by other investigators (9,10). SNC meteorites are characterized by a cumulate texture (11,12), with alignment of mafic silicates either due to crystal settling in a gravity field, or to flowage, or to both (9,13). Impact melts from the Moon and Earth display a range of clast-bearing basaltic textures, but none have cumulate texture. These data indicate that melt sheets do not evolve cumulate texture as proposed by Singer and Melosh. Rather, as various field studies and theoretical models demonstrate, an impact melt sheet rapidly loses heat internally to thoroughly intermixed cool debris. We emphasize that all levels of the Manicouagan melt sheet (which is the largest terrestrial example known) are "typical" impact melt rocks and do not display cumulate textures. Geochemistry: Impacts homogenize the target, thus each separate lunar or terrestrial impact melt displays a limited range of compositions; no fractionation is apparent in the major and trace element data (14). Figure 1 compares the relatively small scatter in major element chemistry for the 230 m thick Manicouagan melt sheet (14) with the chemical fields for SNC meteorites. The meteorites have compositions dominated by mineral end members: olivine (chassignites and ALHA-77005), clinopyroxene + olivine (nakhilites), or pyroxenes + plagioclase (shergottites), consistent with their origin as cumulates. Based solely on major element composition, if the SNC meteorites were impact melts, they would represent 3 separate events. The distinct initial Sr ratios among the shergottites and ALHA-77005 at their time of crystallization (17) preclude this possibility. Isotopic compositions of impact melts are also effectively homogenized such that whole rock isochrons are not generally possible (15,16). In contrast, the earliest history of shergottites and ALHA-77005 are constrained by whole rock isochrons (17). These data indicate that the geochemistry of SNC meteorites is incompatible with an origin in an impact melt sheet.

ARE SNCs ENDOGENETIC IGNEOUS ROCKS FROM ASTEROIDS?

Meteorite data is used to constrain the thermal evolution of asteroids (despite the growing uncertainty that asteroids are meteorite parent bodies (1,18,19,20)). Thermal models for asteroids have two general features: (1) early heating to account for 4.5 b.y. ages of chondrites and most achondritic meteorites (e.g., eucrites), and (2) rapid subsequent cooling due to their small size. Thus it is difficult to account for young events requiring high temperature (e.g., SNC meteorite ages). Only Moon size asteroids that start hot or have high U and K/U values can produce melts as recently as 1.5 b.y. ago (21) and there is no evidence that such large asteroids existed. Minear (22, personal comm.) has attempted to specifically model the late formation ages of SNC meteorites by assuming that an entire 800 km asteroid is composed of fragmental material with chondritic levels of K, U, & Th. Thermal conductivity is initially low (modeled from lunar fragmental breccias), and increases by a factor of 10 as portions of the asteroid are heated. This model allows melting of a few percent of the asteroid's core between 3.5 and 1.5 b.y.

Minear's model barely accounts for the formation age of SNC meteorites and can account for the cumulate or flow texture observed. However, isotopic and geochemical data for SNC meteorites are not consistent with this origin. Rb-Sr isotopic studies of shergottites and ALHA-77005 (17) indicate establishment of the meteorite source regions in a large-scale differentiation event at about 4.5 b.y. Such an event is inconsistent with Minear's model because early heating would raise the thermal conductivity, the asteroid would rapidly cool, and young SNC meteorites could not form. The time-averaged LREE enrichment of the ALHA-77005 source, suggested by Sm-Nd isotopic data (17), indi-

SNC METEORITES

Ashwal, L. D. et. al.

cates that its formation about 4.5 b.y. ago involved retention of residual garnet (23). Garnet implies formation at pressures in excess of 8-10 kbars, twice the central pressure of Ceres, the largest asteroid. A similar argument can be made for the shergottites.

The easiest means of getting meteorites from an asteroid's core is total fragmentation. Destruction of an 800 km asteroid creates an immense swarm of asteroids with similar orbits (Hirayama family) equal to about 1/3 to 1/4 of the total mass of the asteroid belt. No such family has been identified.

The evidence presented above strongly suggests that SNC meteorites cannot be impact melts from the asteroids or elsewhere. Minear's thermal model for late melting within a large asteroid appears reasonable but the characteristics of SNC meteorites convincingly argue against their origin in an object as small as the largest asteroid. Additionally there is no evidence for the recent breakup of a large asteroid. Theories of asteroidal origin for SNC meteorites cannot be supported.

REFERENCES

1. Wood, C.A. and L.D. Ashwal, 1981, Proc. Lunar Planet. Sci. Conf. 12, in press.
2. Singer, A.V. and H.J. Melosh, 1981, EOS, 62, 941.
3. Simonds, C.H., et al., 1978, Jour. Geophys. Res., 83, 2773-2788.
4. Simonds, C.H., et al., 1978, Proc. Lunar Planet. Sci. Conf. 9, 2633-2658.
5. Warner, J.L., et al., 1973, Proc. Lunar Sci. Conf. 3, 481-504.
6. Simonds, C.H., 1976, Amer. Mineral., 61, 569-577.
7. Warner, J.L., et al., 1977, Proc. Lunar Sci. Conf. 8, 2051-2066.
8. Floran, R.J., 1978, Proc. Lunar Planet. Sci. Conf. 9, 1083-1114.
9. Stolper, E. and H.Y. McSween, Jr., 1979, Geochim. Cosmochim. Acta, 43, 1475-1498.
10. Smith, J.V. and R.L. Hervig, 1979, Meteoritics, 14, 121-142.
11. Bunch, T.E. and A.M. Reid, 1975, Meteoritics, 10, 303-315.
12. Floran, R.J., et al., 1978, Geochim. Cosmochim. Acta, 42, 1213, 1229.
13. Berkley, J.L. and K. Keil, 1981, Amer. Mineral., 66, 1233-1236.
14. Floran, R.J., et al., 1978, Jour. Geophys. Res., 83, 2737-2759.
15. Jahn, B.M., et al., 1978, Jour. Geophys. Res., 83, 2799-2803.
16. Reimold, W.U., et al., 1981, Contrib. Mineral. Petrol., 76, 73-76.
17. Shih, C.-Y., et al., 1982, Geochim. Cosmochim. Acta, in press.
18. Opik, E.J., 1965, Adv. Astron. and Astrophys., 4, 301-336.
19. Wetherill, G.W., 1979, Icarus, 37, 96-112.
20. Wood, C.A., 1982, Lunar Planet. Sci. XIII, this volume.
21. Toksoz, M.N., et al., 1978, The Moon and Planet., 18, 281-320.
22. MINEAR, J.W., ET AL., 1979, Lunar Planet. Sci. X, 842-843.
23. Ma, M.-S., et al., 1981, Proc. Lunar Planet. Sci. Conf. 12, in press

Fig. 1 - ACF diagram (wt. %) comparing compositions of Manicouagan impact melts (8) and SNC meteorites. ALHA-77005 is included in the chassignite field.