

THE COLLISIONAL LIFETIME OF 951 GASpra; P. Farinella, University of Pisa, Italy; D.R. Davis, Planetary Science Institute, Tucson AZ; A. Cellino and V. Zappalà, Torino Observatory, Torino, Italy

951 Gaspra, the first target of a close asteroid encounter by an interplanetary probe, is a 16-km diameter S-type asteroid of very irregular shape, located in the crowded Flora region near the inner boundary of the asteroid belt. The lifetime of Gaspra against disruptive collisional events (which of course is the upper bound on the age of this asteroid--presumably itself the outcome of a collisional break-up) depends on three factors: (i) its probability of colliding with other asteroids, having the typical distribution of orbital elements existing in the asteroid belt; (ii) the size of the smallest projectile capable of shattering and disrupting Gaspra; (iii) and the abundance of such objects in the present belt. We shall now try to separately estimate these factors.

(i) By using a computer program based on Wetherill's algorithm (1), we have computed the intrinsic collision probability and the average collision velocity of Gaspra with all of the 682 asteroids with diameters  $> 50$  km, as inferred from IRAS observations. This lower limit was due to the need of using a nearly-complete sample of bodies, unaffected by observational biases; of course, this computation was based on the assumption that the smaller asteroids have essentially the same distribution of orbital elements as those  $> 50$  km used in our sample. Gaspra's orbit can intersect the orbits of 326 objects in our projectile sample; the average impact velocity  $V$  is 5.45 km/s (with a 1-sigma dispersion of 1.75 km/s) and the average intrinsic collision probability per unit area per unit time is  $2.69 \times 10^{-18} \text{ yr}^{-1} \text{ km}^{-2}$ . Since the relevant projectiles are much smaller than Gaspra (as we shall see), multiplying this number by the squared radius of Gaspra we get a collision rate of about  $1.7 \times 10^{-16} \text{ yr}^{-1}$ . To get Gaspra's lifetime, we must know the number of relevant projectiles existing in the asteroid belt capable of destroying it.

(ii) The projectile-to-target diameter ratio needed to shatter an asteroid is  $(4S/\rho V)^{2/3}$  (2), where  $\rho$  is the material density (for which we will assume a value of  $2.5 \text{ g/cm}^3$ ) and  $S$  is the impact strength, namely the energy density needed to produce a barely catastrophic outcome. As discussed in Davis *et al.* (2), laboratory experiments on rocky targets give values of  $S$  of about  $3 \times 10^7 \text{ erg/cm}^3$ . For Gaspra, this would yield a critical projectile diameter  $d$  of about 0.9 km. However, the relevant value of  $S$  could be lower by up to an order of magnitude for two different reasons: first, if S-type asteroids are made of primitive, chondritic material (a debated issue!), they could be somewhat weaker than basaltic rocks; second, if we assume a strain-rate scaling of strength, implying that  $S$  is proportional to the  $(-1/4)$  power of the target size (3), this would yield an "effective" strength for Gaspra of about  $2 \times 10^6 \text{ erg/cm}^3$ . In this case, we would get  $d = 0.35$  km. Notice that according to the experimental results of Davis and Ryan (4), a reaccumulated ("rubble pile") structure would not necessarily imply a significantly lower impact strength. However, even with a strength of the order of  $10^6 \text{ erg/cm}^3$ , a shattering impact would be probably energetic enough to effectively disperse the target material against self-gravity.

(iii) The number of existing asteroids in the sub-km size range is subject to considerable uncertainty. The best data on the magnitude distribution of small asteroids is still the

COLLISIONAL LIFETIME OF 951 GASPRA; Farinella *et al.*

Palomar-Leiden Survey (5) and the McDonald Survey (6). Dohnanyi (7) showed that the magnitude frequency size distribution is approximately represented by a power law distribution having a slope 1.837 (incremental mass), which was in good agreement with his equilibrium slope of 1.839 based on a model using size-independent collisional outcomes. While this assumption is probably not valid for asteroids of any size, the observational constraint is a real one. Dohnanyi (7) used a mean albedo of 0.2 to convert the magnitude-frequency distribution to a diameter frequency one; this value is now known to be too high by a factor of  $\sim 3$ -6. Chapman (8) adopted a mean albedo of 0.06 to derive his diameter frequency distribution; however, the best available current data on the asteroid size-distribution for different taxonomic types suggests that the dark C- and P-type asteroids are the dominant types at small sizes. Hence, the mean albedo may be smaller than 0.06 and it may vary with size. We estimate the number of projectiles capable of shattering Gaspra using the PLS and MDS data with a mean albedo of a) 0.06 and b) 0.03 to be  $2.5 \times 10^6$  and  $6.0 \times 10^6$ , respectively. These numbers should be increased by about one order of magnitude to get the number of objects larger than 0.35 km.

Thus if Gaspra has the weak impact strength predicted using scaling theory, then its collisional lifetime probably ranges from  $\sim 1.0 \times 10^8$  years to  $2.4 \times 10^8$  years. If its impact strength is comparable to that measured in the laboratory for basalt, then Gaspra's collisional lifetime is an order of magnitude larger than the above value. If Gaspra is strong, we are not sure that it is much younger than the age of the solar system. Gaspra is almost certainly a fragment from a larger asteroid that was collisionally shattered in the past. While this origin has been the one usually proposed for Gaspra, our quantitative assessment of its age suggests that Gaspra's surface may be one of the youngest extraterrestrial surfaces that we have seen in the solar system. Improved values of the asteroid size distribution down to the sub-kilometer size are essential in order to refine our estimate of Gaspra's lifetime and to determine the actual age of Gaspra from Galileo imagery.

- (1) Wetherill, G. (1967), *JGR* **72**, 2429; (2) Davis, D.R. *et al.* (1989), in *Asteroids II*, 805; (3) Housen, K. and K. Holsapple (1990), *Icarus* **84**, 226; (4) Davis, D.R. and E.V. Ryan (1990), *Icarus* **83**, 156; (5) Houten, C.J. van, Houten-Groeneveld, I. van, Herget, P., and Gehrels, T. (1970), *Astron. Astrophys. Suppl. Ser.* **2**, 339-448; (6) Kuiper, G.P., Fujita, Y., Gehrels, T., Groeneveld, I., Kent, J., Van Biesbroeck, G., and Houten, C.J. van (1958), *Astrophys. J. Suppl. Ser.* **3**, 289-428; (7) Dohnanyi, J.S. (1971), in *Physical Studies of Minor Planets* (ed. T. Gehrels), NASA SP-267; (8) Chapman, C.R. (1974), *Geophys. Res. Lett.*, **1**, 341.