GEOLOGY OF THE WABAR METEORITE CRATERS, SAUDI ARABIA; E. M. Shoemaker[1] and J.C. Wynn[2], [1]U.S. Geological Survey and Lowell Observatory, Flagstaff, AZ 86001, [2]U.S. Geological Survey, Reston, VA 20192.

In March of 1995, we were privileged to accompany an expedition sponsored by the Zahid Corporation of Saudi Arabia to the Wabar Craters in the Rub' Al-Khali desert (The Empty Quarter) of the southern Arabian peninsula (at 21°30.2' N latitude and 50°28.4' E longitude). Transport across the sand sheet of the northern Rub' Al-Khali was by Humvees and a 4 x 4 Volvo truck, which carried a backhoe for the purpose of exposing the structure of the crater rims. Although numerous visitors have examined the Wabar meteorite craters over the 62 years since St. John Philby's first report, no detailed investigation of the geology of the craters had been undertaken prior to our expedition. We spent 5 days during the week of March 12 at the craters carrying out a systematic survey of the craters themselves and the surrounding strewn field of impact glass and impact-formed "instant rock."

Parts of three craters were exposed at the time of our visit (Fig. 1). Their diameters are estimated at 11, 64, and 116 m. We refer to these as the 11-m, Philby A, and Philby B craters. Contrary to inferences in a number of previous reports (e.g. [1], [2], [3]), the craters have been formed entirely in loose sand of the active Rub' Al-Khali sand sheet. No bedrock is exposed in the near vicinity of the craters and no bedrock fragments occur in the ejecta from the craters. The lower walls of the craters are lined with a breccia composed of clasts of shock-compressed sand, much of which is shock metamorphosed to a firm rock (instant rock). The exposed rims of the two largest craters are mantled with bombs and lapilli of black and white slaggy impactite glass and with large and small clasts of instant rock. At the 11-m crater, the ejecta rim has been entirely eroded away; only the breccia lining the lower crater walls is exposed. Survival of the craters in the shifting sands of the Rub' Al-Khali is due solely to the presence of the impactite glass and instant rock that mantles the crater rims and resists transport by the wind and to the resistant breccia lenses lining the crater walls.

The 11-m crater was discovered by Wynn on a visit to the craters in May, 1994. No previous visitors had reported this small crater; evidently it had been uncovered by deflation only shortly before Wynn's 1994 observations. Pre-crater sand has been fairly deeply eroded around the 11-m crater, and all of the rim and upper crater walls have been lost by eolian scour. The breccia of the lower walls is about 20 cm thick and dips about 30° inward at the level of exposure. Clasts in the breccia range in strength from weakly compressed sand that can be easily crushed between the fingers to hard blocks exhibiting a pronounced slatey cleavage. Abundant small oxidized fragments of meteorites are dispersed in the breccia.

Only the southeastern part of Philby A was exposed in 1995. The northwestern half was covered by a prominent seif dune. When seen by Philby in1932, the crater rim was completely exposed [1]. When the site was photographed from the air by Holm in 1961, the crater apparently was completely covered with sand [2]. In 1995, the sand-filled floor of the crater was 3 m below the level of the southeastern rim. The impactite-mantled rim deposit was exposed over an area about 50 m by 130 m (Fig. 1). A fallout deposit of glass bombs and clasts of instant rocks with scattered oxidized and metallic meteorite fragments rests on an ejecta blanket of sand that is about 1 m thick at the crater rim. The rim has been eroded back about 6 m from the preserved 0.5-m thick breccia lining the crater wall, leaving a topographic bench where deformed pre-crater sand is exposed. We excavated a trench in the southern rim to study the deformation and obtain samples for thermoluminescence dating of the pre-crater sand deposit. Providentially, it had rained the night before our arrival, and the damp sand held the walls of the trench long enough for us to obtain a structural cross-section (Fig. 2). Bedding in the pre-crater sand is upturned in the southern wall; outward dips become progressively steeper toward the center of the crater, reaching an observed maximum of 50°. Hence the structure of this crater in sand resembles that of Meteor Crater and of several other meteorite craters in bedrock mapped by the Shoemakers in Australia. Small thrust faults dipping both toward and away from the crater were observed outside the zone of sharp upturning of the beds.

Just the crest and a small part of the breccia-lined wall of Philby B, the largest crater, were exposed at the time of our expedition. The crater was well exposed in 1932 and may have been about 12 m deep. In 1960, Holm [2] estimated the depth of the crater at about 5 m; James Mandeville (written communication, 1994) estimated the depth at 8 m in 1965. Jens Munthe (written communication, 1990) described the crater as being a little over 1 m deep in 1990. The depth was about 2 m when visited by Wynn in 1994 but had increased by wind-scouring to about 3.5 m in 1995. A fallout deposit of impactite bombs and instant rock cap the southern exposed rim, much of which was barely emergent above the post-crater sand in 1995. The eastern rim had been eroded, and only a lag deposit of glass and instant rock was preserved. Our attempt at obtaining a cross-section of the rim of Philby B was unsuccessful, as the sand continually collapsed during backhoe excavation of the trench.

A strewn field of impactites and instant rocks, exposed in patches between younger sand dunes, extends about 500 m northwest of Philby A and about 300 m southwest and south of Philby B (Fig. 3).The patches of glass and instant rock essentially mark the surface of the sand sheet at the time of impact. Material in the southern part of the strewn field is chiefly ejecta from Philby B, 50% or more of which consists of instant rock. Curiously, the material thrown farthest from Philby B to the south is entirely instant rock. In contrast, the strongly shocked ejecta from Philby A is dominated by black impact glass. The most distant, northwestern patches of the strewn field consist chiefly of scattered spheres and teardrops of glass a few mm in diameter. We suggest that most of the glass was carried up in a hot, buoyant, turbulent plume that was then blown downwind roughly in the direction of the wind we observed in March, 1995. Iron meteorites and oxidized meteorite shale balls are dispersed over the exposed strewn field but are most abundant near the craters. A large, aerodynamically shaped iron, the "Camel's Hump", was recovered by ARAMCO about 200 m southwest of Philby B.

A fission-track age of 6400 ± 2600 was reported for the impactite glass by Storzer [5], but we think that this age probably is an order of magnitude too high. It is unlikely that the craters and the glass strewn field have survived for several thousand years in the active sand sheet. We anticipate that samples of instant rock and pre-crater sand submitted to John Prescott of the University of Adelaide for thermoluminescence dating will yield a much better estimate of the age.

REFERENCES [1] Philby, H. St. J. B., 1933, The Empty Quarter: Henry Holt, N.Y. [2] Chao, E.C., Fahey, J.J., and Littler, J., 1961, Science, v. 133, p. 882-883. [3] Murali, A.V., See, T.H., Blanchard, D.P., 1988, LPSC XIX, p. 815-816. [4] Holm, D.A., 1962, Am. Jour. Sci., v. 260, p. 303-309. [5] Storzer, D., 1971, Meteoritics, v. 6, p. 319.

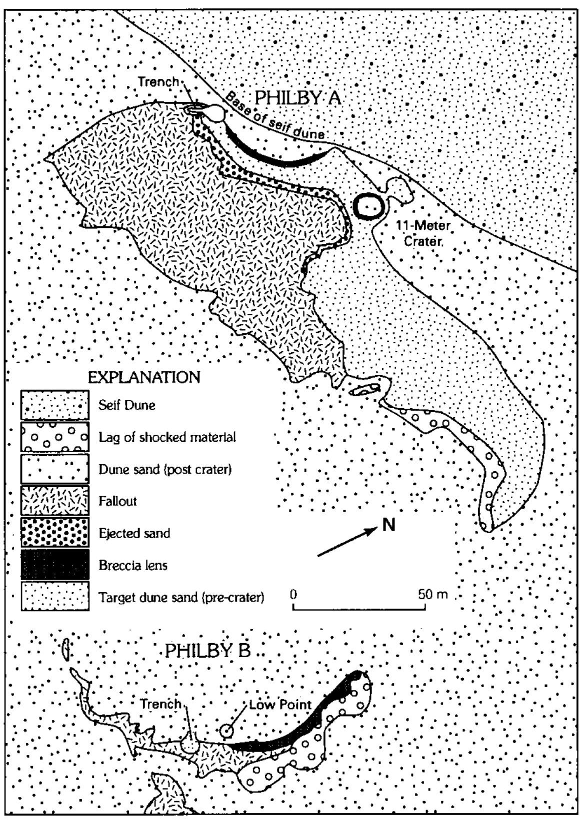

Figure 1. Geologic map of the Wabar Craters. Geology by E.M. Shoemaker, 1995.

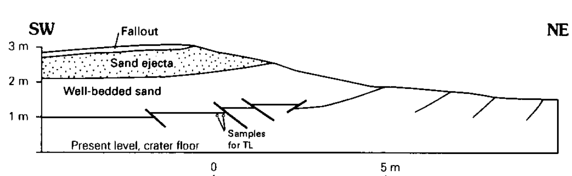

Figure 2. Cross-section through southern rim of Philby A crater. Geology by E.M.Shoemaker, 1995.

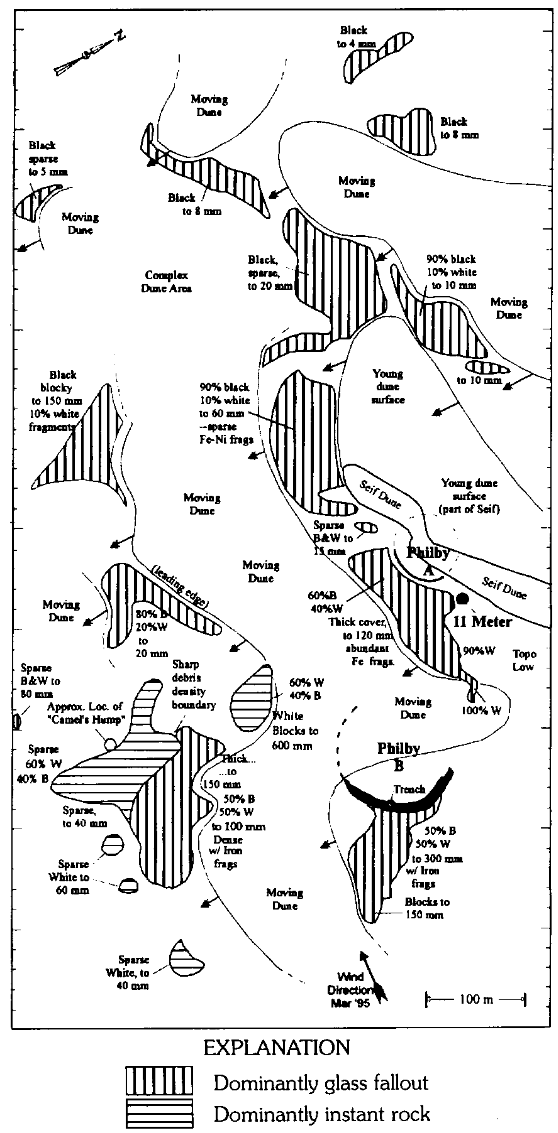

Figure 3. Map of strewnfield of impactite glass and instant rock. Geology by J.C. Wynn, 1994 and 1995.