and unprotected southeast margin of the Bermuda platform, strongly suggest that submarine planation has been a slow but not ineffective process. This conclusion may bear on inferred rates of truncation of reefs and oceanic atolls during recent periods of low stands of the sea in other areas of the world.

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24 May 1967

Surveyor I: Location and Indentification

Abstract. *Surveyor I landed on the lunar surface on 2 June 1966 and obtained more than 11,000 pictures of the environment with its television camera. The same region was photographed by the 24-inch (61-centimeter) camera of Orbiter III on 22 February 1967. Surveyor I has been located in these Orbiter photographs; its image was found and all search and identification criteria were satisfied by the site.*

Surveyor I gathered extremely detailed information about the lunar surface in its immediate vicinity. Before this information could be extrapolated to other areas, viewed with lower resolution, the "ground truth" area of Surveyor had to be located and related to some category of characteristic surface.

Identification of Surveyor I in Orbiter III's photographs could enable direct comparison of the site, and possible correlation as to geology and terrain, with potential Apollo sites and additional Surveyor sites that were already defined in Orbiter's photographs across the lunar equatorial belt. Identification could also enable recommendation of other potential landing sites in terms of the statistical parameters characteristic of the distribution of craters with respect to number and size on the site of Surveyor I.

Surveyor I was approximately located by the spacecraft itself; the infor-

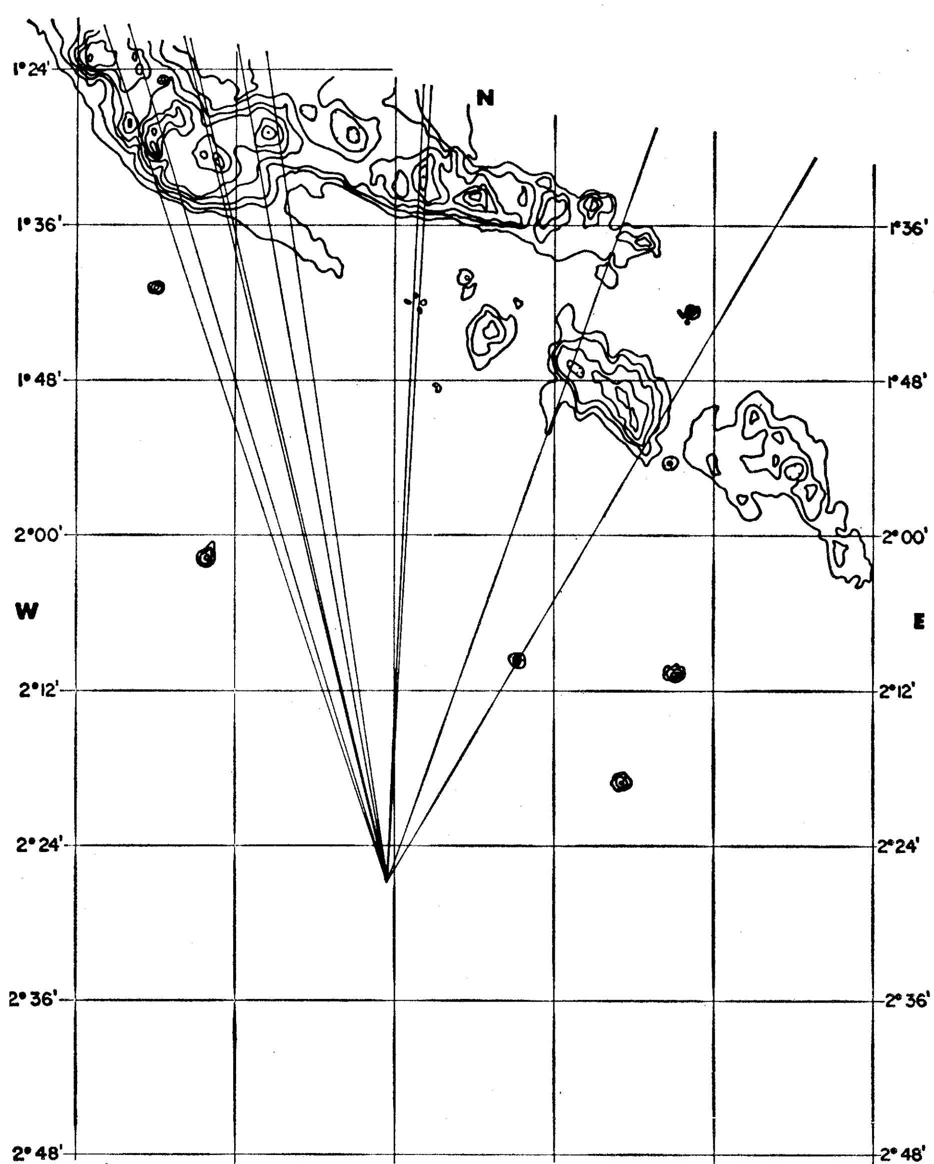

Fig. 1. Azimuthal projections from Surveyor I, superimposed over contours of low mountains to the north.

Fig. 2 (top left). Enlargement of image of Surveyor I from Orbiter III's frame H-194.

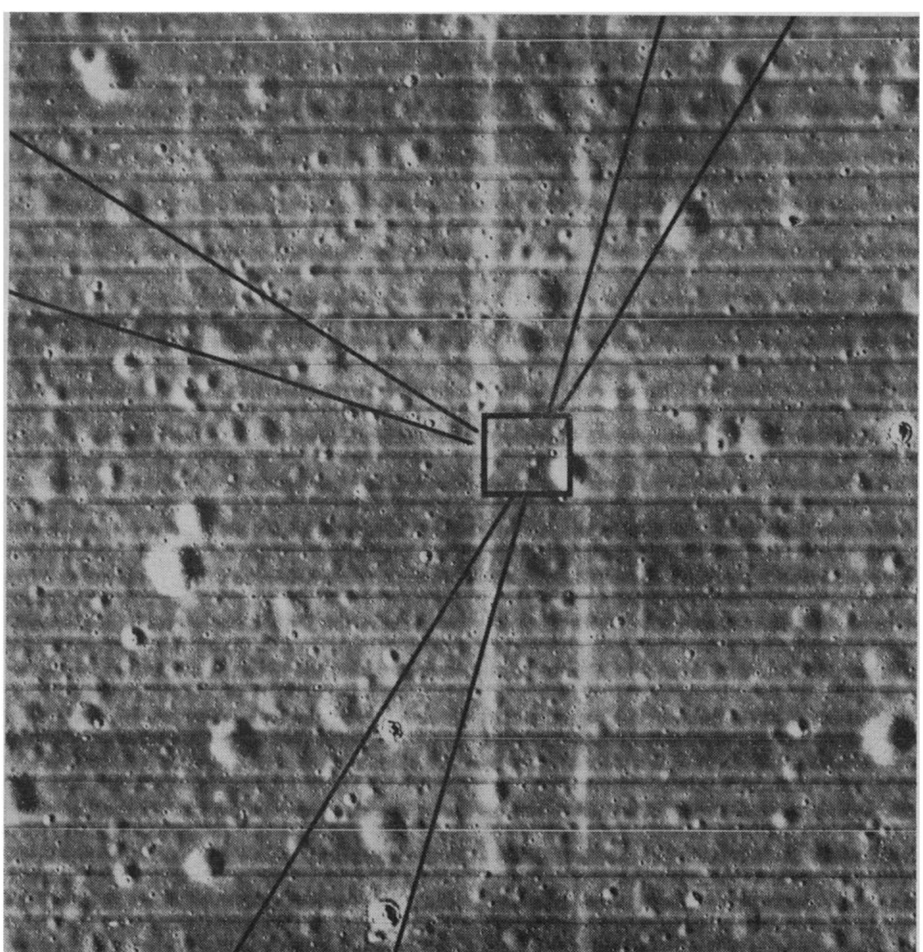

Fig. 3 (bottom left). Portion of frame H-194 (by Orbiter III) with ground projection of RADVS beams.

mation it provided included its inflight tracking before it landed, power-return profiles from the radar beams during landing, Doppler variations in spacecraft telemetry subsequent to the landing, and triangulation on the lunar surface by use of distant objects recorded by its camera.

Surveyor I had to be located within the area of resection from the low mountains observed over its horizon. It was known to lie between two shallow craters on a north-south line, and west of a rimmed crater. Objects capable of increasing a radar return should be located so as to correspond to the respective beam patterns. The image of the spacecraft and the length and shape of its shadow should correspond with predictions from its known configuration and angles of illumination. Orbiter's and Surveyor's photographs should correspond, point to point; exact azimuths could be used for reference.

Before this investigation, the limits of the search area had been well established from the trigonometric resection of objects photographed by Surveyor I. Astronomical photographs and lunar charts had been used for reference (*1*).

In August 1966 Orbiter I's photographs of the area with its wide-angle camera yielded overlapping stereo coverage with 8-m ground resolution; they were used in compilation of topographic contours of the entire region (*2*). The azimuths of the features seen above the northern horizon were drawn on an overlay sheet, which was fitted over the topographic contour map so that the highest elevations fell along the observed angles of azimuth (Fig. 1). The resection so obtained fell less than 500 m from the spot where Surveyor I was subsequently found.

On 22 February 1967 Orbiter III photographed the site of Surveyor I on three successive orbits; the camera was aimed away from the vertical to obtain convergent stereographic photographs with the lens of 24-inch (61-cm) focal length. When these telephoto frames reached Earth, the area of

Surveyor I was thoroughly searched. All objects remotely resembling Surveyor were identified for further examination; most of them later proved to be rocks casting elongated shadows on downslopes; the rest were subjected to the immediate criterion that the spacecraft must lie between two shallow craters on a north-south line, with a rimmed crater to the east.

By elimination the search narrowed to a single candidate appearing in both framelet 875 of frame H-183 and framelet 248 of frame H-194 (Fig. 2). After general topographic correlation between this site and the data televised from Surveyor I, the area was examined in the light of the radar information telemetered during the spacecraft's descent.

The RADVS (Radar Altimeter Doppler Velocity Sensor) system comprised four beams: a range beam aimed vertically downward, and three Doppler beams aimed 25 deg away from the vertical. From the landed spacecraft the Doppler beams 1, 2, and 3 were aimed approximately southwest, northwest, and northeast, respectively (Fig. 3) (*3*).

Beam 1 (southwest) indicated a radar cross-sectional increase of approximately a factor of two, having two peaks located about 2350 and 1450 m from the landing site. Beam 2 (northwest) indicated an increase about 525 m from the site. When the ground projections of the RADVS beams are combined with the lunar features seen along their azimuths, one finds three sharp-rimmed craters, within the beam patterns, at the positions of cross-sectional increase.

Although it was not expected that individual parts of Surveyor I could be distinguished at such a level of resolution, we had reason to believe that the shadow might be distinctive in character. The solar panel and the planar array had been extended along the mast to maximize the cross section and length of the shadow; thus, under perfect conditions of resolution, we expected to see the bright spacecraft, the shadow of the body and spaceframe, and the shadow of the mast section, with a break or "neck" between the dense shadows of the vertical panels.

Since the shadow could not be adequately characterized by visual examination, the area was scanned with a recording microdensitometer, which enabled examination of isophotometric patterns and gradients of image brightness below the limits of visual detection. Figure 4 shows the isodensity contours from framelet 875, frame H-183, together with a photograph of a 1 : 5 scale model of Surveyor, similarly oriented and illuminated. Following are keys to interpretation of these contours:

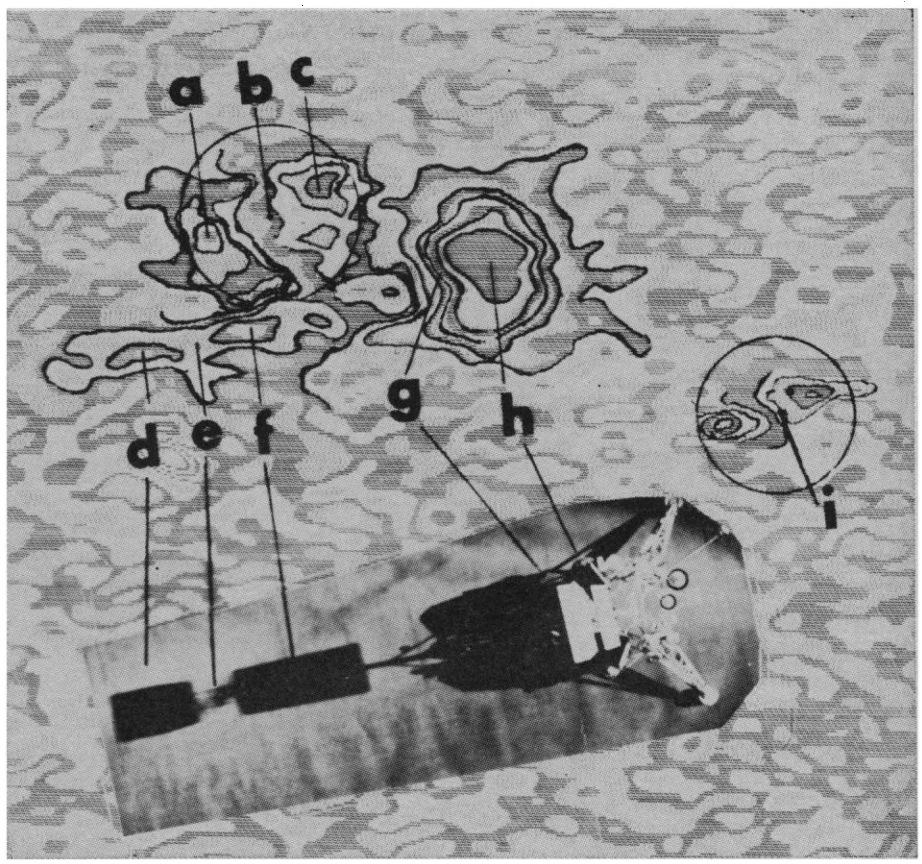

Fig. 4. Relation of a photograph of a model of Surveyor I to isodensity contours of the landing spot in Orbiter's framelet 875, frame H-183.

1) The shadow of Surveyor falls adjacent to a lunar crater centered at *b*. The brightest point of the sunlit inner wall of this crater is at *a*, and the darkest part of the crater's shadow is at *c*.

2) The shadow of Surveyor's mast contains two points of maximum darkness, *d* and *f*, separated by a detent, or partial break, at *e*.

3) There is another dark minimum at the base of the shadow, followed by a steep gradient in density, *g*, toward the brightest part of the image, *h*.

4) A small crater can be detected at *i*.

The size and shape of the image of the spacecraft, as well as the images of nearby objects in the field of view, correlated positively with Surveyor I and its known environment. This correlation was continued by matching Orbiter and Surveyor pictures along identical angles of azimuthal projections; more than 30 of the major features in Surveyor I's panoramas have so far been positively identified, while interpretive analysis continues.

The investigators feel that all criteria for identification have been met satisfactorily. The location chosen fits Surveyor's observations with respect to both triangulation of the horizon and radar data. Analysis of the image shows agreement with the predicted shadow pattern, and the data on lunar features common to the Orbiter and Surveyor photographs correlate positively. Thus we regard the location of Surveyor I as adequately proven.

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25 April 1967

Sea Levels 7,000 to 20,000 Years Ago

Abstract. *Relative sea levels for early post-Pleistocene time are best known from radiocarbon dates of sediments on the continental shelves off Texas and off northeastern United States. Differences in indicated rates of the rise of relative sea level and in depths of the shelf-breaks reveal differential vertical movement of the two shelves during this time, with the result that the Atlantic shelf has sunk with respect to the Texas shelf.*

During the past decade several hundred radiocarbon age determinations of sediment from continental shelves and from coastal bore holes have provided information on the position of sea level during post-Pleistocene times. Most of the measurements are for the past 6000 years. They show a slow rise that began 2000 to 4000 years ago, lasted until the present, and was preceded by a faster rise. Regional or local differences in the apparent rate of rise and of the date at which the rise slowed (*1*) have been interpreted as resulting from variations in the rate of eustatic rise of sea level and from the effects of local isostatic movements of the coastal zone due to relief of ice load, to weighting by deltaic sediments, and to weighting by sea water that deepened on the continental shelves as glaciers melted (*2*).

Dates for sea levels older than 6000 years are relatively sparse. There are 13 such dates for the continental shelf off Texas (*3*, *4*)—the largest published set of appropriate radiocarbon measurements covering this period. These extend back about 17,000 years and are based on shells, partly those of *Crassostrea virginica* (Gmelin), the common edible oyster that lives in bays that generally are less than about 4 m deep.

Since 1965 additional dates have been obtained for shells of *C. virginica* from the Atlantic continental shelf between Cape Hatteras and Georges Bank (*5–7*). One date was obtained for a deeply submerged peat deposit that contained some salt-marsh material (*8*). These 11 dates for oyster shells and peat, most of which were available in 1965 (Table 1 and Fig. 1), indicated relative positions of sea level for the Atlantic shelf that are lower than those for the Texas shelf during the same period; however, the oldest dates were only 11,000 years and the greatest depths were only 59 m for the Atlantic shelf, and data from the two shelves (Fig. 2) exhibited considerable overlap.

During 1966 Garrison obtained five more dates that included several from older and deeper deposits of the Atlantic shelf (Table 1). These dates are for shells found in piston cores collected aboard the University of Rhode Island's research vessel *Trident*. A shallow-water environment is indicated by some of the shells (although others are from mollusks that live in a wide range of depths) and also by the nature of the sediment that encloses the shells. Accordingly, a description of the sediment is appropriate.

Core T 228 consists of sediments that are shown by seismic subbottom profiling to lie atop a 145-m terrace just east of Hudson Canyon (*9*, *10*). The core (80 cm long) contained layers of clay balls in a sandy matrix alternating with layers of very silty fine- to medium-grained sand. Several large fragments of the sea scallop, *Placopecten magellanicus* Gmelin, enclosed within a silt sand layer at 46 to 63 cm were dated. This mollusk lives in a wide range of depths and is common at 100 m; however, the clay balls deposited with these shells probably were derived from the erosion of another terrace that lies at about 120 m, when sea level was slightly above that terrace.

Core T 203 was from the flank of a small ridge that has a relief of 5 to 10 m and rises above an erosional terrace whose average depth is about 120 m. The core consisted of 100 cm of grayish-brown sand underlying 12 cm of greenish sandy silt. This sand was fine- to medium-grained and well sorted at the top but became coarser and pebbly near the bottom. Shell fragments, mostly of *Mesodesma arctatum* (Conrad), were abundant throughout the lower 100 cm, but many whole valves were strongly imbricated in the bottom 15 cm of the core. The species is common on exposed beaches, especially adjacent to the mouths of streams and tidal inlets. Only the imbricated shells were removed and dated by their content of radiocarbon.

Core T 206 was 110 cm long. The uppermost 10 cm consisted of fine-grained sand and silt with abundant planktonic foraminifera. Below a sharp break at 10 cm, the lower part of the core was fine- to medium-grained subround sand that was very clean and well sorted. A date was obtained on a collection of shell fragments between 63 and 83 cm, including specimens of *M. arctatum*. Both sand and shells are indicative of shallow water, and the date probably relates to the destructive phase of a former delta, on the surface of which the core was obtained.

Core T 147, 117 cm in length, contained medium- to coarse-grained grayish-brown sand underlying sandy silt above a sharp contact at 47 cm. A date was determined for shells of *M. arctatum* enclosed in the sand at 107 to 117 cm. This sand may be a Holocene transgressive deposit atop a reworked Pleistocene surface and beneath the southern part of a large silt body in this area (*10*, *11*). The coarse-grained, well-sorted nature of the sand in this core suggests that it was deposited no more than about 10 m below sea level, in agreement with the restricted habitat of *M. arctatum*.

Core T 307 has the same stratigraphic relations as core T 147, except that it came from the northern edge of the silt body. This core had clean fine- to medium-grained gray sand sharply overlain by 30 cm of silty, very fine sand. A date was obtained for fragments of the razor clam, *Ensis directus* Conrad, in the lower sand at 55 to 65 cm; this mollusk is typical of sand flats but occurs as deep as 15 m.

The assemblage of dates shown in Fig. 2 indicates conclusively that relative sea level was lower for the Atlantic than for the Texas shelf, or in reality that the shelves have undergone differential movement during at least the past 16,000 years. Such movement could be accompanied by broad warps or sharper irregularities in the region of movement. Although the available dates for nearshore mol-