

Resurvey of

The Heart of the Grand Canyon

1971 - 1978

National Geographic Society - Boston Museum of Science

A joint project under the direction of Bradford Washburn

Final Report by Bradford Washburn

Director of the Museum

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The first formal map of the Bright Angel area of the Grand Canyon was published in 1903 as a result of the extraordinary survey of 1902-03 by parties of the U. S. Geological Survey under the leadership of E. M. Douglas --- with topography by François Matthes and control by H. L. Baldwin, Jr., and J. T. Stewart. This excellent "reconnaissance" map (scale 1:48,000, with 40-foot contours) was not materially improved until the new USGS Bright Angel Quadrangle (scale 1:62,500, with 80-foot contours) was published in 1960, by photogrammetric methods, from aerial photographs taken in 1954 and 1960.

I enjoy making maps. I was an instructor of cartography before I came to the Museum of Science in 1939 and I have tried to keep up with the great advances in cartographic techniques which have occurred in the last forty years

--- and whenever the opportunity arose I became involved in an interesting exploratory mapping project. In the fall of 1969 my wife and I visited the Grand Canyon and were disturbed by the fact that no large-scale maps of the area existed.

A map with a scale of an inch to a mile (1:62500) is simply inadequate to depict such incredibly rough country, with extremely intricate trails involving hundreds of tight switchbacks --- for use of either the hiker or the scientist who has any desire or need to know precisely where he is --- or, indeed, precisely where he is going! This is also far too small a scale for the accurate plotting of the geology, botany or archaeology of this heavily-frequented and much-studied part of the Canyon:

After considerable research, it became clear that neither the National Park Service nor the U.S. Geological Survey planned to remap the Canyon area on a larger scale, and I became intrigued with the idea of making a number of new sheets of the most intensely-used part of the Canyon on a manuscript scale of 1:4800 --- a foot to a mile --- with the long-range hope of eventually coalescing

these large sheets into a single map on a scale partway between this and that of the small-scale government sheets.

Mrs. Washburn and I discussed this project with Harry R. Feldman of Boston, one of New England's top professional surveyors, with whom we had worked before on the control of our large-scale maps of Squam Lake, New Hampshire and the Squam Range, and he expressed keen interest in working with us at the Canyon. The Museum of Science has owned a Wild T-3 theodolite for many years and Harry had just acquired a new Laser Ranger which appeared to be ideally suited to making precise distance-measurements over the incredibly rough Canyon terrain.

It was our plan to work together as volunteers, encouraging other volunteers to help us --- and financing the project with any grants-in-aid that we could secure as the project progressed. Before plunging into a major commitment, we decided to visit the area once more, using a modest grant from my Museum of Science research fund, to try to feel the situation out --- to see what the working conditions were, to investigate the availability and cost of reliable

helicopter support and to actually make a few preliminary observations along and near the South Rim. We also speculated further by having vertical photographs taken of the entire area under consideration by Mark Hurd Aerial Surveys of Goleta, California. These were made with a Zeiss camera from an altitude of 16,000 ft. (sealevel) and flown both north-south and east-west in order to thoroughly cover every detail of the incredibly rough terrain.

We studied the existing maps thoroughly and secured all available control from the U.S. Coast & Geodetic Survey and U.S. Geological Survey. The area that interested us extended westward from Yaki Point eight miles to Hermit Creek, northward across the Canyon to Point Sublime and then eastward again to the vicinity of Bright Angel Lodge on the North Rim. This was a large area --- well over one hundred square miles and it covered most of the "heart" of the Canyon which was then being visited by nearly three million tourists and hikers each year.

There was very little precisely-marked government control in this area. The USC & GS had first-order triangulation stations at Yaki Point ("Middle"), Point Sublime and Cape Royal. The positions of these stations were very accurate,

but their altitudes were far less precisely known. The USGS had a triangulation station near Hopi Point ("Rowe"), another one ("Angel") at the North Rim Ranger station and another at Obl Point. Rowe and Obl were easily accessible, but Angel lay amid huge trees, and a high tower would have been needed in order to observe from it. A very accurate line of levels had been run down the Bright Angel Trail to the Colorado River by François Matthes' party in 1902 and a number of bench marks from this work still remained. Also, the National Park Service had done considerable additional leveling in the Inner Canyon and along ten miles of the lower course of Bright Angel Creek, in connection with the establishment of the water pipeline between Roaring Springs (on the North Kaibab Trail) and the South Rim complex.

What this all added up to was that all the control of the existing maps of this part of the Canyon depended on baseline measurements made in the desert many miles away, and that, except for a small number of widely-separated points, no reliable and marked control existed in our area of interest. We therefore decided to start the work with a clean sheet of white paper on which we marked the grid

coordinates of Yaki Point (USC & GS station "Middle") and Point Sublime (USC & GS station "Sublime"). We assumed these stations to be precisely positioned --- and this of course yielded the azimuth between them. This azimuth was also checked in the field with theodolite work at "Middle" to USC & GS station "Royal" which lay east of our network.

We diverged for the only time in the whole project from our policy of an all-volunteer group of field workers in connection with doing precise leveling to establish a very solid datum for our project. To do this we hired Edward A. Krahmer of Sun Lakes, Arizona (highly recommended to us by the USGS) to run two level-loops for us from USC & GS bench-mark S-61 (6876.164 feet) at the head of the Santa Fe railroad yard at Grand Canyon Village. One of these closed loops ran out to Yaki Point and established the altitude of "Middle" as 7259.908 ft. The other ran out to Hopi Point, passing USGS station "Rowe" on the way, and set an altitude of 7042.953 feet at a new triangulation station which we set up at the tip of the point, in full view of the other great points along the central part of the South Rim: Yaki, Yavapai, and Pima; as well as virtually all of our key points on the North Rim and in the Canyon itself. Our entire map was to be hung on the positions of Middle and Sublime, the azimuth of the line

between them and the altitudes brought to "Middle" and Hopi from S-61.

Mr. Kraemer also swung past a new station which we set on the roof of Yavapai

Museum (firmly related to its stone foundation) and gave it an altitude of

7082.225 ft. Also accepted as vertical control down in the Canyon were those

of Matthes' 1902 bench-marks related to the Bright Angel Trail, and all of the

National Park Service level stations between Roaring Springs and Indian Gardens.

We are extremely grateful for all of the assistance given to us in this regard by the USC & GS, the USGS and the Park Service --- and for five years of continuous help and advice given to us by Robert Lovegren and Merle Stitt, the superintendents of Grand Canyon National Park, and a score of the members of their staff without whose advice and counsel our work would have been quite impossible.

Our first trip to the Canyon was made in 1971 (Feb. 17-28) before we had developed solid plans for the project --- partly to appraise the whole situation, and partly to actually start some of the work if conditions looked favorable and Park Service interest in what we hoped to do appeared high. Those in our tiny

party were Mrs. Washburn and I, plus our daughter Betsy (who lived in Denver) and Wendell Mason of Boston, a longtime friend, professional surveyor, and Harry Feldman's chief assistant.

This first trip was extremely successful. We experienced the usual incredibly fine Canyon weather (a pleasant change from the myriad weather problems encountered working in Alaska and the Yukon) We established solid relations with the Park Service; we located all of the key survey stations on the South Rim described in the lists given to us by the government; and we also set up a number of our own new stations both along the South Rim and somewhat out into the Canyon. We also set up a good working relationship with Grand Canyon Helicopters who performed most of our support for the first three years in the field. Late winter is an excellent time to work at the Canyon and we accomplished a great deal, despite the fact that we were in the field for only 10 days. Needless to say, because we were all busily employed on other major jobs and doing this "on the side," it was clear from the start that it would take us a long time to reach our goal, a tiny bite on each trip, but we enjoyed it this way and we rapidly developed

a delightful spirit of camaraderie between the two of us who were "regulars" on each trip and the many volunteers who worked so enthusiastically with us.

After the first trip, we reviewed progress and were very pleased. We had only spent \$2400, had already set up a very sound composite base along the South Rim (Yaki-Yavapai-Hopi-Pima) and had used the helicopter and laser enough to be certain that they were the basic tools needed for our success. However, the laser instrument (Laser Ranger II) was not powerful enough to measure distances over five miles long, and we needed something with much more range to develop a sound network across to the other side of the Canyon --- several of the sights that we needed ranging between seven and thirteen miles.

So we contacted Laser Systems and Electronics of Tullahoma, Tennessee, which had made Harry's Ranger II, and asked for their help. Out of this telephone call developed a working relationship that has been of extraordinary importance, not only to this Grand Canyon project but also to our subsequent work both in Alaska and New Hampshire. Our second trip was planned for almost a full month (June 16 - July 11, 1971) and this time our volunteer ranks were expanded to

include not only Wendell Mason but Harry Feldman as well as Buddy Cutshaw and Wayne McQueen of Laser Systems --- to field test a new Laser instrument which was under development at the time.

It would take many, many pages of intricate text to cover the day-to-day work of each of these trips, all of which, of course, is recorded in our logs of the project. This account will simply deal with the basic steps of progress as we went forward and will recount the principal techniques used in our work.

For the second time, we invested very little of our time down in the Canyon, but concentrated on measuring the long lines so essential to the development of a strong overall survey network --- and some of these reached significantly beyond the limits that we had first set for our project. We continued to add to the control out in the Canyon by measurements to and from Zoroaster, Cheops, Set and Ra --- all points that rose dramatically above the Canyon floor, yet were easily accessible by helicopter.

Each of our survey stations consisted of a one-inch hole, three inches deep, drilled in the rock, using a Black and Decker Rotohammer, operated by

current supplied by a Homelite generator --- both contributed to our project by the manufacturers. This gear was hauled by helicopter to almost all of our stations, but a half-dozen holes were cut by using an old-fashioned hand-drill and sledge-hammer.

When the hole was completed, we drove into it a 3" x 3/4" galvanized pipe nipple, then added a coupling and a section of pipe, varying in length from 2 ft. to 5 ft., to which we attached our targets (see illustration). Those which we had to see from a number of different directions were 16" plastic spheres (National Geographic world globe cores!). Those which were to be sighted from only one direction were simply rectangular plywood targets bolted to the iron pipes. All were painted flat white, then spray-painted with fluorescent orange, which appeared to be the most practical color for visibility against the complex Canyon backgrounds. Repainting was necessary about twice each year, as the paint rapidly faded in the intense desert sunlight.

As our stations were established, they were marked with large white cloth targets staked out on the ground, and photographed from the air at low

altitude, so that they could be precisely related to our 1970 high-altitude photography. This was obviously not the normal way to mark control --- which should all have been targeted in advance and photographed before field-measurements started --- but this orderly procedure could not be followed on an informal project such as ours, inching slowly forward, with exceedingly limited finances as well as a tiny contingent of personnel.

At the conclusion of the two trips in 1971, all of our vacation time was exhausted and we retreated to Boston to sum up the results of our work. We had spent, in all, 26 days in the field, had made 85 helicopter landings. We were now sure that what we were doing made sense. Our preliminary calculations were yielding excellent results. Our trusted Wild T-3 theodolite was working perfectly and the two Laser Rangers had made distance measurements speedy and simple. But it was clear that, unless we wanted to whittle away gently on our project for years, we would need much more financial assistance than my small Museum research fund could provide --- particularly because a great deal more helicopter work lay ahead, as we worked further and further away from the South Rim ---

and we had not yet even started the costly phase of photogrammetric control-proliferation and contouring.

Accordingly, in the fall of 1971, we approached the National Geographic Society to see if we could enter into a collaborative arrangement with its Committee for Research and Exploration to split our future expenses equally between the Museum and the Society. This first proposal envisaged a map that would cover 84 square miles, 10.5 miles E-W and 8 miles N-S, stretching from the South Rim to a point approximately 3-1/2 miles north of the Colorado River. To our delight, this proposal was accepted by the Society on December 10, 1971, and the remapping of what we called the "Heart of the Grand Canyon" became a formal reality.

Our third trip (February 18 - March 5, 1972) continued and expanded our station-marking and angular measurements in the southern half of our area and started detailed mapping of the trails, with work on the Bright Angel, Hermit and Waldron, assisted by our longtime friend Jack Pechman of Denver. No laser work was done on this trip.

As we became more familiar with the area, it also became more and more apparent that, although much more fieldwork would be involved, it would make no sense to have our northern limit so far short of the North Rim. So we reapproached the National Geographic about the advisability of extending our work one mile further northward, to encompass Ribbon Falls, Shiva and Buddha Temples. This enlargement of the project was approved by the Society on June 8, 1972:

This increased the size of the area to be mapped by 10.5 square miles (total now 94.5 square miles) and we arranged to have an additional strip of E-W aerial photos made to cover this new area.

While this field work was progressing, Lockwood Mapping was at work contouring the parts of our map on which the control had been completed. This work was done at a scale of 1:4800, between March and July 1972 --- scribing the 50-ft. contours directly from a Wild A-7 plotter onto plastic "scribecoat" sheets, thus avoiding the loss of detail and quality inevitable when contours are first marked in pencil, then later scribed onto the final manuscript by another draftsman.

Our fourth trip involved a great deal of activity with both laser and theodolite. In addition to Wendell Mason, Buddy Cutshaw rejoined us with a very powerful new instrument, the Rangemaster, with which, for the first time, we were able to make the long sights between Yavapai and Bright Angel points (10 miles) and from Yaki Point to Point Sublime (13.5 miles). Our work afoot on the trails intensified, and was done whenever we had windy days which made helicopter work impractical. Throughout 1972, now working with nearby Landis Aerial Surveys of Phoenix, we completed a complex series of low-altitude (8500 ft.) vertical stereo-photo-strips along the trails, as it was impossible to secure the desired detail in them from 16,000-foot photography.

Although a considerable amount of control still remained to be added (as well as a massive amount of trailwork) the early summer trip in 1972 essentially broke the back of the overall project. We were now thoroughly familiar with the area and how to work in it. We had a top notch group of volunteers, and the helicopter pilots, led by Dan Nicholson, had now become expert at the demanding sort of pinnacle-landing work that was essential to our project.

In late August and early September 1972, Trip No. 5 (Aug. 30-Sept. 18) took a tremendous slice out of our agenda. Ed Krahmer carried out a line of levels for us along a three-mile section of woodroad northward from Tiyo Point, thus giving us strong vertical control across the middle of the wooded North Rim plateau. This level-line also had a strong start, as our figures and those of the USGS for the altitude of Tiyo Point agreed within a foot. This simply reconfirmed what repeatedly had happened to date: wherever we zeroed in on a precise spot which was also in the USGS survey, our figures and theirs virtually coincided --- the big difference between our maps lay in the enormous detail that our low-altitude photography and large-scale contouring yielded --- and this was the reason for our work. In addition, because of this large scale we were forced to add an enormous amount more control spread throughout the area.

We completed all of our observations in the new northern extension on this trip and also made a precise large-scale survey of the tree-covered area around Indian Gardens. Harry Feldman and Wendy Mason helped us throughout this period, and Dick Hinderlie and Margo Sweet assisted by making a large number of distance-

measurements along the trails. And one of the most delightful high-points of the whole project was the discovery of an ancient bench mark on the Bright Angel that had been "lost" for many years --- by Ranger Gary Howe's two young sons Rusty (age 11) and Ronnie (age 9)! We told them more or less where they had to search, offered a \$10 reward for finding it --- and their sharp young eyes, coupled with a lot of patient scrambling among rocks and bushes, won the prize!

As the fall of 1972 deepened, great progress had been made, and on October 30 we sent the first nine sheets of our manuscript to the National Geographic, covering 94.35 square miles --- complete topographically, but still missing a substantial amount of trail-detail. This photogrammetric work was done by Lockwood Mapping, Inc. of Rochester, New York under the direction of Ray Byrne and Keith Adams.

When we forwarded these sheets to the National Geographic, we recommended one more major addition to the map: to extend it another 3.88 miles further northward, to take in the whole southern edge of the forested North Rim plateau, as well as the Grand Canyon Lodge and the NPS North Rim Ranger Station. While this proposal was under consideration, a pleasant bolt of lightning struck!

Conrad Wirth, the eminent past director of the National Park Service, was a member of the National Geographic's Board of Trustees. While the Board was considering our proposed addition, he not only spoke in favor of it but also recommended that we also add a strip all along the eastern edge of the map in order to include most of Bright Angel Creek and all of the course of the North Kaibab and Clear Creek Trails. Although this meant extending our work for at least another year, we were delighted at this proposal --- which was favorably approved by the National Geographic on December 20, 1972. This added 70.24 square miles to our map, bringing the grand total to 164.602 square miles.

With the completion of the first nine of the large-scale sheets involved in the original survey plan, it was very exciting to see the end-result of all of our labors in the field beginning to take the sort of shape we'd dreamed about. We now prepared a battle-plan for completing the entire twice-expanded project: Four more sheets were needed to complete the first expansion to the North Rim. Then four more were required to cover Mr. Wirth's eastern edge. Trip Number 5 (August 31 - September 16, 1972) yielded the control still needed to contour the entire North

Rim area and Lockwood proceeded with work on these four sheets in the spring and summer of 1973.

In the midst of this activity, the National Park Service decided that a new very-large-scale map of the South Rim Headquarters area was needed. Low-altitude pictures of this had already been flown by Hurd, so we provided the needed laser-control and it too was contoured by Lockwood Mapping during the period April - November 1973 at U.S. Government expense. This proved extremely valuable from our standpoint, as it yielded a very detailed up-to-date map of a very intricate part of our sheet and we were glad to contribute our control-work for it in order to speed its completion.

In fact 1973 was the busiest year of the whole project. Three trips were made to the Canyon. Trip No. 6 (March 22 - April 2) closely followed a helicopter flight by Dick Hinderlie and Dan Nicholson on February 24th to drill and target six of the new stations required to control the central part of the eastern addition. Heavy snows of course prevented effective work on either rim at that time of year. Mrs. Washburn and I and Wendell Mason joined Dick for two intensive weeks of

late winter helicopter-and-laser work that nailed down our needs in the dramatic region of the Ottoman Amphitheatre, Howlands Butte, and Zoroaster Canyon. Then we returned in the early summer of 1973 for Trip No. 7 (June 12 - July 8) to complete both the northern and southern ends of the eastern edge, after the snows had melted and foot-travel again became easy on the rims.

During this period of intense activity in the field, additional volunteers were very important to us, particularly on the North Rim, and not only Harry Feldman joined us to help with many key laser-sights, but Dick Hinderlie, Fred Eidsness and Lindsey Happel worked for scores of hours with us on this most complex and difficult part of the whole map --- because steep slopes and dense forest made it impossible for us to use helicopters, and most of our final stations had to be marked, drilled and occupied afoot. We also reconnoitered the entire 14-mile length of the North Kaibab Trail and started the seemingly-endless task of marking accurately on our low-altitude aerial photographs the parts of the trail that were concealed by trees or deep shadows. Dan Nicholson, our close friend and leader of most of our helicopter-flying up to this point, had left to teach helicopter pilots

in Iran early in the summer of 1973 and shortly after this Jerry McMullin, an equally competent pilot from Madison Aviation, took over the bulk of flying for us.

Our eighth trip was the shortest of all --- only four days (October 21-24, 1973). I had a lecture in Seattle and returned to Boston via the Canyon, meeting Mrs. Washburn there for an intensive attack on the complex details of the upper five miles of the North Kaibab, before the winter snows engulfed them. David Ochsner, NPS ranger and gifted photographer, accompanied us on this trip. Of all of our many forays to the Canyon, this was the most beautiful --- with the brilliant blue skies of fall, chilly nights, thrilling stars and the aspens in all their autumn splendor.

As the fall of 1973 progressed, Lockwood's photogrammetrists were busily engaged in plotting the contours of our last sheets. Sheet 13, covering Bright Angel Point and the North Rim headquarters area, was completed on September 24 and work then progressed southward along the eastern edge of the map, till sheet 17 was finished on January 8, 1974. As these sheets arrived in Boston, one by one, they

had to be meticulously checked for accuracy of detail. Long sections of the trails were still incomplete, although the drainage, topography and buildings were essentially finished by early 1974.

Trip No. 9 from February 20 - March 5, 1974 dealt almost entirely with the trails, and we did scores of miles of walking along the Bright Angel, Tonto, River, North Angel and Clear Creek trails --- long segments of which were invisible on our vertical pictures, either because they were obscured by shadows or because they were so infrequently traveled that there were not the slightest traces of them on even the low-altitude pictures. We had found on two past trips that late February and early March is a perfect time for work in the depths of the Canyon and this one simply reinforced that conviction. And we had new and congenial hiking companions in Charlie Hovey and his son from Boston --- and Ron and Ann Merritt of Russell, Massachusetts.

Whenever possible, we tried to tie our Canyon trips to other necessary Museum activities on the West coast which would reduce our travel costs and stretch our budget-dollars. On July 25, 1974 we returned to the South Rim en route

to Boston from Alaska --- and stayed through July 29th --- Trip No. 10. These were four extremely intensive days of work: out to Widforss Point and back to detail this 5-mile trail afoot and under a broiling sun; then over to Uncle Jim Point and back to finalize the invisible parts of this little-traveled North Rim path; then slowly and meticulously down the upper five-miles of the North Kaibab Trail to check its final manuscript; then down the Bright Angel to check the intricate contortions of its upper 4-1/2 miles --- as far as Indian Gardens.

It was two miles down the Bright Angel on this beautiful final morning (July 29, 1974) that we had the most exciting moment of our whole project. As we rounded a sharp curve, we came upon two young men walking up the trail hand-in-hand. One asked me what we were doing and how our measuring wheel worked. His companion expressed avid interest and said that a good map would have made their trip more interesting. Then his friend turned to him and said, "Joe, how'd you like to feel it?" It was not till then that we realized that Joe was totally blind! I led his deft fingers to the wheel, its spokes, the Veeder-counter and the tiny "tripper" which logs off each foot of distance. We chatted for a few minutes about

accurate maps and how helpful they are to hikers. Then we said goodbye and they headed briskly off up the trail beneath the searing summer sun. As we resumed our descent, our hearts welled with respect for that brave young fellow and his generous guide --- on an adventure that will never be forgotten --- either by them, or by us!

As 1975 arrived, our work was drawing to a close. We had already made ten trips to the Canyon and spent 122 days in the field. We made our last winter trip (No. 11) from February 22 to March 1 and focused it on introducing Paul Witzler to the Canyon. He had flown there from Berne, Switzerland, where he worked at the Landestopographie, Switzerland's Federal Topographical Survey. Paul was the world's top expert on shaded relief --- the subtle shadows that give a three-dimensional feel to a flat map. He spent two weeks at the Canyon as our guest, studying its shapes and colors, and made important recommendations to us later about the colors needed to depict the Canyon's savage relief most effectively on our new map. One day we walked the entire nine-mile length of the Clear Creek Trail, checking every detail of it in our final manuscript. Another we completed

the lower half of the Bright Angel --- five hours to do 3-1/2 miles. Then down the lower two-thirds of the steep Hermit Trail, completing it too, all the way to the Colorado River. When we left, Paul had developed a marvelous understanding of the terrain, both from the air and on the ground --- and the end of our work was just around the corner.

Our final trip (Number 12) was from June 28 to July 6, 1975: Two weeks of picking up loose ends; very low-altitude aerial photography of a number of intricate spots on the trails; and final coordination and farewells to all the volunteers of the Park Service who had helped us so much during the last four eventful years.

Although the public has always had the illusion that one moves directly from work in the field to the printing press in map production, a long, complex frustrating interval always lies between these two extremes. The Grand Canyon map was no exception to this rule. Up to this point, the Museum and the Society had shared the expense equally. From now on to the end, this map was entirely a National Geographic project.

Four steps still remained: The final coalescing of all of Lockwood's 17 sheets of contouring into a single sheet at 1:24,000 (one-fifth the original scale); the completion of the large-scale maps of the trails and their reduction and integration into the final manuscript; the lengthy work of cliff-drawing; and, finally, the equally time-consuming and demanding task of drawing the shaded relief.

During the final phases of our field work, Raytheon-Autometrics of Sudbury, Massachusetts had been preparing strip-maps of the trails at twice the scale of the 17 manuscript sheets --- 1:2400. These strips were made of the Bright Angel, the South Kaibab, the Hermit, the North Kaibab and the lengthy Tonto Trail. The detail-work on these trails sheets consumed a large part of our final weeks in the field. An immense amount of work had to be done on foot checking details and, as mentioned before, filling in scores of gaps caused by shadows and trees and in areas where the terrain was so bare and rocky that the paths were invisible even in enlargements of the low-altitude photographs. It was not until April 23, 1976 that I had completed the drafting of the last of these trail-sheets which were done on my own drafting

table in Belmont. This was slow, meticulous, fascinating work and I enjoyed it immensely. Without this accurate detail it would be impossible for a hiker to find his exact position on these wonderful trails --- and this was one of the main objectives of our whole project. Later on it is our plan to publish very-large-scale strip-maps of at least two of the most important of the trails, but that will be another story.

While this last field work was going on, the final contours and drainage were being scribed at the National Geographic, by Norbert and Walter Vasques, and Thomas Gray was working on intricate problems of nomenclature and compilation of all this data.

The cliff-drawing was executed for us by Rudi Dauwalder and Alois Flury at the Swiss Federal Institute of Topography in Berne during the period from July 23, 1976 to February 1, 1977. A map of the Grand Canyon without considerable use of cliff-hachures would involve a huge amount of meaningless concentrations of brown ink where dozens of parallel contours were jammed together on the steep slopes

--- and, far worse, in areas where hundreds of feet of utterly vertical cliffs were encountered. Dauwalder and his associates were the top people in the world in this exacting frontier between art and science and they did the work superbly --- often investing more than a day of intense labor to produce a few square centimeters of cliffs. The illustrations clearly show how a typical cliff-drawing problem was handled on the slopes of Isis Temple. The only drawback of this technique from the standpoint of pure science is that in areas where cliffs are really perpendicular (or overhanging) there is no "room" to do the hachuring, and some "artistic license" must be taken in "stealing" a bit of space for this purpose from the slope immediately above and below the cliff.

This work was all done on a scale of 1:24,000, a huge reduction of the 17 original sheets, coalesced into a single manuscript 33" x 34" If our scale had been larger, the sheet would have been hopelessly unwieldy for use in the field --- or we would have had to resort to two sheets. If it had been smaller, we would have sacrificed most of the fine detail that was, after all, the basic objective of the whole project.

Dauwalder's work was done on four small sheets which were fitted together and sent to Washington in February, 1977. There expert craftsmen at the National Geographic's Department of Cartography coordinated them with the contour-manuscript, meticulously removing the thousands of crammed contours whenever they were replaced by cliff-drawing (see illustration).

Then another full year of tremendously demanding artwork followed, as National Geographic artist Tibor Toth, trained a dozen years ago by Swiss expert Paul Ulmer, carried out the relief-shading (October 21, 1976 - September 7, 1977). Unlike the cliff-drawing which is cut in a manuscript emulsion by a sharp scribing tool, shaded relief is produced by employing both the airbrush and a variety of pencils of differing degrees of hardness.

Although I enjoyed the thrill of coordinating this work by mail, telephone and occasional on-the-spot conferences in Washington and Berne, the great basic burden of managing the many stages of this lengthy and intricate process fell on the able shoulders of Bill Peele, the National Geographic's chief cartographer --- who tragically had a severe heart attack on August 10, 1977 right at the peak of

the activity. His assistant, Richard Rogers, carried the burden superbly in an anguishing interregnum before Richard Darley succeeded as the new chief cartographer September 11, 1978.

In the late fall of 1977, the editors decided that the map would be published as an insert in the July 1978 National Geographic Magazine --- and the next eight months saw a veritable tempest of cartographic activity: final coordination of the contours, drainage, cliffs, shadows and trails; addition of titles and nomenclature after the most careful checking with local experts of the National Park Service and Professor Harvey Butchart, the clearly-acknowledged authority on the location of reliable springs, place-names and other essential details.

Finally the new map of the Heart of the Grand Canyon went to press on May 4, 1978. It was printed in six different colors ~~on waterproof paper~~ by R. R. Donnelley & Sons Co. --- 10,400,000 copies on 1,100,000 pounds of paper, using almost exactly 17 tons of printers ink! This edition, which appeared in the National Geographic Magazine for July 1978, as planned, had to be considerably

narrower than the full area that we had mapped, as the full size (east and west) would not fit onto the "web presses" needed to print an edition of this size. Later, in June, a separate edition of 34,500 sheets was printed ^{on waterproof paper} by Lebanon Valley Offset Co. with the full 33" x 34" size --- appended to this report and for sale at the National Geographic Society, the Grand Canyon and the Museum of Science.

This project accomplished substantially more than simply the production of a new 1:24,000 map of the central part of the Canyon. In the long run, the 17 manuscript sheets which were reduced and coalesced to make this medium-scale composite map of the area may have more value than the 1:24,000 sheet --- as they contain a vast wealth of fine detail (even individual rocks, trees, bushes and tiny undulations of the footpaths) that could not possibly be reduced to a smaller scale than 1:4800.

This detail could easily have been omitted from the master manuscripts at a considerable saving in cost. However, their production on this scale and with this fine detail was a basic part of this project, which, in addition to yielding the 1:24,000 sheet for hikers, campers and tourists, envisaged substantial

professional value in these large-scale manuscripts for use by geologists, botanists, archaeologists and other scientists for precise plotting of their field work in years to come.

These sheets were meticulously studied and revised during 1979. The scribed manuscripts, completed on November 12, 1979, are now stored at the Cartography Department of the National Geographic Society in Washington. One set of cronaflex positive prints is there and a second is kept at the Museum of Science in Boston. Copies of these sheets may be purchased at cost from the ~~Society~~ ~~of the~~ Museum by those wishing to pursue serious scientific studies in the field.

Two similar manuscript sheets covering the complex and extremely precipitous Inner Canyon area on a scale of 1:2400 were prepared by Swissair Photo & Vermessungen in Zurich during 1975-76. These maps are also available at the Museum of Science --- not the National Geographic.

Finally, pencil manuscripts by Raytheon/Autometrics of the five famous trails (Bright Angel, Hermit, North and South Kaibab and Rim) on a scale of 1:2400 are filed and available for reference at the Museum of Science. These large-scale

manuscripts and those of the Inner Canyon were used in conjunction with the 1:4800 sheets to assure maximum possible accuracy of the trails, and they are certain to prove very useful to those doing any sort of field work along the trails that requires a precise knowledge of position.

In conclusion, I wish to express the utmost gratitude to the National Geographic Society and my Museum without whose full and generous support we could never have attempted this project --- and to the scores of volunteers, recorded elsewhere, whose enthusiastic and selfless cooperation made the field work successful. I doubt whether a surveying project of this scope and complexity has ever before been attempted by an all-volunteer group.

And lastly, I cannot close without expressing my admiration for the extraordinary work of the topographers who preceded us at the Canyon over a period of almost exactly 100 years. What they produced working afoot and on horseback with plane tables and transits instead of theodolites, lasers and helicopters was, of course, one of the greatest accomplishments in all topographic history. It was a thrill and a privilege to travel in their footsteps in this epicenter of our world's most awe-inspiring scenery.

SURVEY DATA

GRAND CANYON SURVEY

1971 - 75

Station Types

There are 92 control points in this survey

- 75 of them were fixed by both laser and theodolite (see attached list)
- 7 of them were occupied by theodolite and sighted by theodolite from one or more other stations: (2) Boulder (5) Colonnade (9) Cremation (11) Data (22) Horus (55) Phantom USGS (85) Tonto
- 8 were targeted by helicopter and fixed by triangulation from two or more points: (7) Cope (15) Grama (33) Johnson (45) Newton (51) Pattie (47) O'Neill (52) Perch (72) Set A
- 2 were not visited at all and their peaks were intersected from two or more points: (32) Isis (48) Osiris

The altitudes of 12 stations were determined by leveling:

From USC & GS Bench Mark S-61 (6876.164 ft.) (20) Hopi (44) Middle (USC & GS

also (41) Maricopa (42) Maricopa A

(67) Powell Point (USGS) (70) Rowe (USGS) (90) Yaki (91) Yavapai

From USGS Bench Mark 3870.292 ft. on Bright Angel Trail

(24) Indian Gardens (65) Plateau Point

From USNPS Pipeline level line:

(54) Phantom Ranch (55) Phantom USGS

Two USC & GS stations were occupied with both theodolite and laser:

(44) Middle (81) Sublime

Three USGS stations were occupied with both theodolite and laser:

(46) Obi (67) Powell Pt. (70) Rowe

Technical Notes on
the Survey Program

The resurvey of the heartland of the Grand Canyon 1971-1975 was based on two USC & GS survey stations on the North Rim of the Canyon (Sublime and Obi) , one USGS station (Rowe) and one USC & GS station (Middle) on the South Rim --- also USC & GS Bench Mark S-61 on the South Rim. Leveling of the USGS along the Bright Angel Trail was used as datum along this trail, as was National Park Service leveling along the lower ten miles of the North Kaibab Trail.

In all, 92 survey stations were used in this new network. Seventy-five of these were positioned by both theodolite and laser observations (see list). Two were unoccupied intersected points; 8 were targeted intersected points; and three were positioned by existing US government coordinates. The azimuth from "Middle" (at Yaki Point) to "Point Sublime" (both USC & GS stations) was assumed as the basic direction on which all others were hung. This direction was also checked by observations at Middle to USC & GS station "Royal" at the southeastern tip of the North Rim, well outside the area being mapped.

Horizontal and vertical angles were measured with a Wild T-3 theodolite. Slope distances were measured with a Laser Ranger II, a Ranger III, and a Range-master I, loaned to the project by Laser Systems and Electronics Inc. of Tullahoma, Tennessee, now a division of Keuffel & Esser, Inc. Although most stations were occupied by both theodolite and laser, a small number were not instrument-stations and positioned by intersection of targets set up on them in advance. Two stations (Isis and Osiris) were intersected and not occupied at all.

The helium-neon laser of the Rangers that were used was modulated by a crystal-controlled, electro-optical cell and directed onto an array of retro-prisms, positioned at the point to which the distance measurement was to be made. The reflected beam returned from the prisms to the Ranger which is both a transmitter and receiver. Here the light-beam is converted into an electrical signal. The transmitted and reflected beams are compared by the instrument's self-contained computer which performs a succession of "phase-comparison" measurements, averages them and then converts the result into a direct digital distance readout --- either in hundreds of a foot or millimeters, as desired.

One problem related to the precision of these distance-measurements remains unresolved, though of little practical importance, because of the relatively short lengths of the lines: This arose from the fact that all "parts-per-million" corrections fed into the Ranger's computer were based on the average barometric pressures and temperatures, taken at both ends of the line at the time of measurement. Without the costly use of a helicopter to fly a thermometer along the line at the time the measurement is being made, it is clearly impossible to ascertain the true average temperature of the air-mass out in mid-air between the Canyon's pinnacles.

The stations in the network (see diagram) were distributed as evenly as possible over the area to be mapped, except in the area of the heavily-forested North Rim plateau. However, vertical control was brought into the center of this area by leveling northward up a woodroad from Tiyo Point. The positions and altitudes of four points on the South Rim (Yaki, Yavapai, Hopi, and Pima) precisely linked by both laser and theodolite, anchored near the center on USGS "Rowe" and on the east at USC & GS first order station "Middle" provided a "composite base" for the network. All points out in the Canyon and along its opposite rim were

linked by triangulation or trilateration to this South Rim axis, with checks to "Sublime" (slightly beyond the West edge of the map) to the west and "Obi" to the east on the North Rim.

All computations were carried out on the Arizona State Grid System. The laser slope-distances were first reduced to the horizontal and then to sea level and finally to the grid system. Horizontal angles, as measured in the field, were used directly in the grid computations, without change. The theoretical difference between field angles and grid angles was less than one arc/sec and was therefore ignored.

Elevations were based on the altitudes of Yaki and Hopi, tied by closed, precise level-loops to USC & GS Bench Mark S-61 (6876.164 ft.) at the head of the Santa Fe railroad tracks on the South Rim. All other elevations were computed from vertical angles and horizontal distances, the great majority of which were slope-corrected laser-distances. In many cases, reciprocal vertical angles were observed, which gave additional strength to the station involved. It is our belief that all altitudes are accurate within 0.2 foot. Many are within 0.1 foot. Geographical positions are probably accurate to within 0.10 foot. The appended

Control Diagram makes clear the distribution of the survey stations and the method used to fix the position of each. Many of these stations were in essence trilaterated and the horizontal angles used for checking only. Tables of Altitudes, Geographical Positions and Laser Data are also appended for reference purposes.

Since this work was completed, a controversy has arisen with regard to the altitude of Bench Mark S-61. This has not yet been resolved, but, if an error does indeed exist at this station as alleged, all altitudes on this map must be adjusted upward by approximately two feet.

Photogrammetric Notes

The photography used to produce this map was on a scale of 1:24,000, using a Zeiss RMK-A-15/23 camera No. 21220, 152.46 mm focal length. The pictures for the basic 13 sheets were made by Mark Hurd Aerial Surveys of Goleta, California. The photographs for the four sheets along the eastern edge were made by Landis Aerial Surveys of Phoenix, Arizona, using a Zeiss RMK-A-15/23 camera No. 21178, 152.57mm focal length. These two contractors roughly split the low-altitude photography at 12,000 ft. and 8500 ft. used by Raytheon-Autometrics to map the trails. Lockwood Mapping, Inc. of Rochester, New York did the overall photogrammetry and the 1:2400 contouring of the Inner Canyon area was done by Swissair Photo & Vermessungen of Zurich.

Vertical relief was depicted by 50-foot contours, supplemented by 25-foot contours in the gentler gradients of the rims and the Tonto plateau. The computation of the field data was done by Harry R. Feldman, Inc. of Boston, Mass. using coordinates based on the Arizona Grid datum. The horizontal and vertical photogrammetric model control was achieved through a semi-analytical triangulation program for both the vertical and horizontal solution.

Compilation utilized a Wild A-7 Autograph on which the pencil chuck of the plotting table was replaced by a scribe-point. K & E scribecoat material was used as the compilation base. By use of direct scribing without the intermediate pencil step, a much more accurate reproduction of the character of the terrain was possible.

A number of unusual problems were encountered and procedures to deal with them were developed which will be helpful in facing similar mapping in the future. Often the operators would lose stereo-vision while contouring the high vertical cliffs and had to back up and start the contour-line over again. Deep shadows, even at noon, on the north sides of the vertiginous cliffs made contouring of these areas difficult --- and trails were often completely invisible where they passed through these shadows.

The plotting of the trails and drainage were done on different sheets from the contours. This was essential in this unusual project and it resulted in a number of special problems. In many areas because of the bare, arid terrain, there were a multitude of drainage-courses, which would have seriously cluttered the sheets

if they had all been depicted. The selection of the key courses was often very difficult. Then, when plotting the trails and drainage, the slope was often dropping so rapidly that it was very difficult to synchronize and maintain a precise Z-position, correctly coordinated with an equally-accurate X and Y position. This problem often resulted in a slight lateral shift in the location of the planimetry, which later had to be corrected to fit the contours in the final manuscript which coalesced both sheets. Normally these problems would have been easily controlled on a single penciled manuscript sheet, simultaneously involving drainage, contours and trails.

We owe a special debt of gratitude to Ray Byrne and Keith Adams of Lockwood, John Baber of Raytheon-Autometrics and Werner Altherr of Swissair Photo --- and to all of their skilled associates who actually did this intricate and painstaking work.

National Geographic Grants
to Grand Canyon Project
Applications and Approvals

1. Application made on October 15, 1971
Approval on December 10, 1971 \$30,000

2. Application made on May 2, 1972
Approval on June 8, 1972 (add 1 mile to N. edge) \$5,000

3. Application made on November 13, 1972 (letter-report of October 30)
Approval on December 20, 1972 (add 3 more miles to N. edge and 2 miles
all along E. edge) \$22,537

4. Final accounting sent to the NGS on December 5, 1974
and response from Dr. Payne on December 9, 1974

5. Map was printed in May, 1978
10,485,000 sheets, 6 colors (reduced size to fit magazine)
In June 1978 34,500 full-size sheets were printed for public sale
and inclusions, later, with final report on project in National Geographic
Research Reports.

6. Manuscript finally revised by Bradford Washburn in the winter of 1979
and completely-revised final scribed manuscript sent for filing at NGS
on November 15, 1979. One set of 17 composite scribed positive corona-
flex sheets sent to BW and NGS on the same date.

Growth of the Grand Canyon Map

1. The Original Area: East-West --- 54,800 ft. --- 10.38 miles)
North-South --- 42,720 ft. --- 8.09 miles) Total 83.97 sq. mi.

Approved by National Geographic, December 10, 1971

2. Add one mile Northward: East-West --- 54,800 ft. --- 10.38 miles)
North-South --- 5,280 ft. --- 1.00 miles) Total 10.38 sq. mi.

Approved by National Geographic, June 8, 1972

- 3a. Final northern addition: East-West --- 54,800 ft. --- 10.38 miles)
North-South --- 20,490 ft. --- 3.88 miles) Total 40.27 sq. mi.

- b. Eastern edge addition: East-West --- 12,200 ft. --- 2.31 miles)
North-South --- 68,500 ft. --- 12.972 miles) Total 29.97 sq. mi

Approved simultaneously by National Geographic, Dec. 10, 1972

Total size of map, as contoured by Lockwood Mapping (17 sheets @ 1:4800)

12.972 miles (68,500 ft.) North-South)
12.689 miles (67,000 ft.) East-West) 164.602 square miles

Size of Map distributed in National Geographic Magazine, July 1978 (printed May 1978)

12.642 miles (66,750 ft.) North-South)
8.097 miles (42,750 ft.) East-West) 102.36 square miles

Size of Map for public sale (printed June 1978)

12.50 miles (66,000 ft.) East-West)
12.78 miles (67,500 ft.) North-South) 159.80 square miles

The Grand Canyon Map

Work at the Canyon by Dr. and Mrs. Washburn
and Others

<u>Year</u>	<u>Time at the Canyon</u>	<u>Workdays</u>	<u>Helicopter Landings</u>
1971	February 18 - 27	10	27
1971	June 16 - July 11	16	58
1972	February 19 - March 1	12	48
1972	May 29 - June 15	18	76
1972	August 31 - September 17	18	124
1973	February 24 (R. Hinderlite)	1	7
1973	March 24 - 31	8	101
1973	May 4 (Krahmer)	2	4
1973	May 21 (Krahmer)	2	4
1973	May 27 (Nicholson)	1	4
1973	June 13 - July 4	21	101
1973	October 21 - 23	3	11
1974	February 21 - March 4	12	114
1974	July 26 - 29	4	7
1975	February 22 - March 1	8	13
1975	June 28 - July 6	<u>8</u>	<u>13</u>
		144	712

Lockwood Mapping

Sheet Completions

Large-scale plot of Phantom Ranch area -- June 17, 1971

Bridging of area covered by sheets 1-9 -- November-December, 1971

Sheets 1-9 plotted between March 4, 1972 and July 30, 1972

Sheets 10-13 plotted between May 15, 1973 and September 19, 1973

Large-scale sheet of Headquarters area contoured April - November 1973

(Photos July 2, 1972)

Sheets 14-17 plotted between October 1, 1973 and November 15, 1973

Delivery of final cronaflex copies of scribed sheets:

- | | |
|----------------------|------------------------|
| 1. August 3, 1972 | 10. October 3, 1973 |
| 2. July 26, 1972 | 11. October 3, 1973 |
| 3. July 26, 1972 | 12. September 28, 1973 |
| 4. April 17, 1972 | 13. September 28, 1973 |
| 5. March 1972 | 14. November 28, 1973 |
| 6. December 28, 1973 | 15. November 28, 1973 |
| 7. August 19, 1972 | 16. November 28, 1973 |
| 8. June 22, 1972 | 17. January 8, 1974 |
| 9. June 29, 1972 | |

GRAND CANON SURVEY

Name	Positions and Altitudes of Control ("L" denotes leveled altitude)		Survey Station Marks		Types of Control		
	NGVD29 Elevation	NAD 27 AZ C Grid Coordinates	Left in field at conclusion of project		* Laser Ranger	** Theodolite	*** prisms/target on
1. Angel A	8145.51	N1889707.98 E461254.60	USGS bronze disc	*	**	-	-
2. Boulder	5683.7	N1878200.58 E4063359.21	Drill-hole in rock	-	**	***	-
3. Clear	4030.4	N1855151.25 E464972.88	Drill-hole with pipe and sphere	-	**	***	-
4. Cheops	5386.6	N1862418.82 E439687.26	Concrete observing stand and bronze disc	*	**	-	-
5. Colonnade	6238.6	N1875818.23 E438797.79	Drill-hole with pipe	-	**	-	-
6. Confuctus	7073.0	N1884912.95 E410129.23	Drill-hole with pipe	*	**	-	-
7. Cope	3522.0	N1853206.42 E418127.89	Drill-hole with pipe	-	**	-	-
8. Corner	4967.2	N1832044.23 E471583.41	Drill-hole with pipe	*	-	-	-
9. Cremation	3894.2	N1853533.79 E453051.54	Drill-hole with pipe	-	**	-	-
10. Crystal	3991.7	N1873333.06 E404795.83	Drill-hole with pipe	*	**	-	-
11. Dana	5033.6	N1852652.10 E431163.00	Drill-hole with pipe	-	**	-	-
12. Dragon	4450.8	N1888276.70 E426637.95	Drill-hole with pipe	*	**	-	-
13. Dragon (North)	7661.1	N1898037.84 E424626.74	Drill-hole with pipe	*	**	-	-
14. Gorge	3820.3	N1847006.32 E469075.33	Drill-hole with pipe and sphere	-	**	***	-
15. Grama	7733.4	N1895867.32 E411753.34	Drill-hole with pipe and sphere	-	-	***	-

GRAND CANYON SURVEY

Name	Positions and Altitudes of Control ("L" denotes leveled altitude)		Survey Station Marks		Types of Control		
	NGVD29 Elevation	NAD 27 AZ C Grid Coordinates	Left in field at conclusion of project		* Laser Ranger	** Theodolite	*** prisms/target or
16. Grandeur	7032.4	N1842898.79 E439381.14	Drill-hole	-	-	***	
17. Greenland	8315.0	N1897209.67 E475233.95	Drill-hole with pipe	-	**	***	
18. Hattan	5967.2	N1868638.30 E460207.55	Drill-hole with pipe	*	**	-	
19. Hermit	6650.4	N1841946.69 E413139.78	Bronze disc	*	**	-	
20. Hopi	7042.730 (L)	N1846394.62 E429774.70	Bronze disc	*	**	-	
21. Horsethief	6346.3	N1836184.03 E409380.76	Drill-hole with pipe	-	-	***	
22. Horus	6130.2	N1870417.15 E423315.40	Drill-hole with pipe and sphere		*	-	
23. Howlands	5571.4	N1854099.78 E472703.87	Drill-hole with pipe		*	**	
24. Indian Gardens	3849.56 (L)	N1847577.94 E438117.70	Bronze disc		*	**	
25. Indian Gardens A	3939.9	N1846661.08 E437138.79	Drill-hole	-	-	***	
26. Indian Gardens B	3924.2	N1847540.78 E437023.19	Drill-hole	-	-	***	
27. Indian Gardens C	3871.8	N1848012.20 E437681.45	Drill-hole	-	-	***	
28. Indian Gardens D	3815.8	N1848401.72 E437954.53	Drill-hole	-	-	***	
29. Indian Gardens E	3734.4	N1849276.63 E438361.92	Drill-hole	-	-	***	
30. Indian Gardens F	3799.3	N1848258.57 E438740.16	Drill-hole	-	-	***	
31. Indian Gardens G	3913.8	N1849759.46 E438142.65	Drill-hole	-	-	***	

GRAND CAN SURVEY

Name	Positions and Altitudes of Control ("L" denotes leveled altitude)		Survey Station Marks		Types of Control:		
	NGVD29 Elevation	NAD 27 AZ C Grid Coordinates	Left in field at conclusion of project		* Laser Ranger	** Theodolite	*** prisms/target of
32. Isis	7013.9	N1870665.40 E435072.80	Nothing left			**	-
33. Johnson	5298.2	N1866916.30 E449923.20	Drill-hole with pipe and sphere			**	***
34. Knee	5401.2	N1860262.85 E469883.62	Drill-hole with pipe and sphere			-	***
35. Komo	7987.4	N1882943.45 E469551.71	Drill-hole with pipe			**	***
36. Laser	4038.9	N1880209.02 E416491.93	Drill-hole with pipe			**	***
37. Ledge	6534.8	N1878406.28 E448988.11	Drill-hole with pipe			-	***
38. Lookout	4499.9	N1846127.66 E412950.68	Drill-hole with short pipe			-	***
39. Lyell	5348.1	N1836531.15 E467180.17	Drill-hole with pipe			**	***
40. Manzanita	8108.8	N1887512.32 E475296.34	Drill-hole with pipe			-	***
41. Maricopa	6988.06 (L)	N1841574.19 E432137.51	Drill-hole		*	**	-
42. Maricopa A	6994.93 (L)	N1841903.13 E432213.88	Drill-hole		*	**	-
43. Mesa	4836.7	N1862394.43 E414839.81	Drill-hole with pipe		*	**	-
44. Middle (USC & GS)	7259.908 (L)	N1840705.52 E450811.59	USC & GS bronze disc		*	**	-
45. Newton	5918.8	N1841545.53 E459955.73	Drill-hole with pipe			-	***
46. Obi (USGS)	7928.6	N1876730.86 E471902.45	USGS bronze disc		*	-	***

GRAND CA SURVEY

Name	Positions and Altitudes of Control ("L" denotes leveled altitude)		Survey Station Marks		Types of Control		
	NGVD29 Elevation	NAD 27 AZ C Grid Coordinates	Left in field at conclusion of project	Left in field at conclusion of project	*Laser Ranger	**Theodolite	***prisms/target
47. O'Neill	5308.8	N1844968.00 E448830.00	Cafrn with pipe in it				
48. Ostris	6637.2	N1872253.77 E420375.84	Nothing left			**	***
49. Ottoman	4382.9	N1864992.68 E473354.87	Drill-hole with pipe	*		**	-
50. Parapet	6923.868	N1840470.37 E435259.15	Bronze disc				
51. Pattie	5308.8	N1845240.01 E459107.22	Drill-hole with pipe				
52. Perch	6269.1	N1875618.37 E426727.80	Drill-hole with pipe and sphere				
53. Pima	6765.0	N1845459.90 E416473.41	Bronze disc	*		**	-
54. Phantom Ranch	2546.21 (L)	N1857788.53 E447705.03	Bronze disc			**	***
55. Phantom (USGS)	2518.2 (L)	N1857099.48 E447415.02	Nothing left (corner of house)			**	-
56. Phantom A	3724.9	N1858246.21 E450012.58	Drill-hole with pipe	*		**	-
57. Phantom B	3874.6	N1854086.88 E450221.32	Drill-hole with pipe	*		**	-
58. Phantom C	3885.7	N1853850.03 E445335.45	Drill-hole with pipe	*		**	-
59. Phantom D	4117.2	N1857588.51 E443995.55	Drill-hole with pipe	*		**	-
60. Phantom E	4091.1	N1861121.06 E447281.91	Drill-hole with pipe			-	***
61. Phantom F	4123.8	N1861328.90 E441893.03	Drill-hole with pipe			-	***
62. Phantom H	4104.8	N1860932.54 E446587.22	Drill-hole with pipe			-	***

GRAND CANYON SURVEY

Name	Positions and Altitudes of Control ("L" denotes leveled altitude)		Survey Station Marks		Types of Control		
	NGVD29 Elevation	Grid Coordinates	Left in field at conclusion of project		* Laser Ranger	** Theodolite	*** prisms/target
63. Phantom J	4058.7	N1861749.80	E444199.65	Drill-hole with pipe	-	-	***
64. Phantom K	3760.1	N1857369.96	E453317.25	Drill-hole with pipe	*	-	***
65. Plateau Point	3781.66	N1853215.59	E441312.68	Bronze disc	*	-	***
66. Powell	5427.3	N1872091.30	E453071.20	Drill-hole with pipe	-	-	***
67. Powell Point (USGS/BM)	7043.883 (L)	N1846054.90	E430964.40	USGS Bench mark (bronze disc)	-	-	***
68. Ra	6077.9	N1870649.10	E415445.26	Drill-hole with pipe	*	**	-
69. Ribbon	3715.7	N1877119.37	E460043.11	Bronze disc	-	**	***
70. Rowe (USGS)	7066.857 (L)	N1846085.30	E430055.65	Buried disc marked with iron pipe	*	**	-
71. Set	6016.4	N1863435.00	E423147.40	Drill-hole with pipe	*	**	-
72. Set A	5290.3	N1862232.55	E425895.71	Drill-hole with pipe	-	-	***
73. Shiva	5254.3	N1871940.07	E429024.87	Drill-hole with pipe	-	-	***
74. Shoshone	7278.5	N1835770.07	E458113.13	Bronze disc	*	**	-
75. South Rim Hqs. No. 1	6978.7	N1837418.08	E436323.18	No permanent mark left	-	-	***
76. South Rim Hqs. No. 2	6856.8	N1837625.66	E432928.44	No permanent mark left	-	-	***

GRAND CANION SURVEY

Name	Positions and Altitudes of Control ("L" denotes leveled altitude)		Survey Station Marks Left in field at conclusion of project	Types of Control	
	NGVD 29 Elevation	NAD 27 AZ C Grid Coordinates		*Laser Ranger	**Theodolite ***Prisms/target
77. South Rim Hqs. No. 3	6833.0	N1839738.03 E432882.87	No permanent mark left	-	***
78. South Rim Hqs. No. 4	7162.4	N1840369.34 E444804.75	No permanent mark left	-	***
79. South Rim Hqs. No. 6	7075.3	N1839557.93 E442214.17	No permanent mark left	-	***
80. South Rim Hqs. No. 8	6912.3	N1840450.57 E434909.86	No permanent mark left	-	***
81. Sublime (USC & GS)	7457.5	N1891602.88 E401712.28	USC & GS bronze disc	*	-
82. Sumner	5156.1	N1850474.73 E453179.96	Drill-hole with pipe	*	-
83. Tiyo	7762.8	N1884934.72 E437701.55	Drill-hole with pipe and sphere	-	***
84. Tiyo (NW)	7944.8	N1895514.10 E433181.03	Drill-hole with pipe and sphere	-	***
85. Tonto	3702.4	N1853088.15 E438351.55	USGS bronze BM disc	-	-
86. Transept	8101.8	N1896059.49 E450350.11	Drill-hole with pipe and sphere	-	***
87. Transept (Lower)	4774.3	N1883795.10 E463452.18	Drill-hole with pipe and sphere	-	***

GRAND CANYON SURVEY

Name	Positions and Altitudes of Control ("L" denotes leveled altitude)		Survey Station Marks		Types of Control	
	NGVD 29 Elevation	NAD 27 AZ C Grid Coordinates	Left in field at conclusion of project		* Laser Ranger	** Theodolite
88. Uncle Jim	8244.1	N1896252.12 E465135.42	Drill-hole with pipe and sphere	-	-	***
89. Valhalla	8202.6	N1893980.55 E473083.76	Drill-hole with pipe	-	-	***
90. Yaki	7262.235 (L)	N1840710.69 E450855.25	Bronze disc	*	**	-
91. Yavapai	7082.225	N1843324.42 E440864.64	Bronze disc on top of concrete column	*	**	-
92. Zoroaster	7121.	151.65	Bronze disc	*	**	-

GRAND CANYON SURVEY

Positions and Altitudes of Control

("L" denotes leveled altitude)

	<u>Name</u>	<u>NGVD 29 Elevation</u>	<u>NAD 27 AZ C Grid Coordinates</u>	
1.	Angel A	8145.51	N1889707.98	E461254.60
2.	Boulder	5683.7	N1878200.58	E406359.21
3.	Clear	4030.4	N1855151.25	E464972.88
4.	Cheops	5386.6	N1862418.82	E439687.26
5.	Colonnade	6238.6	N1875818.23	E438797.79
6.	Confucius	7073.0	N1884912.95	E410129.23
7.	Cope	3522.0	N1853206.42	E418127.89
8.	Corner	4967.2	N1832044.23	E471583.41
9.	Cremation	3894.2	N1853533.79	E453051.54
10.	Crystal	3991.7	N1873333.06	E404795.83
11.	Dana	5033.6	N1852652.10	E431163.00
12.	Dragon	4450.8	N1888276.70	E426637.95
13.	Dragon (North)	7661.1	N1898037.84	E424626.74
14.	Gorge	3820.3	N1847006.32	E469075.33

GRAND CANYON SURVEY

- 2 -

	<u>Name</u>	<u>NGVD 29 Elevation</u>	<u>NAD 27 AZ C Grid Coordinates</u>	
15.	Grama	7733.4	N1895867.32	E411753.34
16.	Grandeur	7032.4	N1842898.79	E439381.14
17.	Greenland	8315.0	N1897209.67	E475233.95
18.	Hattan	5967.2	N1868638.30	E460207.55
19.	Hermit	6650.4	N1841946.69	E413139.78
20.	Hopl	7042.730 (L) ^a	N1846394.62	E429774.70
21.	Horsethief	6346.3	N1836184.03	E409380.76
22.	Horus	6130.2	N1870417.15	E423315.40
23.	Howlands	5571.4	N1854099.78	E472703.87
24.	Indian Gardens	3849.56 (L) ^{tr}	N1847577.94	E438117.70
25.	Indian Gardens A	3939.9	N1846661.08	E437138.79
26.	Indian Gardens B	3924.2	N1847540.78	E437023.19
27.	Indian Gardens C	3871.8	N1848012.20	E437681.45
28.	Indian Gardens D	3815.8	N1848401.72	E437954.53
29.	Indian Gardens E	3734.4	N1849276.63	E438361.92

GRAND CANYON SURVEY

- 3 -

	<u>Name</u>	<u>NGVD 29 Elevation</u>	<u>NAD 27 AZ C Grid Coordinates</u>	
30.	Indian Gardens F	3799.3	N1848258.57	E438740.16
31.	Indian Gardens G	3913.8	N1849759.46	E438142.65
32.	Isis	7013.9	N1870665.40	E435072.80
33.	Johnson	5298.2	N1866916.30	E449923.20
34.	Knee	5401.2	N1860262.85	E469883.62
35.	Komo	7987.4	N1882943.45	E469551.71
36.	Laser	4038.9	N1880209.02	E416491.93
37.	Ledge	6534.8	N1878406.28	E448988.11
38.	Lookout	4499.9	N1846127.66	E412950.68
39.	Lyell	5348.1	N1836531.15	E467180.17
40.	Manzanita	8108.8	N1887512.32	E475296.34
41.	Maricopa	6988.06(L) [~]	N1841574.19	E432137.51
42.	Maricopa A	6994.93(L) [~]	N1841903.13	E432213.88
43.	Mesa	4836.7	N1862394.43	E414839.81
44.	Middle (USC & GS)	7259.908 (L) [~]	N1840705.52	E450811.59

GRAND CANYON SURVEY

- 4 -

	<u>Name</u>	<u>NGVD 29 Elevation</u>	<u>NAD 27 AZ C Grid Coordinates</u>	
45.	Newton	5918.8	N1841545.53	E459955.73
46.	Obi (USGS)	7928.6	N1876730.86	E471902.45
47.	O'Neill	5308.8	N1844968.00	E448830.00
48.	Osiris	6637.2	N1872253.77	E420375.84
49.	Ottoman	4382.9	N1864992.68	E473354.87
50.	Parapet	6923.868	N1840470.37	E435259.15
51.	Pattie	5308.8	N1845240.01	E459107.22
52.	Perch	6269.1	N1875618.37	E426727.80
53.	Pima	6765.0	N1845459.90	E416473.41
54.	Phantom Ranch	2546.21 (L) ^e	N1857788.53	E447705.03
55.	Phantom (USGS)	2518.2(L) ^c	N1857099.48	E447415.02
56.	Phantom A	3724.9	N1858246.21	E450012.58
57.	Phantom B	3874.6	N1854086.88	E450221.32
58.	Phantom C	3885.7	N1853850.03	E445335.45
59.	Phantom D	4117.2	N1857588.51	E443995.55

GRAND CANYON SURVEY

- 5 -

	<u>Name</u>	<u>NGVD 29 Elevation</u>	<u>NAD 27 AZ C Grid Coordinates</u>	
60.	Phantom E	4091.1	N1861121.06	E447281.91
61.	Phantom F	4123.8	N1861328.90	E441893.03
62.	Phantom H	4104.8	N1860932.54	E446587.22
63.	Phantom J	4058.7	N1861749.80	E444199.65
64.	Phantom K	3760.1	N1857369.96	E453317.25
65.	Plateau Point	3781.66 (L) ^b	N1853215.59	E441312.68
66.	Powell	5427.3	N1872091.30	E453071.20
67.	Powell Point (USGS/BM) 7043.883 (L) ^a		N1846054.90	E430964.40
68.	Ra	6077.9	N1870649.10	E415445.26
69.	Ribbon	3715.7	N1877119.37	E460043.11
70.	Rowe (USGS)	7066.857 (L) ^c	N1846085.30	E430055.65
71.	Set	6016.4	N1863435.00	E423147.40
72.	Set A	5290.3	N1862232.55	E425895.71
73.	Shiva	5254.3	N1871940.07	E429024.87
74.	Shoshone	7278.5	N1835770.07	E458113.13

GRAND CANYON SURVEY

- 6 -

	<u>Name</u>	<u>NGVD 29 Elevation</u>	<u>NAD 27 AZ C Grid Coordinates</u>	
75.	South Rim Hqs. No. 1	6978.7	N1837418.08	E436323.18
76.	South Rim Hqs. No. 2	6856.8	N1837625.66	E432928.44
77.	South Rim Hqs. No. 3	6833.0	N1839738.03	E432882.87
78.	South Rim Hqs. No. 4	7162.4	N1840369.34	E444804.75
79.	South Rim Hqs. No. 6	7075.3	N1839557.93	E442214.17
80.	South Rim Hqs. No. 8	6912.3	N1840450.57	E434909.86
81.	Sublime (USC & GS)	7457.5	N1891602.88	E401712.28
82.	Sumner	5156.1	N1860474.73	E453179.96
83.	Tiyo	7762.8	N1884934.72	E437701.55
84.	Tiyo (NW)	7944.8	N1895514.10	E433181.03
85.	Tonto	3702.4	N1853088.15	E438351.55
86.	Transept	8101.8	N1896059.49	E450350.11
87.	Transept (Lower)	4774.3	N1883795.10	E463452.18
88.	Uncle Jim	8244.1	N1896252.12	E465135.42
89.	Valhalla	8202.6	N1893980.55	E473083.76
90.	Yaki	7262.235 (L) ^o	N1840710.69	E450855.25

GRAND CANYON SURVEY

- 7 -

	<u>Name</u>	<u>NGVD 29 Elevation</u>	<u>NAD 27 AZ C Grid Coordinates</u>	
91.	Yavapai	7082.225	N1843324.42	E440864.64
92.	Zoroaster	7121.7 (L) ⁶	N1862447.60	E462151.65

SURVEY STATION MARKS

Left in the field at the conclusion of the project.

- | | | |
|-----|--------------|--|
| 1. | Angel A | USGS bronze disc |
| 2. | Boulder | Drill-hole in rock |
| 3. | Clear | Drill-hole with pipe and sphere |
| 4. | Cheops | Concrete observing stand and bronze disc |
| 5. | Colonnade | Drill-hole with pipe |
| 6. | Confucius | Drill-hole with pipe |
| 7. | Cope | Drill-hole with pipe |
| 8. | Corner | Drill-hole with pipe |
| 9. | Cremation | Drill-hole with pipe |
| 10. | Crystal | Drill-hole with pipe |
| 11. | Dana | Drill-hole with pipe |
| 12. | Dragon | Drill-hole with pipe |
| 13. | Dragon North | Drill-hole with pipe |
| 14. | Gorge | Drill-hole with pipe and sphere |
| 15. | Gramma | Drill-hole with pipe and sphere |
| 16. | Grandeur | Drill-hole |
| 17. | Greenland | Drill-hole with pipe |
| 18. | Hattan | Drill-hole with pipe |
| 19. | Hermit | Bronze disc |
| 20. | Hopl | Bronze disc |
| 21. | Horsethief | Drill-hole with pipe |
| 22. | Horus | Drill-hole with pipe and sphere |

23.	Howlands	Drill-hole with pipe
24.	Indian Gardens	Bronze disc
25.	Indian Gardens A	Drill-hole
26.	Indian Gardens B	Drill-hole
27.	Indian Gardens C	Drill-hole
28.	Indian Gardens D	Drill-hole
29.	Indian Gardens E	Drill-hole
30.	Indian Gardens F	Drill-hole
31.	Indian Gardens G	Drill-hole
32.	Isis	Nothing left
33.	Johnson	Drill-hole with pipe and sphere
34.	Knee	Drill-hole with pipe and sphere
35.	Komo	Drill-hole with pipe
36.	Laser	Drill-hole with pipe
37.	Ledge	Drill-hole with pipe
38.	Lookout	Drill-hole with short pipe
39.	Lyell	Drill-hole with pipe
40.	Manzanita	Drill-hole with pipe
41.	Maricopa	Drill-hole
42.	Maricopa A	Drill-hole
43.	Mesa	Drill-hole with pipe
44.	Middle	USC & GS bronze disc
45.	Newton	Drill-hole with pipe
46.	Obt	USGS bronze disc

47.	O'Neill	Cairn with pipe in it
48.	Osiris	Nothing left
49.	Ottomar.	Drill-hole with pipe
50.	Parapet	Bronze disc
51.	Pattie	Drill-hole with pipe
52.	Perch	Drill-hole with pipe and sphere
53.	Pima	Bronze disc
54.	Phantom Ranch	Bronze disc
55.	Phantom USGS	Nothing left (corner of house)
56.	Phantom A	Drill-hole with pipe
57.	Phantom B	Drill-hole with pipe
58.	Phantom C	Drill-hole with pipe
59.	Phantom D	Drill-hole with pipe
60.	Phantom E	Drill-hole with pipe
61.	Phantom F	Drill-hole with pipe
62.	Phantom H	Drill-hole with pipe
63.	Phantom J	Drill-hole with pipe
64.	Phantom K	Drill-hole with pipe
65.	Plateau Point	Bronze disc
66.	Powell	Drill-hole with pipe
67.	Powell Point(USGS)	USGS Bench mark (bronze disc)
68.	Ra	Drill-hole with pipe
69.	Ribbon	Bronze disc
70.	Rowe (USGS)	Buried disc marked with iron pipe

71.	Set	Drill-hole with pipe
72.	Set A	Drill-hole with pipe
73.	Shiva	Drill-hole with pipe
74.	Shoshone	Bronze disc
75.	South Rim HQ 1	No permanent mark left
76.	South Rim HQ 2	No permanent mark left
77.	South Rim HQ 3	No permanent mark left
78.	South Rim HQ 4	No permanent mark left
79.	South Rim HQ 6	No permanent mark left
80.	South Rim HQ 8	No permanent mark left
81.	Sublime (USC & GS)	USC & GS bronze disc
82.	Sumner	Drill-hole with pipe
83.	Tiyo	Drill-hole with pipe and sphere
84.	Tiyo NW	Drill-hole with pipe and sphere
85.	Tonto	USGS bronze BM disc
86.	Transept	Drill-hole with pipe and sphere
87.	Transept (Lower)	Drill-hole with pipe and sphere
88.	Uncle Jim	Drill-hole with pipe and sphere
89.	Valhalla	Drill-hole with pipe
90.	Yaki	Bronze disc
91.	Yavapai	Bronze disc on top of concrete column
92.	Zoroaster	Bronze disc

Grand Canyon Survey

Types of Control

*occupied by Laser Ranger, **occupied by theodolite, ***prisms and target only

1.	Angel A	*	**		34.	Knee		**	
3.	Clear		**	***	35.	Komo		**	***
4.	Cheops	*	**		36.	Laser		**	***
6.	Confucius	*	**		37.	Ledge			***
8.	Corner	*			38.	Lookout			***
10.	Crystal	*	**		39.	Lyell		**	***
12.	Dragon	*	**		40.	Manzanita			***
13.	Dragon N	*	**		41.	Maricopa	*	**	
14.	Gorge			***	42.	Maricopa A	*	**	
16.	Grandeur			***	43.	Mesa	*	**	
17.	Greenland		**	***	44.	Middle (USC &GS)	*	**	
18.	Hattan	*	**		46.	Obi (USGS)	*		***
19.	Hermit	*	**		49.	Ottoman		**	***
20.	Hopi	*	**		50.	Parapet	*	**	
21.	Horsethief			***	53.	Pima	*	**	
23.	Howlands	*	**		54.	Phantom Ranch		**	***
24.	Indian Gardens	*	**		55.	Phantom "USGS"		**	
25.	Indian Gardens A			***	56.	Phantom A	*	**	
26.	Indian Gardens B			***	57.	Phantom B	*	**	
27.	Indian Gardens C			***	58.	Phantom C	*	**	
28.	Indian Gardens D			***	59.	Phantom D	*	**	
29.	Indian Gardens E			***	60.	Phantom E			***
30.	Indian Gardens F			***	61.	Phantom F			***
31.	Indian Gardens G			***	62.	Phantom H			***

Types of Control - concluded

63.	Phantom J		***	81.	Sublime (USC & GS)	*	**
64.	Phantom K	*	***	82.	Sumner	*	**
65.	Plateau Point	*	***	83.	Tiyo (USGS)		***
66.	Powell		***	84.	Tiyo NW		***
67.	Powell Point (USGS)		***	86.	Transept		***
68.	Ra	*	**	87.	Lower Transept	**	***
69.	Ribbon		**	88.	Uncle Jim		***
70.	Rowe	*	**	89.	Valhalla		***
71.	Set	*	**	90.	Yaki	*	**
73.	Shiva		***	91.	Yavapai	*	**
74.	Shoshone	*	**	92.	Zoroaster	*	**
75.	South Rim HQ-1		***				
76.	South Rim HQ-2		***				
77.	South Rim HQ-3		***				
78.	South Rim HQ-4		***				
79.	South Rim HQ-6		***				
80.	South Rim HQ-8		***				

Grand Canyon Map

Laser Observation Data

<u>STATION</u>	<u>ALTITUDE</u>	<u>TO</u>	<u>SLOPE DISTANCE</u>	<u>GRID DISTANCE</u>
Angel A	8145.51	Greenland	15,873.67	15,864.98
"	"	Hattan	21,217.09	21,095.68
"	"	Komo	10,711.73	10,705.18
"	"	Manzanita	14,219.41	14,212.37
"	"	Obi	16,796.04	16,786.37
"	"	Transept	12,625.63	12,619.41
"	"	Uncle Jim	7,612.65	7,608.32
"	"	Valhalla	12,583.41	12,577.12
Cheops	5386.60	Zoroaster	22,539.52	22,464.40
Confucius	7073.00	Laser	8,478.20	7,912.70
"	"	Ra - A	15,261.03	15,222.27
"	"	Sublime	10,763.35	10,751.75
Cremation		Phantom F	13,617.18	13,611.40
"		Phantom K	3,849.27	3,845.80
Crystal	3991.70	Dragon	26,476.62	26,464.89
"	"	Laser	13,571.53	13,567.52
"	"	Sublime	18,856.52	18,528.21
"	"	Ra - A	11,182.24	10,982.44
Dragon (North)	7661.10	Confucius	19,573.54	19,556.08
"	"	Sublime	23,812.35	23,800.86
"	"	Tiyo (NW)	8,927.41	8,918.81

LASER DISTANCES

GRAND CANYON MAP - LASER OBSERVATION DATA - 2

STATION	ALTITUDE	TO	SLOPE DISTANCE	GRID DISTANCE
Hattan	5967.20	Cheops	21,457.37	21,442.11
"	"	Ledge	14,892.35	14,875.79
Hermit	6650.40	Crystal	32,596.80	32,476.54
"	"	Sublime	50,982.09	50,954.14
"	"	Tiyo	49,543.95	49,510.11
Hopi	7042.953L	Cheops	18,922.83	18,842.34
"	"	Crystal	36,877.28	36,737.22
"	"	Pima	13,342.73	13,334.09
"	"	Ra	28,198.55	28,170.62
"	"	Ra - A	28,199.07	28,171.13
"	"	Set	18,320.25	18,283.75
"	"	Shiva	25,628.98	25,556.45
"	"	Sublime	53,234.55	53,209.83
"	"	Tiyo	39,371.32	39,346.84
"	"	Middle	21,803.29	21,792.58
"	"	Yaki	21,844.07	21,833.38
"	"	Yavapai	11,512.09	11,507.08
"	"	Powell Point/BM	1,237.70	1,237.25
Horsethief	6346.30	Mesa	26,824.89	26,772.86
Howlands	5571.00	Lyell	18,424.47	18,416.51
"	"	Knee	6,782.31	6,777.70
"	"	Ottoman	10,980.49	10,912.37
"	"	Clear	7,954.87	7,802.17

L = Leveled

GRAND CANYON MAP - LASER OBSERVATION DATA - 3

STATION	ALTITUDE	TO	SLOPE DISTANCE	GRID DISTANCE
Howlands	5571.00	Corner	22,099.99	22,083.99
"	"	Gorge	8,160.60	7,967.65
"	"	Obi	22,777.29	22,645.26
Indian Gardens Δ	3849.56L	Point A	1,344.36	1,341.23
"	"	Point B	1,097.71	1,095.14
"	"	Point C	615.98	615.55
"	"	Point D	840.89	839.79
"	"	Point E	1,720.80	1,716.16
"	"	Point F	924.22	922.34
Maricopa A	6994.93 (L)	Indian Gardens	8,776.94	8,188.93
Maricopa	6988.06 (L)	Hq - 1	5,901.11	5,898.56
"	"	Hq - 2	4,030.96	4,026.97
"	"	Hq - 3	1,988.92	1,981.68
"	"	Hq - 4	12,731.07	12,724.41
"	"	Yavapai	8,905.12	8,900.79
"	"	Hq - 6	10,281.16	10,276.40
"	"	Parapet	3,313.33	3,365.48
"	"	Hq - 8	2,993.75	2,991.40
"	"	Grandeur	7,239.28	7,236.08
Mesa	4836.70	Lookout	16,385.31	16,376.10
Middle	7259.908L	Hopi	21,803.29	21,792.58
"	"	Rowe	21,452.06	21,441.80
"	"	Sublime	70,751.20	70,719.75
"	"	Tiyo	46,154.87	46,131.28

L = Leveled

GRAND CANYON MAP - LASER OBSERVATION DATA - 4

STATION	ALTITUDE	TO	SLOPE DISTANCE	GRID DISTANCE
Parapet	6923.868L	Cheops	22,452.50	22,390.95
"		Maricopa A	3,367.90	3,365.48
"		Phantom F	22,074.61	21,888.37
Phantom A		Phantom B	4,148.42	4,164.56
"		Phantom C	6,422.85	6,418.87
"		Phantom E	3,982.81	3,965.01
Phantom C		Phantom Ranch	4,788.43	4,596.70
Phantom D		Plateau Point	5,143.03	5,130.32
"		Phantom E	4,825.36	4,824.84
"		Phantom A	6,067.79	6,052.87
"		Phantom C	3,979.18	3,971.34
"		Phantom B	7,149.30	7,142.94
"		Phantom J	4,167.96	4,166.29
"		Phantom H	4,232.02	4,230.76
"		Phantom F	4,292.38	4,291.14
Phantom K		Phantom B	4,516.47	4,512.58
"		Phantom F	12,100.45	12,091.65
"		Phantom A	3,421.34	3,418.87
Pima	6765.00	Crystal	30,358.83	30,220.50
"	"	Ra	25,242.73	25,223.20
"	"	Ra - A	25,229.73	25,210.17
"	"	Sublime	48,472.09	48,446.52
"	"	Tiyo	44,851.37	44,820.70

L = Leveled

GRAND CANYON MAP - LASER OBSERVATION DATA -- 5

STATION	ALTITUDE	TO	SLOPE DISTANCE	GRID DISTANCE
Pima	6765.00	Mesa	17,128.40	17,013.14
"	"	Hopi	13,342.73	13,334.09
Plateau Point	3780.53L	Sumner	13,983.61	13,911.41
"	"	Parapet	14,460.23	14,109.61
"	"	Yaki	16,115.57	15,730.01
"	"	Phantom C	4,074.90	4,072.49
"	"	Phantom A	10,052.91	10,049.65
"	"	Phantom K	12,707.87	12,703.09
"	"	Phantom F	8,143.51	8,134.12
Rowe	7066.857	Middle	21,452.06	21,441.80
"	"	Yavapai	11,160.76	11,156.02
Set	6016.40	Cheops	16,589.49	16,571.05
"	"	Ra - A	10,557.08	10,553.02
Shoshone	7278.50	Cheops	32,466.89	32,398.59
"	"	Sumner	25,291.66	25,192.39
"	"	Corner	14,172.52	13,976.06
"	"	Lyell	9,305.71	9,098.92
"	"	Howlands	23,499.73	23,427.93
Sublime	7457.50	Crystal	18,856.52	18,528.21
"	"	Ra - A	25,101.03	25,053.06
Sumner	5156.10	Lyell	27,746.50	27,736.27
"	"	Howlands	20,549.81	20,538.33
"	"	Phantom F	11,370.52	11,319.63

L = Leveled

GRAND CANYON MAP - LASER OBSERVATION DATA - 6

STATION	ALTITUDE	TO	SLOPE DISTANCE	GRID DISTANCE
Transept (Lower)	4774.30	Hattan	15,551.60	15,500.20
Yaki	7262.235L	Angel A	50,119.67	50,088.72
"	"	Hopi	21,844.07	21,833.38
"	"	Rowe	21,493.06	21,482.78
"	"	Sumner	20,018.98	19,900.29
"	"	Zoroaster	24,508.24	24,496.97
"	"	Phantom A	17,915.33	17,555.76
"	"	Howlands	25,691.01	25,624.79
"	"	Phantom F	22,707.76	22,481.53
Yavapai	7082.225L	Hopi	11,512.09	11,507.08
"	"	Phantom Ranch	16,635.61	16,000.17
"	"	Ribbon	39,016.76	38,857.59
"	"	Rowe	11,160.76	11,156.02
"	"	Middle	10,292.05	10,285.93
Zoroaster	7121.70	Obi	17,321.00	17,294.21

L = Leveled

Preliminary Trail Distances

(subject to minor adjustments,
correct probably within less than 100 ft.)

Bright Angel

First Rest House	1.58 miles
Second Rest House	3.01
Indian Gardens	4.61
Pipe Creek Crossing (below switchbacks)	6.77
River Trail Fork (just below Rest House)	7.74
River's edge	7.80

<u>River Trail</u> (added to Bright Angel):	<u>From Fork</u>	<u>Total</u>
S. end of Pipeline Bridge	+ 1.18	8.92
Junction w/Kaipab Trail	+ 1.46	9.20
To Phantom Ranch Dining Room	+ 1.94	9.68

South Kaibab Trail

Cedar Ridge	1.45
Top of Switchbacks	2.93
Tonto Trail Junction	4.42
The Tip-Off	4.59
S. End of Bridge	6.34
Inner Canyon Junction	6.73
Phantom Ranch Dining Room	7.23

North Kaibab Trail

Tunnel	1.73
Bridge	2.68
Top of Cliff Zig-Zags	3.60
Campground Fork	4.72
Bridge	5.43
Cottonwood (Main Bldg.)	6.84
Ribbon Falls (S. Fork)	8.34
Phantom Creek	12.59
Phantom Dining Room	13.69
Inner Canyon Junction	14.18

Hermit Trail

Hermit Basin (Waldron Trail Jct.)	1.30
Crest of Hermit Gorge (sign)	1.70
Lookout Point	4.01
Top of Cathedral Stairs	5.40
Tonto Trail Junction	6.63
Hermit Creek (first crossing)	7.65
Colorado River	8.96

Tonto Trail

Bright Angel to South Kaibab (Checked twice H. Sharpe 21821/21744)	4.13
Bright Angel to Hermit - Tonto Junction Henry Sharpe - Unchecked	11.84

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