Bradford Washburn's
Keynote Speech

MOUNT EVEREST'S SURVEYING HISTORY

Trimble Navigation's Users Conference
Sunnyvale, California
October 15, 1998

It's a pleasure and a real honor to be asked to share with you the complex and exciting history of Mount Everest's position and altitude ----- in which, during recent years, Trimble has played such an important role.

My own interest in Everest began almost exactly seventy years ago, on the evening of October 9, 1926 ----- when I listened, spellbound, to a lecture by Captain John Noel on the great 1924 British attempt to climb Everest, on which George Mallory and Andrew Irvine lost their lives. Sixty years later, on December 20, 1984, our National Geographic team flew over Everest in a Learjet at an altitude of 39,000 feet and took the hundreds of stereo-vertical aerial photographs which soon yielded the first detailed, large-scale map of the Everest area ----- published two years later by the National Geographic Society and my own Boston Museum of Science.

The roots of all the surveying that has taken place on and around Everest during the last century-and-a-half go back to the work of Sir George Everest --- the preeminent figure of the great Trigonometric Survey of India, until his retirement in 1843. A diagram of this incredible undertaking is displayed here for all of you to see ----- and marvel at.

Sir George's successor was Sir Andrew Waugh ----- and it was under his direction that the first position and altitude of fabled "Peak Fifteen" were announced to the world in 1850.

During the year before that, the great peaks of the Eastern Himalaya had been observed from the northern edge of the Indian network by Mr. J. O. Nicholson, using a special 24-inch theodolite. All of these survey stations were at altitudes of only 200 feet above the sea ----- and all were located at distances between 108 and 118 miles from Peak Fifteen.

The unweighted mean of the altitudes computed from these observations resulted in such an amazing figure that Radhanath Sikdar, the Chief Computer, is recorded to have rushed, breathless, into the office of Sir Andrew and exclaimed, "Sir, I have discovered the highest mountain in the world !!!". ----- Peak Fifteen was 29,002 feet high.

The six altitudes that yielded 29,002 were simply added together and the total divided by six ----- a real "unweighted mean".

The data that produced this result were:

FROM	DISTANCE (in miles)	ALTITUDE (In feet)
Jirol	118	28,991.6
Mirzapur	108	29,005.3
Janjipati	108	29,001.8
Ladnia	108	28,998.6
Harpur	111	29,026.1
Minai	113	28,990.4

Unweighted Mean = 29,002 feet

In the midst of these observations, computations and discussion, sincere efforts were made to name this huge peak. Because both Tibet and Nepal, on whose borders the mountain was located, were virtually impossible to enter, and no local names could be discovered ----- though today they are well known, respectively, as Chomolangma and Sagarmatha ----- "Goddess Mother of the World" and "Forehead of the Sky" ----- So, in 1854, Sir Andrew Waugh suggested that it be named Mount Everest in honor of the recently-retired Surveyor General ----- and this met with instant and enthusiastic approval.

29,002 did not last long before professional criticism arose and new efforts were made to do the job better ----- or at least to do it differently. In the period 1880 - 1902 a new series of observations was made from the Darjeeling area ----- from survey-stations that were much higher than before (8,500 - 11,900 feet) ----- but still a long way off ----- 85 to more than 100 miles east of Mount Everest. This new altitude of 28,141 feet was also the unweighted mean of six figures.

The data that produced this result were:

FROM	YEAR	DISTANCE (In miles)	ALTITUDE (In feet)
Tiger Hill	1880	108	29,140
Suberkum	1881	88	29,141
Suberkum	1883	88	29,137
Sandakphu	1883	90	29,142
Phalut	1902	85	29,151
Senchal	1902	109	29,134

Unweighted Mean = 29,141 feet

These more recent data were not only from points much higher than the original observations, but the new computations involved considerably more sophisticated corrections for atmospheric refraction, as well as deflection of the vertical.

The problems that confronted these ancient surveyors are beautifully described in the famous book, **Mount Everest: The Reconnaissance 1921** (pp.10 - 12).

> "The attraction of the great mass of the Himalaya and Tibet", says Mr. Burrard, "pulls all liquid towards itself, as the moon attracts the ocean ----- and the surface of the water assumes an irregular form at the foot of the Himalaya. If the ocean were to overflow Northern India, its surface would be deformed by Himalayan attraction.
>
> The liquid in surveyors' levels is similarly affected and theodolites cannot consequently be adjusted. Their plates, when leveled, are still tilted upward toward the mountains, and angles of observation are too small, by the amount that the horizon is inclined to the tangential plane.

> At Darjeeling the surface of water in repose is inclined about 35 seconds to this plane; at Kurseong about 51 seconds -------- For this reason, all angles of elevation to Himalayan peaks measured from the plains, as Mount Everest was measured, are too small ----- and, consequently, all of our values of Himalayan heights are too small. Errors of this nature range from 40 to 100 feet." ----- (*close quote*).

Another important correction which these early surveyors of Everest took into careful consideration was the now-well-known fact that the exact top of Mount Everest is always a snowdrift. Its altitude is always somewhat higher after the Monsoon snowfalls of June, July and August ---- - and significantly lower in the period from December to June, after the great "winter winds" have blown away all of the summer snowfalls.

The new turn-of-the-century altitude of 29,141 feet never seems to have had the universal appeal that its curious predecessor 29,002 had enjoyed. However, big and significant changes did, indeed, take place in the period 1952 - 1954 ----- For the first time in all history, in the late 1940s, the Survey of India was invited to enter Nepal ----- to provide a triangulation network to control the irrigation program for the huge,

proposed Kosi Dam. This extraordinary new survey was managed by Mr. B. L. Gulatee, Director of the Geodetic and Research Branch of the Survey of India, whose remarkable Technical Paper Number 8, of 1954, The "Height of Mount Everest", is now a classic in all survey history.

Height of Mount Everest

Station (1)	Season (2)	Distance (3)	Height of station (4)	Spheroidal height difference (5)	Sum (6)	δN = Geoidal rise between the station and Mount Everest (7)	Geoidal height of Mount Everest = (6)—(7) (8)
		miles	feet	feet	feet	feet	feet
Mayâm ..	1952–53	47	10948·1	18145·6	29093·7	55	29038·7
Lâori Danda ..	1952–53	42	11877·4	17206·2	29083·6	51	32·6
Aisyâlukharka..	1952–53	42	8670·3	20412·7	29083·0	52	31·0
Chhulyâmu ..	1952–53	41	10160·4	18920·1	29080·5	50	30·5
Pike Sub. ..	1952–53	41	12059·3	17011·8	29071·1	47	24·1
Sollung ..	1952–53	36	11657·9	17411·4	29069·3	40	29·3
Lower Rauje ..	1952–53	30	13357·4	15700·8	29058·2	32	26·2
Upper Rauje ..	1952–53	29	14762·1	14293·1	29055·2	30	25·2
Sollung ..	1953–54	36	11657·9	17409·9	29067·8	40	27·8
Pike Sub. ..	1953–54	41	12059·3	17015·3	29074·6	47	27·6
Upper Rauje ..	1953–54	29	14762·1	14290·7	29052·8	30	22·8
Chhulyâmu ..	1953–54	41	10160·4	18917·8	29078·2	50	29028·2

A system of "crossed-quadrilaterals" carried the Indian network northward for 40 miles from Ladnia and Harpur to two new stations in Nepal, about the same distance south of Mount Everest. From these points, a very complex array of new stations was developed ----- from which more quadrilaterals went Eastward for nearly 100 miles to Darjeeling ----- and others continued to go Northward toward Everest.

This system came to an end in an extraordinary nine-sided figure with two center-points. The northernmost of these stations was called "Upper Rauje" ----- and it was only 29 miles south of Everest !! From ten of these points, new angles were observed to Mount Everest ----- all during the chilly winter months, when it was correctly assumed that Everest's summit would be at its lowest altitude.

These angles of 1953-4 were all observed with Wild T-2 and Tavistock theodolites ----- neither of which is considered a "first-order" instrument. But scores, possibly hundreds of repetitions were made ----- to result in what we today might consider to be "semi-first-order" figures.

However, to do a modern field-check of the accuracy of this data, in the fall of 1996, I asked Buddhi Shrestha, the recently-retired Surveyor General of Nepal, to send two of his most-reliable young men to Upper Rauje, with my Swiss Wild T-3 Geodetic theodolite, to re-observe those 1954 angles "with great care". They did exactly this and made forty-five repetitions of that vertical angle throughout the day ----- November 23, 1996 ----- from long before dawn until well after dusk.

The original Gulatee angle was 5--05--02.45 ----- their new angle was 5--04--59.36. That difference in Everest's altitude would be less than a single foot !!! What amazing work those fellows did almost a half-century ago! Their figures resulted in the presently-accepted position and altitude of Mount Everest:

North Latitude: 27--59--15.85

East Longitude: 86--55--39.51

Altitude above mean Sea-Level: 29,028.81 feet (8848m)

At one of these key stations, exactly 30 miles south of Mount Everest, the observers encountered the greatest deflection of the vertical ever recorded anywhere on earth: 71 seconds of arc.

Anyone who contemplates undertaking a new survey in the Everest area ----- or, indeed, anywhere in the Himalaya, should read every word of Gulatee's great report, and then move onward with a new program aimed at improving and modernizing results.

Nobody now made any significant effort to question the height of Mount Everest for over twenty years ----- until, in 1975, the Chinese climbed to its summit and, for the first time, erected a survey target there ---- one that was strong enough to survive those incredible winter gales for several years.

This Chinese survey was a massive effort, which involved a system of levels all across both China and Tibet ----- an overall distance of no less than 1500 miles. This tour-de-force is described in G. Dashang's report of 1979 and J.Y. Chen's of 1980. The Chinese surveyors worked up onto the Northern ramparts of Everest to altitudes as high as 23,000 feet, set up a new bench-mark at Rongbuk, 16 miles North of Everest, and observed angles to the new summit target from no less than nine different stations in Tibet. They also carried out an exhaustive study of the local geoid.

Amazingly, the new Chinese XYZ of Everest was almost exactly the same as Gulatee's ----- but they also made it clear that their figures were based on a bedrock ledge only nine-tenths of a meter beneath the highest snowdrift. This snow-depth will soon reappear as a vitally-important part of the Everest-altitude story.

In 1987 a completely-new system of surveying entered the Everest scene ----- the Global Satellite System, which we all fondly call "GPS". It not only involved Mount Everest, but also "K-2", the second-highest peak on earth, well known to be 28,250 feet high ----- some 800 miles Northwest of Everest in the Karakoram Himalaya. This altitude had been established way back in the year 1854 by a British surveyor, Col. Thomas G. Montgomerie. Nobody had ever bothered to dispute this figure, as the peak was so far away and its altitude was so much lower than Everest's.

All of a sudden, in March of 1987, Dr. George Wallerstein, a teacher of Astronomy at Seattle's University of Washington, reported that, based on doppler-transit satellite and theodolite data, K-2 was 11 meters higher than Everest ----- 29,064 feet !! Despite the fact that this new altitude depended on only one pass of one satellite and a very sloppy local survey in Tibet, the Italians were thrilled. They had made the first ascent

of K-2 in 1954 and Professor Ardito Desio, the leader of that first-ascent team, quickly assembled a group of expert surveyors ----- to re-survey both K-2 and Everest as fast as possible, during the summer of 1987. They properly used GPS techniques, normal triangulation procedures and top-notch instruments to speedily re-compute the heights of both peaks. To their horror and dismay, their figures not only confirmed Everest's dominance, but widened the difference between the two peaks substantially !!

This was very disappointing to the Italians, but it whetted Professor Desio's interest in the true altitudes of both K-2 and Mount Everest. However, he and his friends laid low for several years, constantly watching what others might do.

In May, 1980, I retired from my many years of responsibility as Director of Boston's Museum of Science ----- and my lifelong interest in Mount Everest tempted me to make a new and detailed large-scale map of the Everest region. I had mapped Mount McKinley in Alaska, as well as the Grand Canyon for the National Geographic Society. Swissair Photo Surveys of Zurich were among my best friends ----- and the Swiss are the world's best cartographers. Together, we agreed enthusiastically to re-map Everest.

We didn't have the funds to develop a huge brand-new GPS survey for ground-control in the area. This seemed unnecessary anyway, as we secured nearly 90 points of what seemed to be reliable control from the small-scale existing maps of the area: those by Morshead and Wheeler in 1921, Spender in 1935, Schneider in the 50's and our special friend, Wang Wenying of China in the 1960's. We then managed to get NASA to take marvelous stereo-photos of all of our area from space in the falls of 1983 and 1984.

Finally, Swedair and Swissair Photo took 360 stereo-vertical pictures of this area from an altitude of 39,000 feet on December 20, 1984. The rest is history: Swissair Photo's expertise soon produced the first large-scale,1:50,000 map of the Everest region in the fall of 1988 ----- and the National Geographic Society immediately circulated them to all of their 11 million members, worldwide.

All of this relatively-recent surveying and mapping has assumed that Everest is exactly where the Surveys of India and China have agreed that it is. This has been the only more-or-less indisputable fact ----- though the details of maps have vastly improved, as the aircraft that carried ever-more-sophisticated cameras have been able to fly higher and higher.

Very recently, however, the plate-tectonics experts ----- who might well be called "grandchildren" of Alfred Wegener, the great German Geophysicist of the early part of this recent century ----- entered the Everest arena. They have emphasized their belief that what we now call India probably started as a part of Antarctica!

Allegedly, millions of years ago, it broke away from its moorings and started to move northward, finally colliding with Asia. However, this was a very different kind of collision from the one that formed Europe's Alps, in which the colliding plate was thrust OVER Europe. ----- India dove UNDERNEATH Asia. This steady northward movement of a whole continent resulted in the uplift of the great 800-mile-long mountain range that we now call the Himalaya ----- and, as it continued its northward movement, it also created an immense, lofty plateau in West China. We call this Tibet.

Working with a miraculous array of data arising from the study of global satellites, today's geophysicists have been focusing their interest on the Himalaya, no longer to make better maps of it, **but to study the rate at which the huge peaks of the Himalaya are still going up** ----- not at all like our ancient, dead Appalachian Range.

Among the outstanding leaders of these plate-tectonics studies have been Dr. Roger Bilham, Professor of Geophysics at the Boulder campus of the University of Colorado and his most-competent graduate students. In 1991, he launched a long-range program on this subject. I am proud to consider Roger as one of my best friends ----- and, at the beginning, I helped him to establish close and friendly relationships with the top surveyors of both Nepal and China.

In the spring of 1991 and again in 1993, Michael Jackson, **now of Trimble**, and also one of Bilham's best students ----- naturally working with Trimble equipment ----- established GPS stations at Lukla, Namche and Pheriche. And two other Bilham students, Paul Bowden and Freystien Sigmundson, set up shop at Rongbuk, Tingri and Lhasa in Tibet.

In very recent years, two more Bilham men, Fred Blume and David Mencin, have added a score of new GPS points to a system which now extends all the way from the northern edge of the Survey of India deeply into China ----- a total now of 32 stations, all trending northward along the western edge of the 87th meridian of longitude. Roger Bilham's ability and his capacity to enthuse others has resulted in a huge amount of new and useful fieldwork throughout Nepal.

While this GPS explosion was going on, I thought that it would be interesting to secure some very-precise vertical theodolite angles to Everest's summit from a number of points much nearer than Gulatee's Upper Rauje. In the winter of 1992, Nepal's Survey Department constructed a very solid concrete meter-high observing stand just above the town of Namche Bazar. That May, Amir Shakya of this department and I, made a long succession of Wild T-3 vertical angles to Everest, now only 18 miles away.

We also worked closely with a climbing team of Alpine Ascents International, who installed two laser-prisms for us right on top of Everest. They also drove a 90-inch set of aluminum pipes vertically into the snow beside the prisms --- and discovered that one must go down much deeper than that before hitting bedrock atop Everest.

We measured a laser slope-distance to those prisms of 97,295.90 feet, a T-3 slope-angle of 10--09--43 ----- and then repeated a similar program at a new GPS point right beside the famous Thyangboche Monastery: slope distance of 14,700 feet at an angle of 12--01--45. These angles were all measured to the nearest **second** of arc.

The exciting thing about these distances and angles is that they have not been measured to a snowdrift ----- but rather to a brilliant, pinpoint ruby laser-prism exactly 15 inches above Everest's snowy summit. That snow-top remained at exactly the same height for four years ----- until the prisms were recently stolen in the highest burglary in all history !!

In 1992, while all this was taking place, little did we realize that 95-year-old Ardito Desio had big plans in mind ---- nor did he seem to be interested in what we had been doing.

During 1991 and 1992, Professor Desio, working with a team of top Italian GPS and Survey experts, financed by the Italian National Research Council, Leica, and Baume et Mercier of Geneva, were planning a massive GPS and laser attack on Everest in the early fall of 1992.

The Chinese set up survey teams at Rongbuk, as well as three other carefully-selected points North and Northeast of Everest. Simultaneously, three Italian stations were occupied in the Khumbu area of Nepal, closely adjacent to the extraordinary new Italian Research Pyramid at Lobuche.

Then, on September 28, 29 and 30, this carefully-planned scenario was activated. GPS, laser and theodolite measurements were simultaneously carried out ----- to link the top of Everest to this amazing array of stations. Even weather-balloons were used to determine temperatures-aloft along the laser slope-lines! Wild and Leica equipment of the most modern type was used in this survey-blitzkrieg ----- and even a top Chamonix guide made two climbs to the top of Everest to install a special survey target and its array of laser-prisms. This entire program was orchestrated beautifully by Professor Giorgio Poretti of Trieste.

The results of this campaign agreed perfectly with the data of Gulatee, but one cannot measure the **micro-changes of plate-tectonics** unless the stations are at points drilled in bedrock ----- and this September data all ended at Everest's **snow**-summit, when it is at the highest elevation in the year!

Hence our determined GPS efforts since 1995 have been to establish the two final ultra-high-altitude stations needed to complete Roger Bilham's extraordinary chain from India, over Everest and deeply into China. These points are at Everest's 25,800-foot South Col and at the Barry Bishop Ledge, highest bedrock in the world ----- only about a 100 feet South of Everest's true snow summit, and only 40 feet lower.

The lowest of these stations, located at the South Col, was installed in 1995 by expert guide Peter Athans ----- and we've now also observed there in 1997 and 1998, for a grand-total of well over 100 hours. This position is presently known to be well-within the scope of a spherical centimeter. During the first two sessions, we used Trimble 4000 SSE GPS receivers. In 1998, a new Trimble 4800 did the job.

This year, Wally Berg of Copper Mountain, Colorado was our team's leader, Charles Corfield was Science Leader, and David Mencin was our number one GPS man at Base Camp. Eric Simonson and Greg Wilson were also guides ----- and very-special power was generated by eight Sherpas who, as a group, had climbed Everest no less than 30 times!!!!

Their scoring-punch was delivered on May 19 and 20. On the 19th everyone but Wally climbed to the crest of Everest's South Summit, where, at an altitude of 28,600 feet, they cached one of our 4800s, as well as lots of oxygen, lithium batteries and miscellaneous gear needed for a summit ascent. Late in the evening of May 19th, Wally Berg started a speedy solo climb right up to the top of Everest. He reached the highest bedrock of the Barry Bishop Ledge at dawn and bored two deep holes in the rock with hammer and chisel. These were needed to accept the "Lok-Bolts" that

held our last GPS station firmly in place. Our 4800 was screwed onto its bolt very early that morning ----- and left there, running with its little lithium battery ----- to be picked up five days later by a Singapore ascent-team, and brought back safely to Base Camp, where David Mencin accepted it with open arms!!!

At Base Camp, David had been through a frantic five days. Chinese Dr. Chen had given us the radio-frequencies of their Rongbuk GPS station ----- and, throughout this period, we were able to run Bishop Ledge, South Col, Rongbuk, our station at Kala Pattar and the Italian station at nearby Lobuche ----- all simultaneously ----- a miracle of management ----- much of which was achieved at an altitude well above 17,000 feet ----- and without the use of supplementary oxygen.

We now have fulfilled our promise to Roger Bilham and have successfully completed the last two stations of his large GPS network. BUT we still have one very interesting point to visit with GPS ----- the snowy true summit of Everest, where we have still to run one of our treasured 4800s --- or maybe something newer and even fancier than that, if Trimble's genei have cooked it up before next May!

This is, indeed, of trifling scientific importance, but the rest of the world still wants to know exactly how high its very highest point is **above sea-level** !! In an easy hour we can determine the difference in altitude between that and Barry Bishop's ledge, but these elevations will be in WGS/84 data ----- not above Sea-Level. Everest's elusive GEOID must still be calculated ----- and then, finally, what on earth will be Everest's REAL SEA-LEVEL ALTITUDE??

Before we dare to report a new Sea-Level XYZ for Everest's highest point, all of our field data must be coordinated with Dr. Muneendra Kumar of the USA's "NIMA", the world's top Geoid expert, who, in turn, will coordinate them with Dr. J.Y. Chen of China and the Surveyor General of Nepal, so that this will be a truly international figure. Well over a year of field work and computations still lie ahead of us.

Heartfelt congratulations to all of the members of our Everest 1998 team, as well as to all of those others who have brought us to this exciting moment ---- **but, above all, our gratitude goes to the miracle-workers of Trimble Navigation, especially to Chuck Maniscalco, the key engineer of the 4800. Without the genius of these fellows, none of us would have the slightest idea about where anything is anywhere !!!**

Now, if I can have the lights turned off, I want to conclude my remarks by showing you a series of slides ----- on the ground and from the air ---- which will give you a better feel for the magnificence, the size and the beauty of Everest and its surroundings.