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THE HIGHEST POINT IN PERÚ- A SHORT HISTORY ON THE SURVEY OF HUASCARÁN

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The highest point in Perú, Huascarán Sur in the Cordillera Blanca, has been measured several times yielding different summit elevations. The summit of Huascarán Sur is commonly cited as 6,768 m in elevation above sea level, but most publications do not reference the year of the survey or method used to determine the elevation. In contrast, the Carhuas 1:100,000-scale topographic quadrangle map by the Instituto Geográfico Militar de Lima, published in 1973, placed the elevation at 6,746 m. When and how these measurements were taken becomes especially interesting with respect to the general evolution of surveying in Perú and historic perception about the location of Perú's highest peak. Determining an accurate and precise summit elevation has additional implications for the neotectonic study of the active Cordillera Blanca normal fault.

Topographic surveys of mountains generally result in multiple measurements through time, using different methods or instruments, and produce a variety of estimates on the height of major peaks. For example, Mount Whitney of North America had at least 19 measurements made by several geologists and geographers followed by mapping studies of the United States Geological Survey, and not until 1994 was the most precise value of 14,491 feet completed (e.g., Moore, 2000, p. 122). These surveying variations are also certainly present in the reported height of Huascarán as demonstrated in the above peak elevations, and in Figure 1 for which the remaining of this paper examines.

The highest point in Perú during the 19th century reconnaissance period was generally held to lie in the Cordillera Blanca and/or the summit of Coropuna in southern Perú, however, no estimates were given on the heights nor for which peak stood out as the greatest. The 1839 inland expedition by Charles Wilkes (1845) gave several elevations through questioning of guides. For example, Cerro de Pasco was reported at 3,960 m (actual 4,338 m). This suggests that barometers were in use in the Andes by this time.

Directly measured elevations in Peruvian Andes were not widely available until published in several plates by Paz Soldan (1865). In these maps the Cordillera Blanca is illustrated without naming the peaks or placing estimates on the elevation of the range. However, in what is perhaps the first comprehensive comparison of elevations, a table and illustration in Plate LXIII «Cuadro general de Alturas comparativas del Perú» by Paz Soldan (1865) gives some sense of elevations: Misti 6,600 m (778 m above actual 5,822 m), Lago de Junin 4,063 m (17 m below actual 4,080 m), Cerro de Pasco 4,352 m (14 m above actual 4,338 m), Huancavelica 3,756 m (98 m above actual 3,685 m), and finally, Pico de Sehama 6,934 m was shown as being the highest. This last peak most likely refers to Sajama (6,522 m), the highest mountain of Bolivia. Apart from overestimating the highest point and including a Bolivian peak in the summary of Perú, from these values one may surmise that most of the summit elevations were not directly measured by barometer because they greatly miss the mark. In contrast, the elevations reported at the pueblos are fairly close to modern values, suggesting that at these locations barometer readings were indeed taken. The errors in early barometer measurements in Perú can be explained by technical difficulties in calibration and equipment failure (see Raimondi, 1874, chapter VII).

The first highly reliable surveys in Perú were made in advance of the Central Railway, amongst others, constructed between 1870 and 1893 from Lima to La Oroya. The triangulated elevations of Huascarán Sur 6,721 m and Norte 6,668 m reported in Raimondi (1873) were made by Hindle, a surveyor for the proposed Chimbote to Huaraz railway, which in 1912 extended only as far as Huallanca. A base line using three control points was used to survey what Raimondi (1873) called the mountain «Cerro de Huascan». In 1874 Raimondi referred to the summits east of Yungay as both the Cordillera Nevada and the Cordillera de Yungay; and during a trip to Laguna Llanganuco informally described the mountain as «el enorme nevado con dos picos.» Likewise, his 1880 Mapa del Perú labeled the mountain as «Nevados de Huascan», marking its elevation at 6,721 m. This same map series places Coropuna at 6,949 m, representing it as the highest point in Perú. Eventually, Raimondi eventually settled upon the name of Huascarán.

In 1904 Charles R. Enock, a British explorer and mining engineer, made an attempt to ascend the mountain. He only climbed to the 5,020-m mark, but made a triangulation of Huascarán at 6,760 m (Markham, 1905; Enock, 1907). Methodology, such as location and control

of base points, instruments used, and errors in survey were not reported. In any event, his measurement was remarkably close and completely overlooked or ignored by all subsequent surveyors of the mountain.

Huascarán Norte was first climbed in 1908, after two previous failed attempts in 1906 and earlier in 1908, by the North American A. Peck accompanied by two Swiss guides R. Taugwalder, and G.zum Taugwald. Some debate remains about the account of the ascent (Kinzl and Schneider, 1950). A mercury barometer was used to directly measure the elevation at the Garganta Col, which lies between the two main summits, at 6,095 m (80 m above actual of ~6,015 m). The barometer was not taken to the summit, and later Peck (1909; 1911) gave an exaggerated estimated of the summit elevation at >7,010 m and probably closer to 7,300 m as based on grade of the slope and time of ascent. Her estimate compounded the 80 m faulty recording taken at the Garganta Col. Peck's (1909) reported elevation spurred in the same year a commissioned survey by Monsieur de Laminat of the Societe Generale d'Etudes et de Travaux Topographiques (SGETT), Paris. Triangulation of the summits using a theodite gave elevations of no greater than 6,763 m for Huascarán Sur, and 6,650 m for Huascarán Norte (Workman, 1910). The survey used four control points along río Santa, making a base 1,600 m long that was measured twice with a 50 m steel tape. Elevation of the control points was established by a leveling survey running up from the coast at Casma. This part of the survey included directly measuring an average sea level. Accuracy of the elevation reported for Huascarán Sur was estimated to be within 10 meters. Their estimated error is consistent with both the measurements by Enock and the currently most cited elevation of 6,768 m.

In 1909 a North American expedition placed aneroids on the summit Coropuna, and then triangulated the elevation at 6,615 m (today considered to be at 6,425 m), establishing that it was not the highest point in Perú (Bingham, 1922). This measurement is important when taken in consideration with the above surveys of Huascarán because the location of the highest point of Perú had finally been determined.

Steinmann (1910; and figure reproduced in Steinmann, 1929) showed a cross section through Huascarán, giving the summit elevation at 6,668 m. Despite these previous surveys, McLaughlin (1924) gave the elevation of Huascarán at 6,614 m without citing a source or method of determination.

The higher of twin summits of Huascarán was not climbed until 1932 by the German and Austrian Alpine Club expedition with members including H. Bernard, P. Borchers, E. Hein, H. Horlin, and E. Schneider. These mountaineers were part of a climbing and cartographic survey conducted in the years 1932, 1936, and 1939, resulting in the first topographical maps of the Cordillera Blanca (Borchers, 1933a, 1933b, 1935; Kinzl, 1940). Photographs from these expeditions are beautifully illustrated in the 1950 book *Cordillera Blanca Peru* by Kinzl and Schneider. The 1932 expedition produced the most cited elevations for major peaks in the range. The topographical surveys by DOeAV (Deutscher und Österreichischer Alpenverein) reported the elevation of Huascarán Norte at 6,655 m and Huascarán Sur at 6,768 m (Schneider, 1969). For both summits a uniform 5 m increase from the SGETT survey.

The DOeAV terrestrial photogrammetry techniques had the vertical control based on triangulation points surveyed by the Servicio Geográfico del Ejercito (SGE) in 1934. These Peruvian points are not separately distinguished in their maps, which do show all the survey points and photogrammetry stations. However, the amount of vertical error inherent in photogrammetry was not discussed in their various published maps. In addition, these errors would be cumulative with the surveying errors of the base triangulation points. One may reasonably wonder if the control points reported by the SGE were the same that were surveyed in the early 1870's for the proposed railway to Huaraz. If this is the case, then the vertical control used by the DOeAV would be the same as that reported in Raimondi and Enock. Many questions remain about their DOeAV survey from incomplete reporting on methodology and errors. The DOeAV (e.g., Kinzl, 1940; Kinzl and Schneider, 1950) seem to have completely been unaware or not willing to acknowledge the previous, and fairly accurate, surveys reported in Raimondi (1873), Enock (1907), and Workman (1910).

In 1964 an updated 1:25,000-scale topographical survey of Huascarán Norte by DOeAV, titled *Nevada Huascarán, Cordillera Blanca, Perú*, also gave the summit at 6,768 m. This map, expertly drawn with 20-m contour interval and even illustrates crevasses in the glaciers, shows just a detailed part of the range focused on the Huascarán summit group. The map does not specifically state whether or not it represents new field data, or simply reprocessing the data from the 1932 survey. However, it does report the triangulation points for vertical control were from the Instituto Geográfico Militar; whether or not these are new survey points or old ones with the new name of IGM replacing SGE remains unclear. Kretschmer (2003) stated that the area of Huascarán was resurveyed in the 1960s as a result of debris-flows at Yungay, and general results from this survey were reported in Schneider (1969). This map marks about 48 triangulation points used in the survey.

It is interesting to note that while the summit elevation of Huascarán Sur remains the same from the earlier maps, elevations reported in the 1964 Huascarán map for other main features have changed. For example, elevations for Yungay, Mancos, La Garganta, Huascarán Norte, and Nevado Chopicalque on the 1932 map are 2,535, 2,570, 6,015, 6,655, and 6,400 m, respectively. In the same order of features, the heights on the 1964 map are 2,538, 2,517, 6,010, 6,654, and 6,354 meters. If the 1964 map includes new data, then the elevation changes between the two maps for La Garganta and Huascarán Norte can be explained by changes in snow thickness and glacial

movement. If the 1964 map reprocessed the 1932 data, the changes must be due to differences in methodology and drafting. In either case, one would expect the elevation of Huascarán Sur to vary accordingly. The variations in the above listed points are not systematic, in other words, they do not reflect only a shift in the benchmarks used. It appears that the various heights reported for Huascarán Sur all were derived from the 1932 survey. If data was reprocessed or reacquired, the reported value of 6,768 m is very unlikely to have been updated. Perhaps the DOeAV did not want to confuse the height of the peak by changing it, or did not want to lower the elevation if subsequent surveys showed it to be less.

The 1973 topographic 1:100,000-scale quadrangle map of Carhuas by the Instituto Geográfico Militar (IGM) de Lima reported a significantly lower elevation of 6,746 m for Huascarán Sur, which is 22 meters less than that of the DOeAV surveys. Despite this work being the most recent, subsequent publications have keep the earlier elevation by DOeAV The Carhuas sheet places the elevation of Huascarán Norte at the same elevation of 6,655 m as the DOeAV maps. Granted that the 1964 DOeAV elevation is closer to the 1909 SGETT survey. No apparent discussion on the errors, methodology, and reason for disregarding the more recent IGM elevation has not been explained in the popular literature (e.g., Ricker, 1977; Sharman, 1995; Gómez and Tomé, 1998; Johnson, 2003). Ricker (1977) does list the peak elevations from both the DOeAV and IGM surveys. It should be noted that Bonnot (1984) used the IGM elevation for Huascarán, which was probably more a matter of convenience due to base maps available rather than making a comparison of previous surveys and selecting the better value. The DOeAV maps are more widely published, and therefore more often cited than the IGM survey.

The 1973 IGM map of Carhuas was made by a completely different methodology, using early 1960s black and white aerial photography, acquired by the United States Air Force, as stereographic pairs in the determination of vertical altitude using the parallax method (e.g., Ray, 1960). Accordingly, this approach should yield different values than the terrestrial photogrammetry and triangulation methods of earlier surveys. The summit elevation of Huascarán is not the only change between the different surveys. The IGM map places Hunadoy Norte at 6,350 m, which is 45 meters less than the DOeAV maps. Nevado Chopicalque is shown as 6,354 m, which is the same as the 1964 survey and 301 m lower than the 1932 survey. Finally, for the pueblo of Mancos the 1964 DOeAV map gives its elevation at 2,517 m, which is 11 m lower than shown on the IGM sheet. These variations are non-systematic and must reflect differences in topographic cartography between the various surveys.

The summit of Huascarán is commonly covered in snow, comprising a surface that probably changes in elevation by several meters depending on climate, wind,

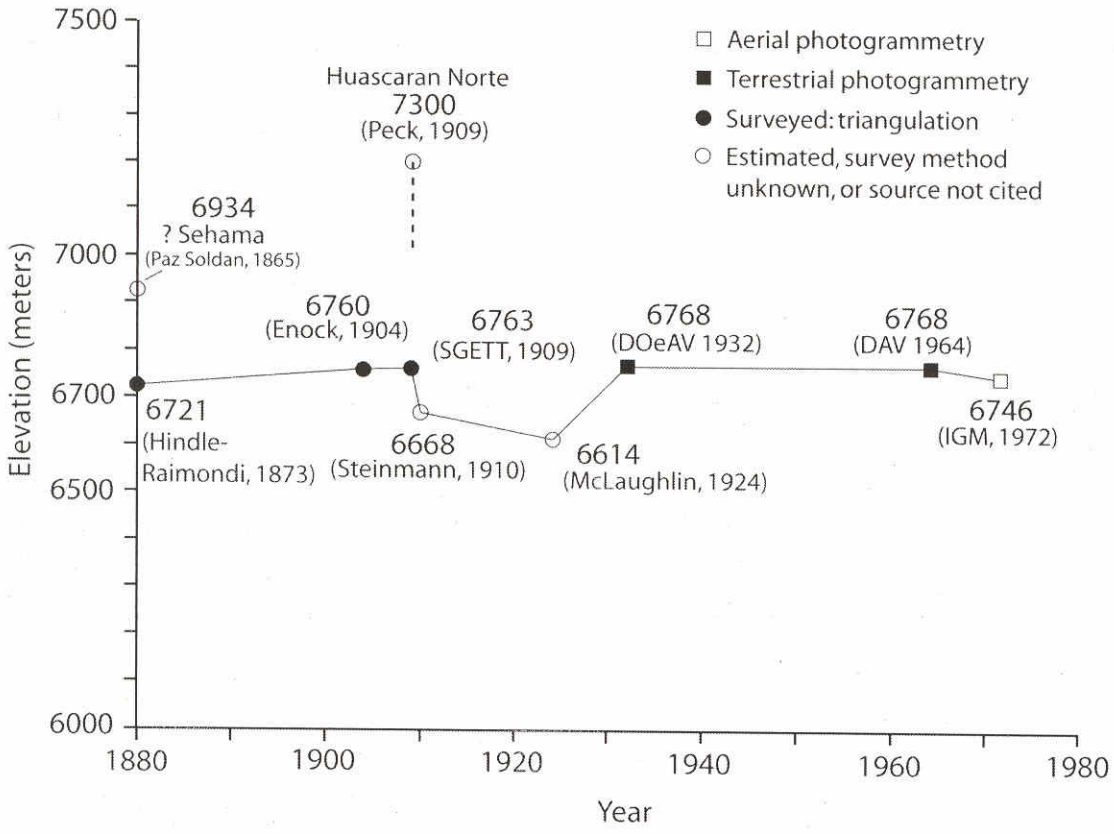

Fig. 1: Estimated and surveyed elevations of Huascarán Sur. Note that the earliest surveys on the Y-axis are not shown with correct corresponding year on the X-axis. The 1964 survey may be repeating the data generated from the 1932 survey

etc. A certain amount of analytical error is to be expected in any measurement, thus repeated surveys will not yield identical results. Unfortunately, most previous surveys did not report an estimate of measurement errors. It seems a combination of analytical errors and snow thickness at the summit should all contribute to the nearly 22 m difference between the SGETT, DOeAV, and IGM surveys. However, can any one reported value be used with confidence? In fact, the SGETT survey is the only one that explicitly details the measurement procedure and also directly measured the average sea level combined with leveling to provide control along the base line. Perhaps their results are the most precise? Surveying technology and methods were probably not greatly enhanced between the 1909 and 1932 surveys. The terrestrial and aerial photogrammetry methods used in DOeAV and IGM maps both rely of stereoscope models that depend on surveyed calibration points for the vertical control. Presently, total stations, laser EDM, and GPS technology offer a major advantage in surveying and should be used to refine our knowledge on important geographic points of Perú. The highest point in Perú has uncertainties in its measured height. Likewise, other peaks and geographic features can be expected to have even more variation in surveyed elevations.

CONCLUSIONS

Huascarán Sur is overdue for an updated elevation survey in light of new surveying technology. A GPS survey used in conjunction with a base station should be able to record the summit height with the vertical error in centimeters. A fixed control point in bedrock of the summit will have to be installed to remove variations of snow thickness on repeated surveys. Active faulting along the Cordillera Blanca fault is probably increasing the summit elevation on a regular basis. Establishing precise vertical control on this summit may yield a future valuable reference in the event of a major earthquake along the Cordillera Blanca fault. Until more rigorous surveys are made of Huascarán, we should all question how high is the highest point in Perú.

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