

Mapping the Cordillera Huayhuash

Digital Alpine Cartography with Imperfect Data

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This paper will examine the issues involved in creating a topographic map for an audience of recreationists (climbers, trekkers, and hikers) for a remote mountain area of Peru. The Cordillera Huayhuash, a sub range of the Cordillera Occidental of the Peruvian Andes, is a compact but impressive massif located a few kilometers south of the better known Cordillera Blanca. Like its sister range it was initially surveyed and mapped in the 30's by an Österreichischen Alpenverein (Alpenvereinskarte/ D.O.A.V.) party. Since then the range has been remapped by the Peruvian I.G.N. at 1:100,000 scale. The two map sheets covering the range while useful do not meet the requirements of climbers and hikers. Unlike the D.O.A.V. sheets (Cordillera Blanca North and South) covering the Cordillera Blanca which are in the process of being updated and reissued, it may be years before the Cordillera Huayhuash sheet is revised by the prestigious European group. Other recreational maps also fail to meet the needs of this special group of users. In the fall of 1999 the Alpine Mapping Guild obtained digital topographic data to the Cordillera Huayhuash and has been preparing a shaded relief topographic map of the range. Initial quality control verification work was done in the field during the 2000 climbing season by the AMG. A first edition of the map is planned for release in late spring of 2002. This paper reviews previously available maps to the areas and how the AMG map improves upon this work to serve its audience's special needs. We will also examine the challenges encountered while developing a map with data initially obtained from "backdoor" sources as is sometimes the case when working in developing countries and the solutions used to develop a final map product.

Keywords: *Cordillera Huayhuash, Andean Cartography, Special cartographic needs of climbers/hikers.*

Located 360 Km north of Peru's capital Lima the Cordillera Huayhuash is a trekking and alpine climbing paradise (see fig. 1). It is a compact range measuring approximately 30km north to south, dominated by 6 peaks over 6000m, and more than a dozen 5000m summits, most located along a single ridge. Unlike its sister range to the north (the Cordillera Blanca, located in Huascarán National Park) it is not as well known by foreign visitors nor Peruvians. The area is divided by three administrative departments and was until recently often obscured on Peruvian maps. Yerupaja (fig. 3), the highest peak in the range at 6617 m, is the highest point in the Amazon basin and glaciers on its northeast side are the hydrological source of the Rio Marañón. The area is under consideration for receiving protected area status as pressures mount from tourist, hiking the 165 km trekking circuit, local subsistence farmers and international mining companies and demands for local resources start conflicting (Kolff, 2002).



Fig. 1 Locator Map

Cartographic Needs

In creating a new map of the Cordillera Huayhuash there were several needs to consider. Climbers, trekkers, and backpackers, the intended audience for the new map have practical needs that cannot be ignored if the map is to prove useful and successful both in terms of its popularity amongst users and economically as a commercial product. There are also philosophical considerations in designing a map to a sensitive, largely uninhabited wilderness area, to be used by an audience with differing skills, expectations and desires regarding their wilderness experience.

Practical Considerations

The cartographer Edward Imhof advises in *Terrain et Carte* (1951) that the alpinist must *never* use a map with a scale smaller than 1:50,000. Numerous instructional manuals also state the desirability of maps at a scale ranging from 1:24,000 to 1: 63,360, such as provided in the United States by the USGS (Graydon, D., 1992). Townsend (1997) notes his preference for the older USGS 1:62,500 series and laments their discontinuation “a pity as the scale is adequate for backpacking and each sheet covers a larger area.”

On a topographic map contour interval which is closely linked to scale is abundantly discussed by Imhof (1965) and the details are beyond the scope of this article. Unless creating a base map photogrammetrically or from a DEM this will not be a consideration. In the case of the Huayhuash map contour interval was dictated by the base data.

In addition to an appropriate scale the literature suggests that contour lines, land cover (vegetation and glaciology), morphology (rock drawings, hachures), hydrology, , recreational information (hiking trails, trailheads, campsites), waterproof/ tearproof material and a UTM grid, to be important factors in a good recreational map (Townsend, C., 1997; Kriz, K., 2000). In general, topographic maps are preferred over sketch maps or guidebook maps as they meet most of the above needs. Graydon notes however that climbers' hand drawn sketch maps "often make up in specialized route detail what they lack in draftsmanship ... and can be effective supplements to other map and guidebook consideration."

What Petrovič (2000) describes as "Mountain Maps" is the ideal product assuming an experienced user. These maps usually consist of a topographic base with mountain tracks, huts and ski mountaineering routes at a scale ranging from 1:20,000 to 1:50,000 and contour intervals between 10 and 25 meters. Petrovič also discusses the usefulness of both panoramic views and route profiles for the ease in which they can be read by users unfamiliar with contours. This is an important consideration when designing for a diverse audience. An excellent example of a "Mountain Map" is the [Stanley Map "Mt Rainier National Park"](#) 1:30,000 sheet. Printed on a waterproof tear proof base it illustrates many of the elements discussed above.

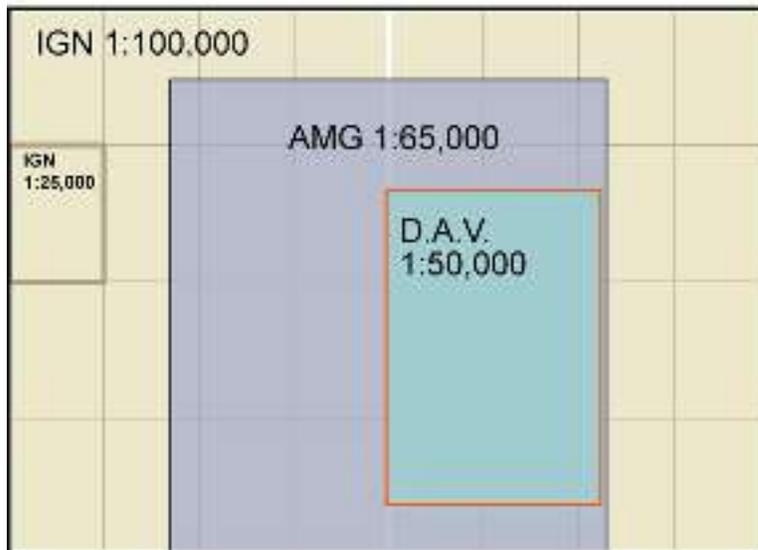


Fig. 2 Approximate spatial coverage of various maps

The spatial extent or coverage of a single map sheet is an important design consideration which depends on scale (fig. 2) The typical self propelled recreational user is unlikely to want to carry more than a few map sheets in his pack, and if possible one

trimmed sheet will be made to suffice by many weight conscious backpackers. It is thus important for a map to have a scale large enough to allow for adequate terrain representation while fitting easily on a single sheet. Cost is also a factor in this equation; producing a large series of maps at a large scale is more expensive for both the publisher and the consumer.

Increasingly cartographers are taking into considerations GPS users by clearly denoting vertical and horizontal datum information, UTM grids and tic marks, and sometimes UTM coordinates for trailheads and other useful locations such as campsites water sources, and route features such as the entrance descent gullies

In many developing countries cartographic needs are met with maps at often inadequate scale for the purpose which they are used. While Imhof's statement may be correct, while traveling in Peru one has unfortunately had to make do with maps at 1:100,000. In sharp contrast countries such as Switzerland produce special topographic series specially designed for ski touring and hiking ([swisstopo](#), 2002). These maps provide single sheet coverage to popular areas, with special symbology and additional information not found on regular topographic sheets. In Austria specialized maps both printed and digital are designed and produced for winter travel and rescue in avalanche prone areas. (Schneeberg project, Kriz, K., 2000 and elsewhere in this proceeding). These user specific end-products are likely to become more common as cartography becomes more internet, database, end product and on-demand driven.

Philosophical Considerations

As cartographers, "selection", as defined by Robinson, A.H. et al (1995) is an important component of our work. Deciding what to leave off the map is dictated largely by technical issues such as scale, clarity, aesthetics, audience and purpose. In some cases ethics, whether personal or dictated by a client may also determine a map's content or symbology choices.

Outdoor recreationists have varying goals and aspirations. Some seek solitude and contact with nature, others adventure or escape from congested urban life. Most cases are likely a combination of these goals and many others. In as much as a map helps its audience fulfill these goals it is important to keep them in mind. When designing a map for climbers and trekkers a question to keep in mind might be *how much information is too much?* The cartographer must strike a balance that fulfills the needs of a wide spectrum of users, from those looking to explore the wilderness with the map as a tool to those seeking detailed instructions to get them from camp A to camp B, with details as to where the best views are along the way, and where dangerous sections are, etc...

Without a doubt these varying outdoor experiences and others are now increasingly being sought in the Cordillera Huayhuash. Potential users of our map belong both guided and independent parties, with differing needs and aspirations. Should the map be designed as a map to be used in conjunction with a guidebook or as a guidebook? These questions raise others such as liability and environmental considerations in

sensitive areas. These questions are obviously beyond the scope of this paper, it is however, in our opinion important to address them early in the project planning phase.

In the case of the project discussed here a conscious decision was made for the map to serve only a map and not a guidebook. For example trails were demarcated but not described, peak heights and names were indicated but not climbing route information nor grade of difficulty. The map was designed for the independent (as opposed to guided) climber, or backpacker with average map reading skills and some knowledge of the area as obtainable from a guidebook.



Figure 3 Yerupaja 6617m (Martin Gamache, 2000)



Fig. 4 Surveying Yerupaja in 1936 from Kinzl et al. 1954



Fig. 5 Detail from D.A.V. Cordillera de Huayhuash (Peru) 1:50,000, 1939. Reproduction not to scale.

Cartographic History

The Cordillera Huayhuash was first described by the German geographer Willem Sievers who visited the eastern side of the range in 1909. He was followed by the American Geographical Society expedition in 1927 who quickly surveyed the area and determined peak heights in excess of 6000m (Neate, 1999).

The Cordillera Huayhuash's cartographic history dates to 1936 with the arrival of the Austro-German D.Ö.A.V. expedition from the Cordillera Blanca (Kintzl et al. 1942 and 1954)(fig. 4). They carried out the first detailed survey of the range using terrestrial photogrammetry and made several notable first climbing ascents. The first topographic map of the range at 1:50,000 based on the 1936 survey was published in 1939 by the Deutscher Alpenvereinskarte (D.A.V., see fig. 5). Printed in three colors with hand drawn hatchures and shaded relief it is in the author's opinion a fine example of expedition cartography. The map was reprinted several times and remained in print until recently. Although useful and informative as a historical document, glacial recession, landform evolution, the lack of toponymic information, dated planimetric information such as access roads, trails and paths, and inconsistencies in peak heights leave the DAV map of limited use as a navigational aid. The details provided by the hatching of F. Ebster can often be difficult to read for users accustomed to the less detailed USGS-style topographic maps.

In 1946 the Swiss Geologist Arnold Heim took the first aerial photographs of the range. More flights were flown in the 1962 as a result of agrarian reform and as a planning tool in response to disastrous aluvóins caused by earthquakes (Morales-Arno, B., 1999). These photographs were field checked in 1966 and base maps were compiled from them in 1970 by the Peruvian Instituto Geografico Militar (IGM) at a scale of 1:25.000. A more easily obtainable and better quality topographic series at 1:100,000 was also published in 1970 and is still available from the Instituto Geografico Nacional.

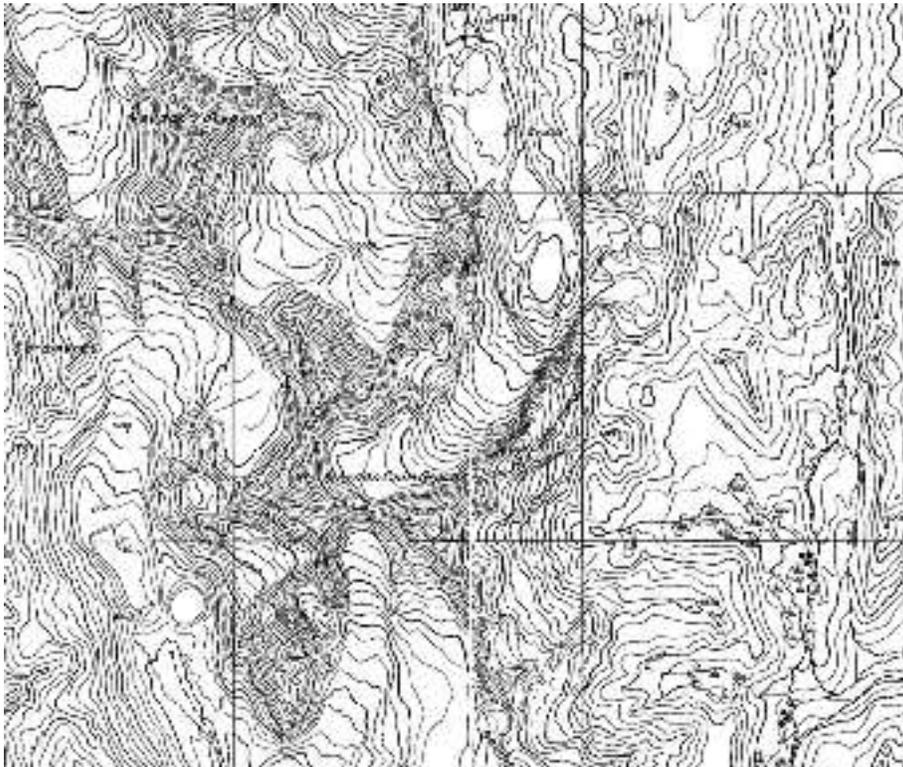


Fig. 6 Detail from IGM, Peru 1:25,000 1970 sheets 21J III NO & NE. Reproduction not to scale.

While useful these topographic map are not well suited to the needs of climbers and trekkers. At a scale of 1:25:000 the IGM maps offer suitable details, however one would need at least 12 sheets in order to cover both the approach and the trekking circuits surrounding the range. The cost of obtaining black and white copies of these sheets would approach \$ 60/ € 58 and would require a long visit to the IGN office in Lima. The copies would lack any color symbology making it hard to distinguish streams from paths and lakeshores from contours (Fig. 6).

The 1:100,000 series resolves some of these issues (Fig. 7). Only two sheets are required to cover the entire Cordillera Huayhuash including the most common trailheads of Cajatambo, Chiquian, and Matacancha. These map sheets are often available through map dealers in North America and Europe and are reasonably priced. Symbolization is appropriate and the map is printed on durable paper in four colors. Glaciated areas are indicated as well as wetlands, both useful for cross country navigation. However, at 1:100,000 this series is inadequate for serious wilderness travel in the complex landscape of the Huayhuash and is more suitable for trip planning at home.

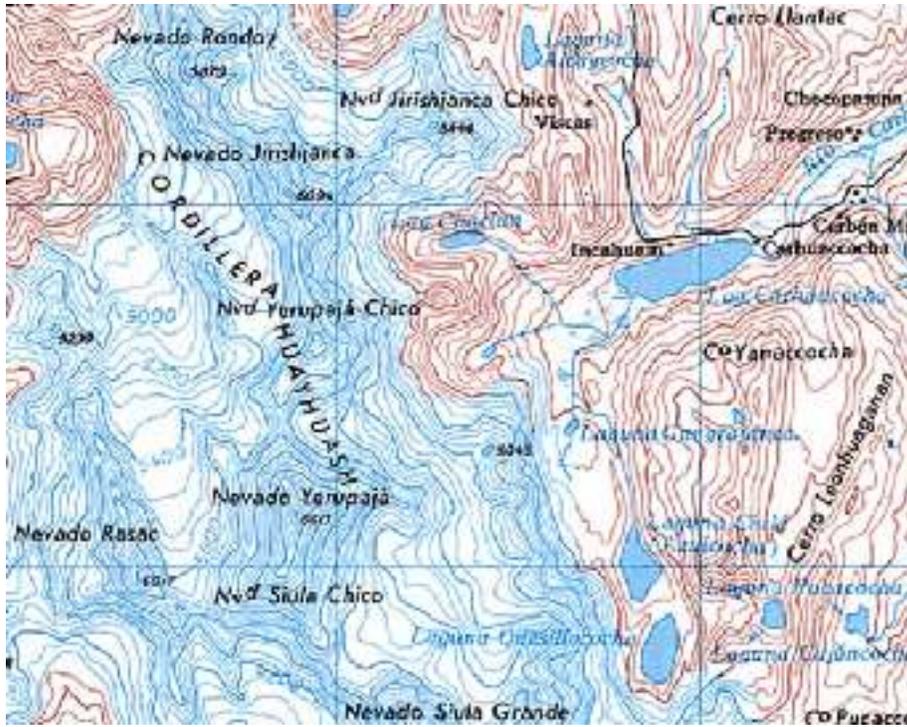


Fig. 7 Detail from IGN, Peru 1:100,000 1969/70 sheet 21J Yanahuanca. Reproduction not to scale.

Both series suffer from similar weaknesses when it comes to place names and age. Being derived from the same 1962 photos, the maps are now less than accurate in their depiction of glaciers, landcover, planimetry, and hydrology. Trails have changed, glaciers receded, bridges have been moved, roads built, lakes formed, etc. The IGN topos reflect conditions as documented by aerial photography in 1962 and field checking in 1966. In addition to the inevitable ageing there were significant omissions at the time of compilation. Place names are often absent or fail to reflect names used by local communities to describe hydrological and landscape features, and by mountaineers to describe peaks and sub-peaks.

There are several sketch maps and tourist maps that cover both the Cordillera Blanca and Huayhuash, however, most of these are not suitable for wilderness navigation and are designed for trip planning purposes (fig. 8). Authors include Felipe Diaz (available in Peru), Jim Bartle (included with trail guide, out of print), and the South American Explorers.

A significant contribution to the cartographic resources of the Cordillera Huayhuash and to the mountaineering history of the region was made by Jan Kielkowski with the publication of his seven volume Cordillera Huayhuash guidebook (fig. 9-10). Originally conceived for the Andean section of the Japanese Mountaineering Maps of the World series this collection consists of orographic sketch maps at three scales (fig. 10), based on the IGN topographic sheets and on field observations. It also includes dozens of beautifully rendered, detailed peak diagrams and sketches showing both approach and climbing routes with route descriptions (fig. 9), and a comprehensive peak name index. The entire collection is a rich source of information for any visitor to the area



Fig. 8 Tourist map by Felipe Diaz (above) and sketch map by Jim Bartle, 1981 (below). Reproduction not to scale.



Fig. 9 Route diagram for Yeropaja from Kielkowski, Cordillera Huayhuash Vol.3, 1991.

servicing both as an atlas and a guidebook. The maps, being based on the IGN sheets, suffer some of their drawbacks, however the author's field work is evident in the abundance supplementation of place and peak names as well as the correct location of passes, paths, base camp locations and climbing routes. Drawbacks include the size of the series (comprised of 7 volumes it is hardly compact), nor is it inexpensive at \$75 for a set from an antiquarian book dealer if you can find it. The work is also in Polish which while not an impossible barrier, makes it less useful for most potential users. The potential difficulties in replacing this work has on most occasions compelled the author to leave his copy at home for use as a reference work rather than as a field map.

As can be seen in the above description of the existing map coverage, prior to now there were many difficulties in finding, purchasing, and traveling with the commercially available maps. This condition presented an ideal situation for an eager cartographer with more time than money and the enthusiasm to create a product that would meet the needs of a large user group.

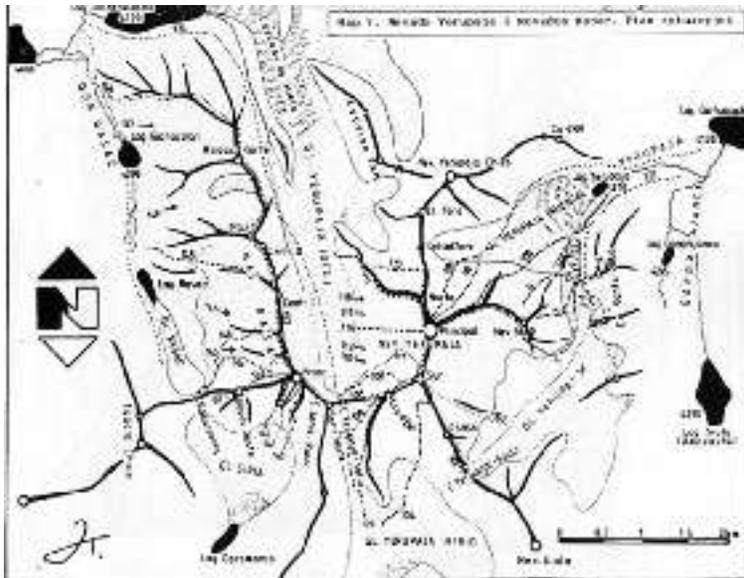


Fig. 10 Examples of the 1:50,000 maps compiled by Kielkowski from the IGN base, Climbing routes are numbered and refer to the text of the guidebook. Reproduction not to scale.

The 2002 Cordillera Huayhuash map

When we naively set out to create a map of the Huayhuash in 1999 we did so under several assumptions:

- **Un-availability of up to date, suitable, quality topographic maps** (Table 1)

As discussed above, the best large scale maps for the range are over 60 years old and/or out of print and difficult to obtain, or at least 30 years old at too small a scale.

Author	Publisher	Scale	Year	Availability
Kinzl et. al.	D.A.V.	1:50,000	1939	Out of Print
I.G.M.	I.G.M.	1:25,000	1969	B/W copies in Lima
I.G.N.	I.G.N.	1:100,000	1969/70	Map distributors & IGN in LIMA

Table 1

- **Limited data sources**

Data sources were limited to existing paper maps and guidebooks and to digital files in shapefile format created by digitizing the 1:100,000 IGN sheets. The vector files we obtained had been created with much attention to details, were unprojected, and lacked metadata. Being based in North America compounded the problems since we did not have ready access to better resources which might be found in Lima.

- **Assume a completely digital workflow**

Our workflow (see figure 11) assumed an entirely digital process with the exception of the final platemaking and offset printing. We wanted to complete all the work on desktop PCs using affordable software and/or publicly available software such as found in local map libraries.

- **Limited financial and human resources**

Compared with a large cartographic institution such as the D.A.V., the Huayhuash map began as two-person effort which quickly became a one-person effort. Resource and financial constraints dictated a somewhat unorthodox approach and creative use of resources. Much of the initial work was done on public computers generously provided by university map libraries in Ottawa and Boston. Landsat imagery was acquired from a public collection maintained by the University of Maryland. The choice to make corrections to an existing digital topographic

base despite numerous flaws was made primarily because of resource constraints. Creating a new base either through our own work or by contracting the job to a third party was beyond our financial and personnel resources.

- **Clear need for this map**

Personal experience living in the Cordillera Huayhuash in 1999, and as a visitor to the region, seeking the best maps on an initial visit in 1998 convinced the author that a new map would be a great service to the increasing number of visitors to the region. Following numerous discussions with local and foreign guides and trekking groups further convinced us that a quality map would be beneficial to trekkers, climbers and backpackers. Due to the risk involved from altitude, weather, inexperience and difficult route finding, people get lost and experience altitude sickness each year while traveling through the area. A quality map correctly indicating spot heights for campsites and passes and correct trail information might prevent easily avoidable accidents by making current and reliable information available to visitors.

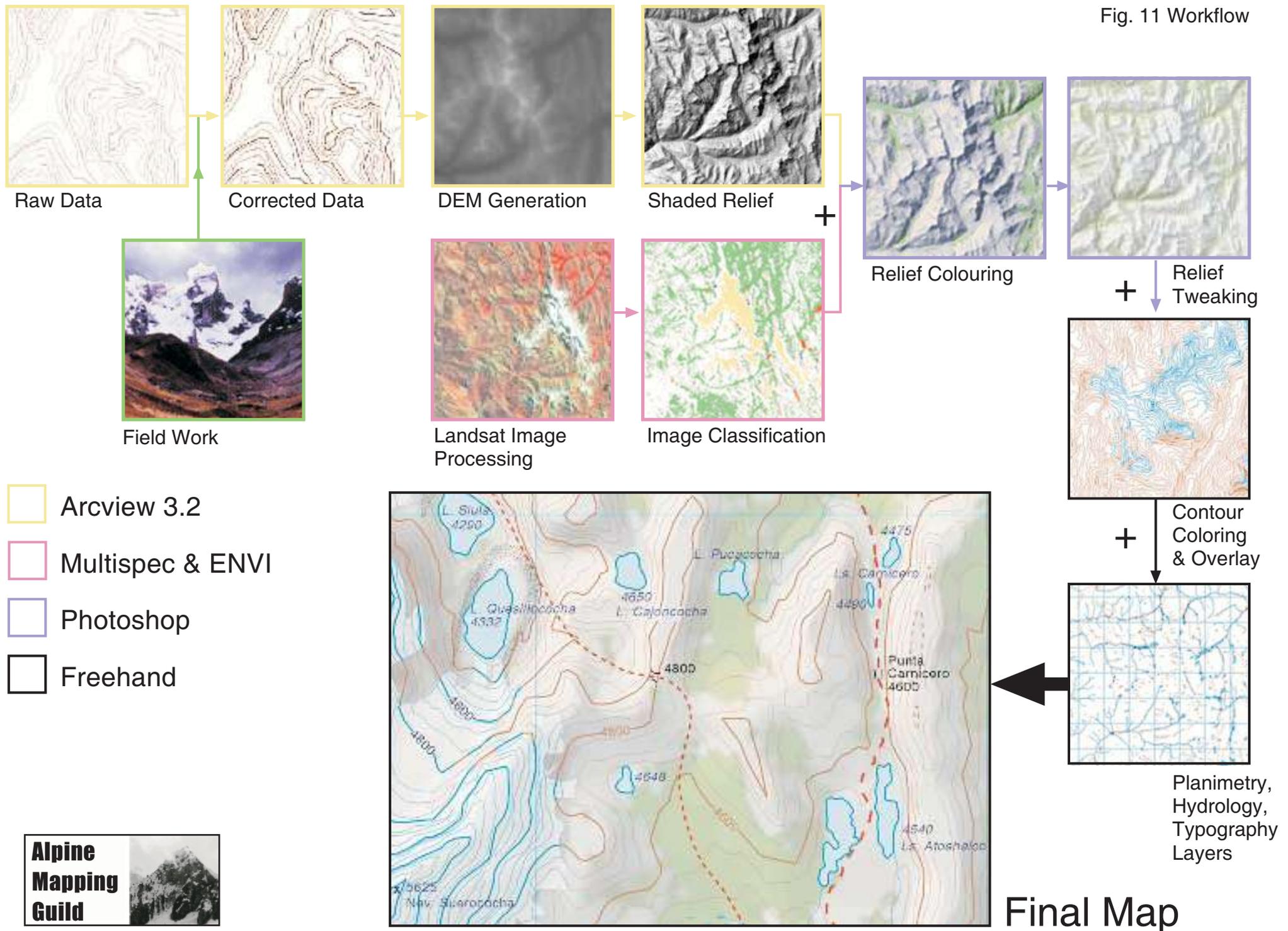
Workflow (see figure 11)

Four types of data were acquired for this project: vector linework, Landsat 5 TM imagery, existing analog maps and guidebooks and field data collected in 2000 and ongoing collection in 2002.

Vector layers were digitized from the 1:100,000 IGN sheets. The layers were obtained from a third party without metadata. This omission caused significant difficulties as the projection information for all vector files were not known nor the method used to create the vector files. Layers were obtained for planimetric features (trails, roads, towns, and villages), hydrology, and contours. Many errors were introduced into the data during the digitizing process which required a large effort to correct. Most errors involved incorrect height values in the contour file which made the creation of a useful DEM impossible until errors were corrected, a time consuming process.

Field work to verify the vector data took place during the summer of 2000, trails were walked and accuracy evaluated by visual confirmation on the ground. The use of a recreational grade GPS to collect route and point information was considered but not pursued. Since our base data lacked projection information, registering data collected with a GPS to the base would have been difficult. A Suunto altimeter, a model normally used by climbers and hikers, was used to collect spot heights at important trail junctions, passes, and campsites. Informal interviews were conducted with local residents as well as with arrieros encountered along the trails. These interviews yielded important toponymic information that was later used to annotate the map. This work is ongoing in collaboration with a community mapping project now taking place in the western part of the range (Norris, T., 2002).

Fig. 11 Workflow



Landsat 5 TM imagery was acquired from the Global Landcover Facility at the University of Maryland. The imagery was radiometrically corrected and false color composites, band ratio and NDSI images created using ENVI, a common imagery analysis software package. Multispec, a freeware program was used to perform unsupervised classification of the images as described by Klein and Isacks (1997) and Kabb and Paul (2000). The resulting classified image was used to colorize the shaded relief model in Photoshop. The entire map was assembled in Freehand using MAPublisher to import and register data layers (see fig. 11 for detailed workflow).

Numerous analog sources were consulted. The works of Kielkowski and Neate were invaluable to verify peak heights and names. Conflicting height values were often found, in such cases the IGN values were taken as the true value in order to remain consistent with Kielkowski who remains the authoritative source for climbing route information until forthcoming guidebooks are published.

Sources of Error and Directions for Future Editions

The completed AMG Cordillera Huayhuash map was published in May 2002 and began selling in Peru in June 2002 in time to coincide with the beginning of the Andean trekking season (fig. 12). Despite numerous flaws we have chosen to adhere to a principle common in the software industry: release early, release often. Numerous sources of errors have caused some issues with the current edition, these include:

- Poorly generalized and missing contours, registration errors between index and intermediate contours introduced by the digitization process;
- Transparency problems arising during pre-press film rip;
- Inaccurate trail and road information due to ongoing road construction;
- Use of 1990 imagery limits the accuracy of the landcover information;
- Lack of projection information introduced errors during the image registration process.

Initial reports from users suggest the map is useful despite the above flaws.

Future editions of the Huayhuash map hope to incorporate new sources of data and design improvements:

- 1:25,000 base map created from IGM sheets and reduced to 1:50,000 scale;
- Detailed land cover information derived from high resolution IKONOS or IRS-C imagery;
- Experiments with digital rock drawing/hatchuring from digital imagery;
- GPS collected trail network and feature locations;
- Climbing route information to work in conjunction with forthcoming guidebooks;
- Bilingual or trilingual editions.



Fig. 12 Alpine Mapping Guild, Cordillera Huayhuash, 1:65,000, 2002.

References

- Bartle, J. (1981) *Trails of the Cordillera Blanca and Huayhuash of Peru*. Healdsburg, Calif.: J. Bartle.
- Graydon, D. (Ed.). (1992). *Mountaineering: The Freedom of the Hills* (5th ed.). Seattle: The Mountaineers.
- Imhof, E. (1951). *Terrain et Carte*. Erlenbach-Zurich: Eugen Rentsch Verlag
- Imhof, E. (1982). *Cartographic Relief Presentation*. Berlin;New York: Walter de Gruyter.
- Kääb, A. and Frank, P. (2000). Methods for Snow and Glacier Mapping. Website: <http://www.geo.unizh.ch/~fpaul/SGI2000/sgidip3.html>. Cited 30 August 2002.
- Kinzl, Hans, Schneider, Erwin, and Awerzger, A., 1954, *Cordillera Huayhuash, Perú: Ein Bildwerk über ein trapisches Hochgebirge Verlag* [Cordillera Huayhuash, Peru: Imagery across a high volcanic mountain range]. Innsbruck: Tiroler Graphik GmbH.
- Kinzl, Hans, Schneider, Erwin, and Ebster, F., 1942, Die Karte der Kordillere von Huayhuash (Perú) [The map of Cordillera Huayhuash (Peru)] *Zeitschrift der Gesellschaft für Erdkunde zu Berlin*, p. 1-35.
- Klein A.G. and Isacks B.L. (1997). Alpine Glacial Geomorphological Studies in the Central Andes using Landsat Thematic Mapper Images. *Glacial Geology and Geomorphology*, 1998,rp01/1998
<http://ggg.qub.ac.uk/papers/full/1998/rp011998/rp01.htm>
- Kolff, A. and Bartle, J. (1998). *Cordillera Huayhuash*. Lima: Nuevas Imágenes.
- Kolff, A.C. *The Political Ecology of Mining and Marginalization in the Peruvian Andes: A Case study of the Cordillera Huayhuash*. Unpublished master's thesis, University of Colorado, Boulder, CO. Website: <http://www.uni-koeln.de/phil-fak/voelkerkunde/forsch/peru/Kolff-MAThesis.html>. Cited 30 August 2002.
- Kriz, K. (2000). "Conceptual Aspects for Large-Scale Topographic Winter Maps". In: Buchroithner, M.F. (Ed): *High Mountain Cartography 2000*. Dresden: Dresden University of Technology, Institute for Cartography.
- Morales-Arno, B. (1999). *Glaciers of South America—Glaciers of Perú*. U.S. Geological Survey. Website: <http://pubs.usgs.gov/prof/p1386i/peru/index.html>. Cited 30 August 2002.
- Neate, J. (1994). *Mountaineering in the Andes* (2nd ed.). London: Expedition Advisory Centre, Royal Geographical Society.
- Norris, T. (2002). Nawa Maps (personal communication).

Petrovič, D. (2000). "How to Represent Mountain Tracks". In: Buchroithner, M.F. (Ed): *High Mountain Cartography 2000*. Dresden: Dresden University of Technology, Institute for Cartography.

Robinson, A.H., et al. (1995). *Elements of Cartography* (6th ed.). New York: John Wiley & Sons.

Townsend, C. (1997). *The Backpacker's Handbook* (2nd ed.). Camden: Ragged Mountain Press.