IMAGE ANALYSIS FOR THE HISTORY OF CARTOGRAPHY: DRAWING CONCLUSIONS FROM THE EVALUATION OF PFYFFER'S RELIEF

Jana Niederöst

Institute of Geodesy and Photogrammetry, Swiss Federal Institute of Technology Zurich,
ETH-Hönggerberg, CH-8093 Zurich, Switzerland, jana@geod.baug.ethz.ch

TS-PS WG V/4 Image Analysis and Spatial Information Systems for Application in Cultural Heritage

KEYWORDS: cultural heritage, history of cartography, digital recording, accuracy analysis, surveying reconstruction

ABSTRACT:

Digital photogrammetry offers effective and accurate procedures for the preservation and inventory of cultural heritage. In case of two- and three-dimensional products of early mapmaking the application of these methods goes far beyond documentation and visualization: it primarily aims at the derivation of new information. This paper reports on conclusions which can be drawn from the quantitative evaluation of one of the most spectacular relief models in history, the relief of Franz Ludwig Pfyffer constructed between 1750 and 1786. At first, the techniques and results of image-based reconstruction and accuracy analysis of this masterpiece are briefly summarized. Due to the lack of written documentation concerning the relief and its constructor, the virtual Pfyffer's Relief and the products of image processing represent a great potential for research in the history of cartography. Thus, the main focus of the paper is the reconstruction of Pfyffer's surveying procedures and the interpretation of the reached accuracy in context of European mapmaking of that period. The work leads to a new knowledge about the cartographic, spatiotemporal but also social and political aspects of the relief creation. As opposed to the previous assumptions it can be concluded that Pfyffer performed systematic and repetitive triangulation and height measurements. His procedures, instruments and results correspond with the scientific status quo in the last quarter of the 18th century, whereas his area-wide height survey was a pioneering achievement at that time.

1. INTRODUCTION

Old maps and three-dimensional relief models are an important part of our cultural heritage. They bear witness of the technical development, social, cultural and politic circumstances as well as of the comprehension of space and landscape at the time they had been created. As such they are precious material, pieces of art that help us to understand our history, territorial dynamics and progress of scientific knowledge. The digital recording of two- and three-dimensional historical cartography enables its preservation for the next generations; however, primarily it should serve for the derivation of new information. Due to the lack of primary written sources this "added value" - gained through the recovering of the metrical content of old topographic works by means of statistical and image processing procedures - is very worthwhile for the historical research. This paper shows how the results of accuracy analyses and visualization can be interpreted and hence, which new conclusions can be drawn concerning the early mapmaking at that period.

The object of the research is one of the most spectacular relief models in history, a large bird's eye view of mountainous Central Switzerland constructed by the lieutenant general Franz Ludwig Pfyffer (1716-1802) between 1750 and 1786. The topographic base of this 6.6 x 3.9 m^2 big masterpiece at a scale of about 1:11'500 are the own measurements of Pfyffer, performed decades before the first Swiss national triangulation was established. The visual verification shows that the relief was a significant improvement of existing maps at that time (Fig. 1) and it also served as a basis for several printed works issued at the end of 18th century. However, because of the very spare written documentation and the relief complexity, neither its formation nor its geometric characteristics have been investigated up till now. Within the scope of an interdisciplinary project supported by the Swiss National Science Foundation and the local cultural authorities, the methods for the quantitative evaluation of old maps and relief models are to be developed. The application of these procedures to the Pfyffer's Relief (or more precisely, to its virtual computer model) and related maps of the region should answer the questions of historians concerning the creation, accuracy and historical context of the relief. The indirect analysis of Pfyffer's topographic work as the only possible way of exploring this chapter of Swiss cartography should complete the following three tasks:

- 3D reconstruction of the relief for the documentation of the cultural heritage and for the numerical evaluation of geometric features of the original,
- Accuracy analysis of the relief and related old maps; interpretation of the results in the context of European mapmaking at that period,
- Investigation of Pfyffer's surveying and model constructing procedures; comparison with contemporary and present methods.

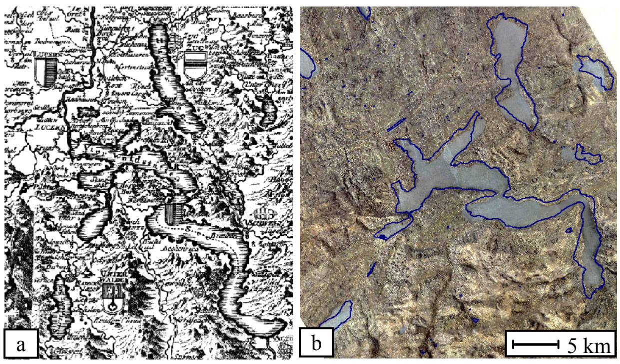

Fig. 1: The depiction of Central Switzerland (a) in the principal map of the region over the whole 18th century (*Nova Helvetiae Tabula Geographica*, J. J. Scheuchzer, 1712), (b) in the georeferenced Pfyffer's Relief overlaid with the current lake contours (blue lines).

In a previous publication (Niederöst, 2003) the methods for the digital recording of Pfyffer's Relief and the quantitative evaluation of the virtual relief and related old maps were presented (they are shortly summarized in Section 2). The analysis yields a number of statistic and visual products, which have a great potential for the research in the history of cartography. Now the most important question is to be answered: Which conclusions can be drawn from the results of the accuracy analysis? This paper aims at the reconstruction of Pfyffer's surveying procedures (Section 3) as well as at the interpretation of the estimated relief accuracy in the context of European cartography in the 18th century (Section 4). The research is based on several sources: a few autographic letters (Pfyffer, 1761) and maps of Pfyffer, archive publications as a testimony of the surveying and cartographic standards of that time and of course, the results of the performed quantitative analyses.

2. DATA PROCESSING

For the generation of a 3D computer model of Pfyffer's Relief, the procedures of image-based object reconstruction were applied. The photogrammetric stereo processing resulted in a digital surface model of 1 cm raster width, an orthoimage and a structured vector data set of significant relief features. The precise digital data set of Pfyffer's Relief including visualization products (Fig. 2) was archived at the Kulturgüterschutz of Lucerne for the documentation of cultural heritage.

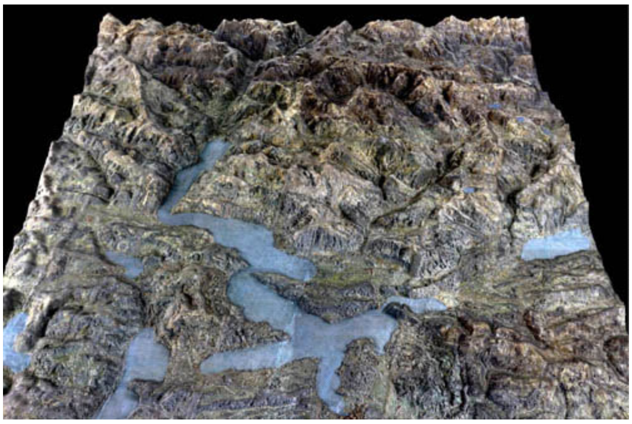

Fig. 2: A view of the photogrammetrically reconstructed texture-mapped Pfyffer Relief

The accuracy analysis of Pfyffer's Relief is based on a number of identical points in the historical and modern data set. Applying a 9-parameter spatial transformation, the accuracy of the relief as well as its metric parameters such as scales and rotation angles were determined. The calculated distortion grid (Fig. 3) allows for a visual presentation of the numeric results of the analysis. Furthemore a new procedure for georeferencing of the historical height, image and vector data was developed. The overlay of the georeferenced data set with the current map information (Fig. 1b) represented a basis for the numerical accuracy analysis of polygonal relief features such as lake forms. Finally, the surface of Pfyffer's model was compared with the national terrain model DHM25 of swisstopo.

In order to understand the spatial and temporal coherences of the relief creation, the following relief-related old maps were also included in the analysis (see also Table 1):

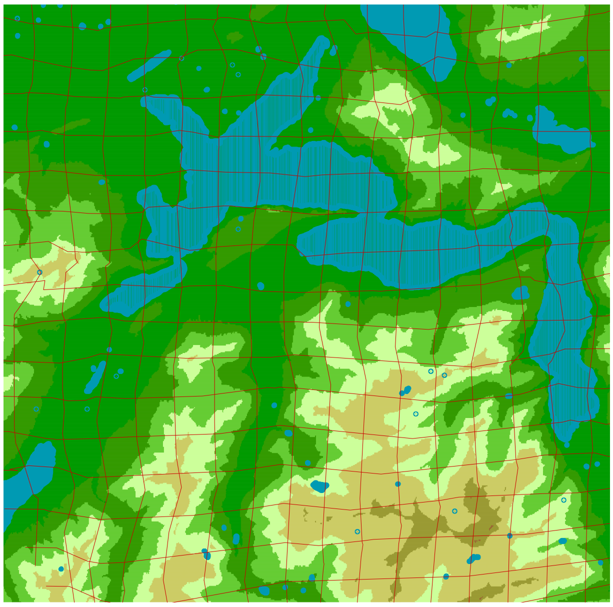

Fig. 3: The distortion grid of Pfyffer's Relief showing the deformation of 2-km coordinate lines on the background of the current national DTM (DHM25, copyright swisstopo).

- The coloured small-scaled drawing of Central Switzerland by Pfyffer's own hand (Fig. 4),
- The fragment of a large-scaled manuscript map of Pfyffer from the region of Rengg valley, which was - re-used as wasted paper - surprisingly found inside the relief during its restoration (Fig. 5),
- The engraved *Carte en Perspective du Nord au Midi*, created by Jakob Joseph Clausner (1744-1795) on the basis of Pfyffer's measurements in 1786 (Fig.6).

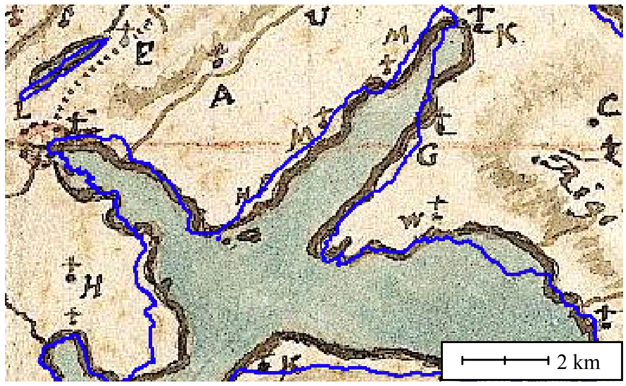

Fig. 4: A part of the georeferenced manuscript map of Central Switzerland of F. L. Pfyffer overlaid with current lake contours.

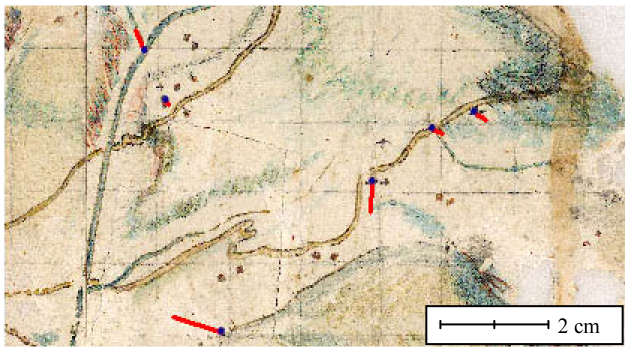

Fig. 5: A part of the large-scaled manuscript map of F. L. Pfyffer overlaid with residuals on identical points (red lines).

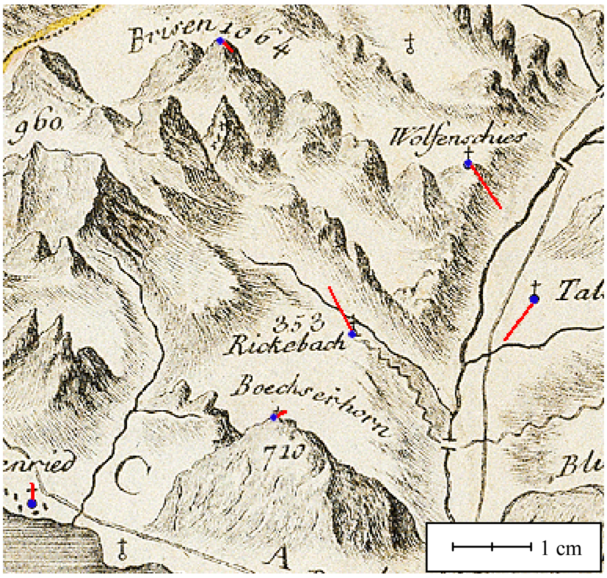

Fig. 6: A part of the map of Central Switzerland by J. J. Clausner created on the basis of Pfyffer's measurements. The map is overlaid with residuals on identical points (red lines).

	(1)	(2)	(3)	(4)
Pfyffer's Relief	208	1:11'700 1:11'400 1:11'200	30.28° south-oriented	470 m 494 m 111 m
Pfyffer's map of Central Sw.	115	1:244'700 1:249'200	-0.65° north-oriented	387 m 528 m
Pfyffer's map of Rengg area	14	1:36'000 1:33'300	15.29° south-oriented	191 m 117 m
Map of Clausner	178	1:125'200 1:123'200	15.62° south-oriented	408 m 483 m

(1) Number of identical points
(2) Scale in coordinate directions
(3) Orientation (or westerly declination, see Fig. 9)
(4) Sigma a posteriori in coordinate directions

Table 1: Results of coordinate transformations with weighted observations: metric parameters of Pfyffer's Relief and related maps.

3. RECONSTRUCTION OF PFYFFER'S SURVEYING AND RELIEF CONSTRUCTING PROCEDURES

F. L. Pfyffer was a passionate surveyor who spent years performing measurements in the alpine terrain, sometimes with a couple of assistants, but mostly on his own. Although he was a self-educated practitioner, he could build on experiences gained during his four decades' career in the French military service which gave him an opportunity to learn modern surveying methods, to get in touch with reputed scientists and instrument makers and to find access to the scientific literature. Back in Switzerland, he decided to present his mountainous homeland in the most natural and understandable form, in the form of a topographic relief. He was aware of the inaccuracy of existing maps of the region and around 1750 he met the challenge to newly map almost 3'500 km^2 at a large scale, including a novelty at that time, the height measurements all over the country.

3.1 Triangulation and detailed surveying

On the basis of Pfyffer's letters (Pfyffer, 1761) to the famous Swiss scientist Micheli Du Crest (1690-1766) it is known now that Pfyffer defined a mesh of large triangles which he surveyed precisely by triangulation. Later on, he densified this primary network by detailed field measurements, using the superordinate triangulation points for forward intersection. The calculated relief accuracy (Table 1) and the more or less homogeneous relief distortions over the whole mapped area (Fig. 3) confirm that the triangulation with its basic principle "from superordinate to subordinate" must have been applied. On the other hand, the accuracy analysis supplies evidence that Pfyffer evaluated his measurements mostly graphically in combination with simple formulas of planar trigonometry instead of adopting more accurate, purely numerical methods under consideration of the curved Earth surface.

Being aware that the requisite for a precise triangulation is a baseline few kilometres long measured with great care, Pfyffer was particularly concerned with the appropriate methods for direct distance measurements. He regularly checked the length of his metal bars and chains (having respectable dimensions from 15 to 120 French feet corresponding to 4.9 and 39 m) along the side of a marmoreal quadrate which he considered to be perfectly shaped. After a long search in mountainous Central Switzerland, Pfyffer finally found a suitable, possibly flat area for the baseline measurements. Then he measured shorter distances in a zigzag manner as well as the corresponding angles and hence he determined the searched baseline length (Fig. 7). With a careful procedure Pfyffer tried to eliminate the impact of systematic errors. Thus, he always laid his chains or bars along a strained cord in order to keep the desired measurement direction and he considered the influence of sloped terrain by a successive horizontal arrangement of the instruments. During the survey for his relief Pfyffer measured several different baselines; only in summer 1761 he mentions about 6 of them. The reason for such excessive measurements was probably the quality control, which was for Pfyffer of great importance.

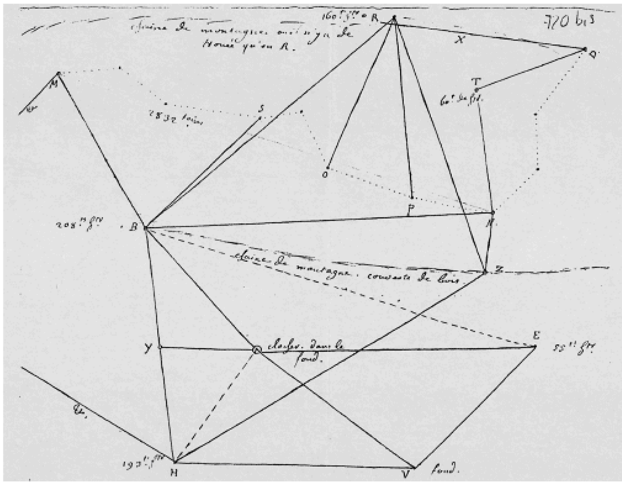

Fig.7: The triangulation sketch of F. L. Pfyffer, found in one of his letters to Micheli Du Crest. The long dotted zigzag line in the upper part was measured using metal chains. Out of these direct measurements Pfyffer determined the length of the baseline MN to 2832 French toises (around 5.5 km).

Before starting angle measurements for the triangulation, Pfyffer had made himself familiar with the territory to be surveyed. During the reconnaissance he checked the reciprocative lines of sight and assigned the future signals and stations. However, as he complains several times in his letters, he was not allowed to erect permanent signal structures, because those were often removed on purpose. Thus, in order not to attract attention, he marked the places using small posts on the ground level or a piece of iron in the rocks. During the measurements his five or six helpers set a purpose-built vertical signal pole on the assigned location and guarded it until the *operation* - as he called surveying - was finished. For communication with his assistants Pfyffer used a big flag in black and white. From time to time he was also forced to use natural points such as single tall firs as signals; in this case he considered the displacement of the station during the subsequent angle measurements at the concerned position. We can conclude that in the time when surveying was not (yet) a state- or military-supported enterprise but rather a cause for suspicion, Pfyffer solved the problems of missing immovable signal structures by means of good preparation and organization of his work.

Pfyffer ordered his surveying equipment and accessories at various places in Europe. To prove the procedures and the accuracy of his instruments to measure angles, he measured at each station with several different pieces of equipment. As a practitioner he was at most fond of a plane table and a graphometer, both instruments which could deliver the graphical results immediately in the field. Pfyffer constructed some surveying instruments himself, too, such as the alidade with a telescope and two diopters in combination with a plane table (Fig. 8 right). The most precise instrument of Pfyffer was a simple English theodolite which he called *le chassis*, the frame (Fig. 8 left). It was a stable, 2 feet high device with a horizontal and a vertical circle, both divided in degrees and minutes. Instead of a telescope the instrument was provided with two peep sight diopters. The major difference of this "frame" in comparison with his other instruments was that it did not allow the underlying with a piece of paper for graphical interpretation. It belonged to a new generation of instruments coming from England, which supplied the surveyor only with the numerical values whereas the abandonment of drawing accessories made them more compact and more accurate.

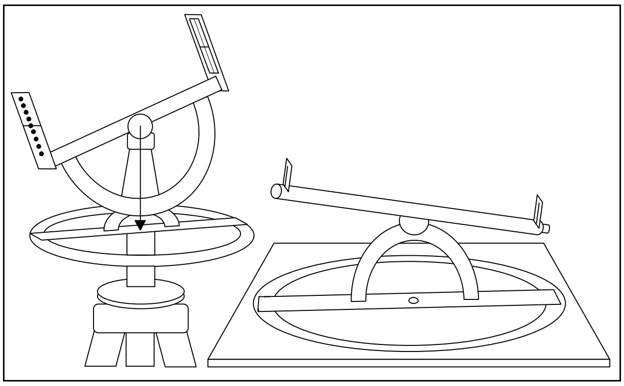

Fig. 8: Two instruments reconstructed according to Pfyffer's description: left an ancestor of a present theodolite, right the alidade with a telescope in combination with a planar table.

The results of numerical analysis using statistical and image processing procedures allowed for coming to a new interesting conclusion concerning Pfyffer's triangulation. As shown in Table 1, the deviation of the relief and the analysed maps from the northern direction amounts to peculiar numbers (around 30 and 15.5 degrees), while the orientation of Pfyffer's manuscript map of Central Switzerland at a scale of about 1:247'000 is almost perfectly northern. What motivated Pfyffer to orient his major topographic works in such an unusual manner? At the end of the 18th century the northern orientation of small-scaled maps became widely accepted and on the other hand, large scale maps still kept an arbitrary orientation according to the position and form of the territory to be mapped. However, the latter could not be the reason for Pfyffer who himself depicted the same area in a north-oriented manuscript drawing (Fig. 4). The answer to this question can be found when looking at the secular variations of the geomagnetic field of the Earth for over 400 years. On the basis of the old measurements we can recognize a steady progressive change in magnetic declination, or angle between magnetic north and geographic north. The publication of (Fischer, 1994) shows that between 1740 and 1790 the westerly declination in Central Switzerland varied from 15° to 19° with a value of about 15.5° for 1750. Thus, Pfyffer oriented his large-scaled topographic works - including the inner constructional parts of the relief - simply according to his compass (Fig. 9). Since Pfyffer's measurements took place within a long time span and over a large area, changes of magnetic declination certainly had a negative influence on the accuracy of his results. To eliminate these errors, repeated and precise astronomic measurements would have to be undertaken, and this was by Pfyffer probably not the case.

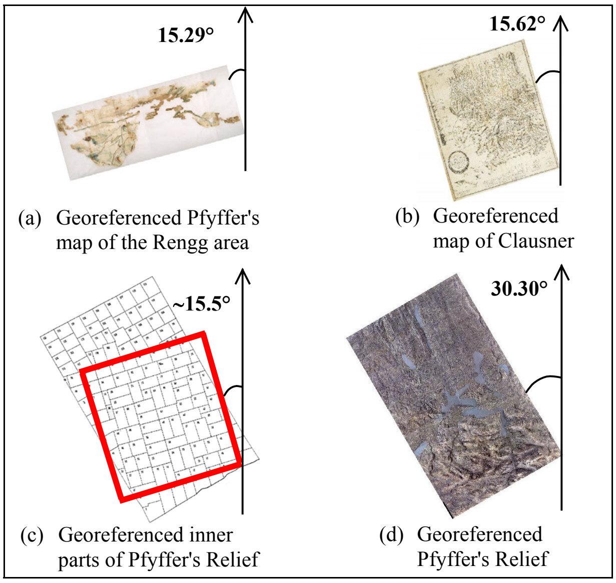

Fig. 9: Orientation of Pfyffer's works, corresponding with the westerly declination of magnetic north (a-c). The original declination of the relief was 15.5° (c). Later on, Pfyffer must have decided - probably for political reasons - to add new constructional parts under a different angle so that the whole relief deviates about 30° from geographic north (c, d).

Pfyffer's surveying was performed before the theory of errors and least squares adjustment had been elaborated. He strived for accuracy in terms of possibly small deviation of the angle sum in a triangle from 180°. His observations were always excessive and thus they enabled the elimination of insecure directions and also a simple averaging of error-afflicted measurements. When content with the triangulation, Pfyffer turned to the detailed measurements. He mapped all the significant terrain objects with his plane table: ways and paths, rivers and small streams, houses, meadows, hedges, ravines and even big stones. He also differentiated oak, beech and fir forests. Under bad weather conditions he transferred the recorded sheets to a large-scaled map and hereafter he began to construct the relief.

3.2 Height measurements

The height measurements represent an area where the pioneering spirit of Pfyffer can be shown in its strongest point. The European maps produced until the first quarter of the 19th century contain no - or only isolated - height information. However, to form the landscape of his relief, Pfyffer needed the area-wide height coverage, which he obtained by performing systematic height measurements as one of the first. The result of his work is not only the relief, but also the map of J. J. Clausner that contains numerous height values (Fig. 6).

Pfyffer's principal instrument to measure heights was the barometer. During his walking-tours he annotated the terrain elevation in regular intervals, obviously based on reading off the barometer. The barometric observation must have been self-evident for Pfyffer, because, as opposed to angle or distance measurements, he never mentions his instrument or the process of his work. The presumption of barometric measurements relies on contemporary travel reports as well as on the results of the accuracy analysis. However, still many questions remain open, particularly Pfyffer's way of derivation of the height values from the quicksilver stand of the barometer, which was a great scientific challenge in the 18th century. The interpretation of Pfyffer's letters and topographic works allows to conclude, that except of barometric observations he applied trigonometric measurements as well. First, he possessed instruments which enabled a straightforward determination of vertical angles (Fig. 8) in his scale-defined trigonometric network. The second clue for trigonometric measurements of Pfyffer are the heights of alpine peaks in the map of Clausner, which were not conquered within the lifetime of Pfyffer (e.g. Jungfrau and Finsteraarhorn, firstly climbed in 1811 and 1812) and thus their heights must have beed determined indirectly. As he was aware of the results of the famous arc measurements in Lapland and Peru, he supposably took the earth curvature into consideration, however, with an unknown amount of flattening, and he probably disregarded the influence of refraction.

Pfyffer had chosen Lake Lucerne as the zero horizon for his height measurements and he estimated its height as 220 toises (428 m) above sea level. A comparison with the lake height in the modern map (434 m) shows an excellent result of Pfyffer's measurements. The small difference of 6 m is evidence of long-term thorough barometric observations as well as of a progressive procedure for the derivation of the heights.

The numerous height values published in Clausner's map constitute the best basis for the evaluation of Pfyffer's measurements. After the conversion from toises above Lake Lucerne into meters above sea level, the heights of 41 well identified localities and summits could be compared with their present values. The average difference (to-be minus is) amounted to -35 m; the negative sign is in accordance with the contemporary phenomena of unreachable mountains considered to be much higher than in reality. In average of absolute values, the 41 tested heights deviate from the present map by 57 m. A clear dependency on terrain elevation can be observed: the average absolute difference in the flat northern area is only 23 m, in variable middle land 61 m, whereas in the mountainous southern part it reaches 82 m. The detailed accuracy analysis of Pfyffer's Relief confirms that due to the same surveying basis the height accuracy of the relief roughly corresponds with the one of Clausner's map. The slight accuracy decrease of the relief in comparison with Clausner's map (the 208 tested identical points of the relief deviate from the current map of 76 m in the height in average of absolute values; Niederöst, 2003) can be explained by the procedure of relief construction. When considering a great number of height measurements undertaken in a large area with the elevation range from 500 m until almost 4'300 m, Pfyffer's achievement is very respectable.

3.3 Relief construction

Pfyffer formed the landscape of his relief on 136 mostly rectangular, transportable and clearly numbered wood plates (Fig. 9c). He marked the position and height of peaks and major localities with vertical wooden sticks and afterwards he modelled the terrain using ordinary materials found in his household: wood, brick shards, carbon rests and cardboard pieces. Then he took a mixture of gypsum and sand for surface formation and to close the gaps between the single constructional parts and he covered it with a layer of beeswax for detailed modelling. Finally, he worked out the surface objects. The forests are made out of green dark- and light-coloured drapery pieces, the water streams of chenille and the ways and small paths of white or red string strained between the nails. The houses appear as red finger-like metal and wax pieces, the churches stick out as small nails plugged upside down into the surface. A surprising result of the accuracy analysis is the unity of relief scales in three coordinate directions: contrary to previous assumptions it can be concluded that Pfyffer did not magnify the heights of the relief on purpose.

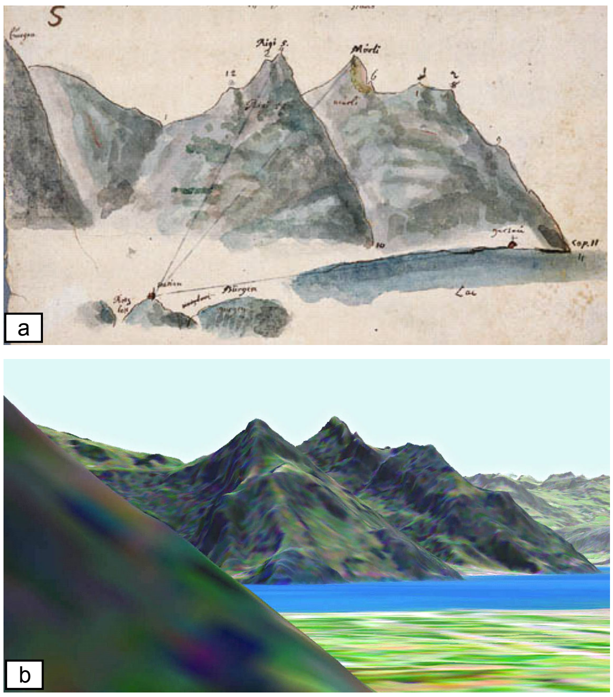

Fig. 10: (a) View of Mt. Rigi, one of 94 existing sketches of Pfyffer, (b) The same view in the present 3D model (DHM25 of swisstopo and a Landsat image of NPOC, www.npoc.ch) showing the distortion of the left-side hill and a perfectly detailed depiction of the background mountain forms.

Except of surveying data, Pfyffer also needed additional information to model mountain forms and the landscape cover of the relief. For this purpose, later relief constructors usually acquired single oblique photographs or terrestrial stereopairs. Pfyffer's way of documenting and indicating the objects to be depicted in the relief was the drawing of coloured landscape sketches (Fig. 10a). Due to the lines of sight to the surrounded, precisely labelled or numbered summits it was previously assumed that Pfyffer created these drawings in connection with his surveying. However, a recent analysis with the help of landscape models has shown that the sketches were created and also used much later for the formation of the relief surface. Their distorted geometry excludes any systematic, perspective or panorama-like landscape projection, whereas the quality and excessive details of the morphology are amazing (Fig. 10). The computer-generated views confirm Pfyffer's concentration on the forms of selected mountains and his disregarding of geometric aspects in the surrounding area. The crucial point of the analysis was to find the places where the sketches had been drawn, which was not an easy task due to the distortions, unusual fields of view and missing or confusing station descriptions.

4. PFYFFER'S PROCEEDURES AND RESULTS IN EUROPEAN COMPARISON

The first product of modern geodesy and systematic land survey was the *Carte géometrique de la France* (1739-1793) at a scale of 1:86'400. The state- and military supported mapping of France under the direction of four generations of the Cassini family was based on one superordinate and two subordinate, computationally evaluated triangulation networks. With the exception of this work, nearly all other 18th century maps were created applying similar procedures and instruments to those of Pfyffer. The following outstanding cartographic products based on graphical triangulation using a plane table and simple instruments to measure angles can be mentioned:

- The huge work of military officers of the Habsburg monarchy at a scale of 1:28'800, created within the first, so called Joseph's survey *(Josephinische Landesaufnahme, 1764-1787)* and covering several countries of today's central and eastern Europe.
- The *Atlas Tyrolensis* at a scale of 1:103'000, created by P. Anich and B. Hueber between 1760 and 1769. The atlas depicts a large area of northern Tyrol in Austria.
- Schmettau's map of Preussen *(Schmettausche Kabinettskarte, 1767-1787)* at a scale of mostly 1:50'000, covering a big part of present Germany.
- Schmitt's map of south Germany *(Schmittsche Karte, 1793-1797)* at a scale of 1:57'600.
- The *Atlas Suisse (1786-1802)* at a scale of about 1:110'000 by J. R. Meyer, J. H. Weiss und J. E. Müller. The atlas displays the entire area of Switzerland.

In order to be able to interpret the geometric quality of Pfyffer's topographic work (Table 1), the results of numerical evaluation of other maps of that period must be taken into consideration. Unfortunately, the research on accuracy analysis of 18th century maps is very rare and in addition, the measures used to express map accuracy are usually very diverse. The numeric results of several investigations are shown in the following:

- According to (Finsterwalder, 1988), the mean position error of 38 identical points of the distortion grid of the mentioned *Schmittsche Karte (1793-1797)* of south Germany is ±2.5 km. The middle distance error of this map by the average distance of 15 km amounts to ±1 km.
- (Brunner, 2002) analyzed the accuracy of the first topographic land survey of Sachsen in Germany (so called *Meilenblätter, 1780-1825*). This map at a scale of 1:12'000 is based on theodolite measurements and a numerically evaluated one-step triangulation. Within the accuracy analysis, the map sheet size was compared with its to-be value of one local mile (6796.56 m). The map is very precise: the 15 selected map sheets created in 1785, 1797 and 1810 deviate from this value in average of 3 m, 68 m and 14 m respectively.
- As a representative of Swiss 18th century maps, the already mentioned *Atlas Suisse (1786-1802)* - considered to be the best map of the country until the first official land survey - was analyzed within the presented project. For the accuracy analysis the sheet Nr. 7 covering the area of Central Switzerland was selected. The evaluation using 115 identical points and applying the same procedures as those for the maps of Pfyffer (Section 2) resulted in the sigma a posteriori of 335 m in the X- and 247 m in the Y-direction respectively.

The way of creation of the above listed European maps provide evidence that at the time of Pfyffer's surveying and relief construction (1750-1786) his procedures and instruments were up to scientific standards of that period. His results hold well with the accuracy of contemporary maps and in particular, his substantial contribution lies in performing pioneering area-wide height measurements and detailed 3D modelling. Considering the conditions under which the relief was constructed - an unfavourable age for landscape exploration and surveying in Switzerland and a large mountainous area modelled at a large scale - Franz Ludwig Pfyffer's achievement is admirable even from today's point of view.

5. CONCLUSIONS

Finished in 1786, Pfyffer's relief attracted numerous visitors from all over Europe to Lucerne. Its unusual bird's eye perspective of an inaccessible mountain barrier was an absolute novelty, a virtual flight in the age of enlightenment. However, with the appearance of new, more precise maps at the turn of the century the opinions on the topographic quality of the relief started to change; the relief was reduced to a kind of handicraft and had almost been forgotten. Due to its complexity and a lack of primary documentation the relief was never investigated until the procedures of photogrammetry and image analysis allowed for drawing conclusions from the geometric evaluation. The results of the presented interdisciplinary research give the painstaking work of Pfyffer its original value back again. The relief must be considered an excellent topographic achievement of that time and a milestone on the way to modern cartography.

REFERENCES

Brunner, H., 2002: Wie Sachsen vermessen wurde. Die Meilenblätter und die kursächsische Landesvermessung von 1780 bis 1825. Dresden, pp. 91-92.

Finsterwalder, R., 1988: Massstab und Genauigkeit alter Karten - gezeigt an einigen Kartierungen Bayerns. In: Cartographia Bavariae: Bayern im Bild der Karte, München, pp. 193-211.

Fischer, G., Schnegg, P.-A., 1994: Updating the geomagnetic survey of Switzerland, in Matériaux pour la Géologie de la Suisse. Géophysique No 27. Neuchâtel, Fig. 2.

Niederöst, J., 2003: A bird's eye view on Switzerland in the 18th century: 3D recording and analysis of a historical relief model. IAPRS, Volume XXXIV-5/C15, pp. 589-594.

Pfyffer, F. L., 1761: 10 letters of Pfyffer to Micheli du Crest, from April 28 to September 15. Landecy, Arch. Micheli, Papiers JBMC no 720bis.