Demarcation of International Border Lines

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Key words: International borders, general contracting, interdisciplinarity, difficult terrain.

ABSTRACT

Disputes about international borders between different sovereigns could be solved by bilateral contracts between the states involved. The United Nations accepts the agreed border line as an international boundary, if the border is exactly demarcated and described by lists of coordinates, reports and up-to-date maps at different scales. It is the solemn duty of each sovereign to settle its state borders to live in peace with its neighbouring countries.

Therefore the paper describes several border demarcation and documentation projects on the Arabian Peninsula during the last decade. The cooperation between the state organisations and the private company as general contractor will be brought into focus. Technical and organisational challenges of these major projects will be shown. The total length of about 2.300 km of border lines, running through extremely difficult terrain, the interdisciplinarity between professions like civil engineers, geodesists, surveyors, photogrammetrists and cartographers as well as the workforce of more than 300 employees give an impression of the projects dimensions.

ZUSAMMENFASSUNG

Streitigkeiten über internationale Grenzen zwischen verschiedenen Staatsmächten können durch zweiseitige Abkommen zwischen den Staaten gelöst werden. Die Vereinten Nationen erkennen eine Grenzlinie als internationale Grenze an, wenn sie exakt vermarkt und durch Koordinaten, Berichte und aktuelle Karten definiert ist. Es ist die eindeutige Verpflichtung einer jeden Staatsmacht, ihre Staatsgrenzen zu regeln, um in Frieden mit ihren Nachbarländern leben zu können.

Der Artikel beschreibt nun mehrere Projekte zur Grenzabmarkung und Dokumentation auf der arabischen Halbinsel während der letzten Dekade. Die Kooperation zwischen den staatlichen Organisationen und der Privatfirma als Generalunternehmer wird hervorgehoben. Es werden die technischen und organisatorischen Herausforderungen dieser Großprojekte aufgezeigt. Die Gesamtlänge von 2.300 km Grenzlinien, welche durch extrem schwieriges Gelände verlaufen, die Interdisziplinarität zwischen Berufen wie Bauingenieuren, Geodäten, Vermessungsingenieuren, Photogrammetern und Kartographen und die Arbeitskraft von mehr als 300 Mitarbeitern gibt einen Eindruck von den Dimensionen dieser Projekte.

RÉSUMÉ

Des litiges à propos de frontières internationales entre différents chefs d'état peuvent être réglés par des traités bilatéraux entre ces états. Les Nations Unies reconnaissent une ligne de frontière comme frontière internationale si elle est exactement délimitée et décrite par des coordonnées, des rapports et des cartes actuelles. Tout chef d'état a le devoir explicite de régler ses frontières d'état afin de pouvoir vivre en paix avec les pays voisins.

L'article décrit donc plusieurs projets de délimitation de frontières et de documentation sur la péninsule arabe pendant la dernière décennie. Il souligne la coopération entre les organisations d'état et la firme privée en sa qualité d'entrepreneur général. Il montre bien le défi que représentent ces grands projets tant du point de vue technique que du côté de l'organisation. La longueur totale de 2.300 km d'une frontière qui passe par des terrains extrêmement difficiles, l'interdisciplinarité des métiers tels que les ingénieurs du bâtiment, les géodésiens, les géomètres, les photogrammètres et les cartographes ainsi que le travail de plus de 300 collaborateurs donne une impression de la dimension de ces projets.

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1. INTRODUCTION

During the long history of the famous cultures existing on the Arabian Peninsula many different constellations of sovereigns were existing. These resulted in various sizes and forms of the particular state territories. Especially the last century brought up modern states, which are committed to their long tradition. So it was only logical, that their state territories have to be clearly defined and documented by respective land and sea boundaries.

The company Hansa Luftbild German Air Surveys is established in the Middle East since about 40 years now, has successfully executed different surveying and mapping projects in this region under quite challenging circumstances. This long standing commitment to this part of the world, the good reputation, recognized quality of work and technical know-how led to several projects on the demarcation of international border lines as can be seen in figure 1.

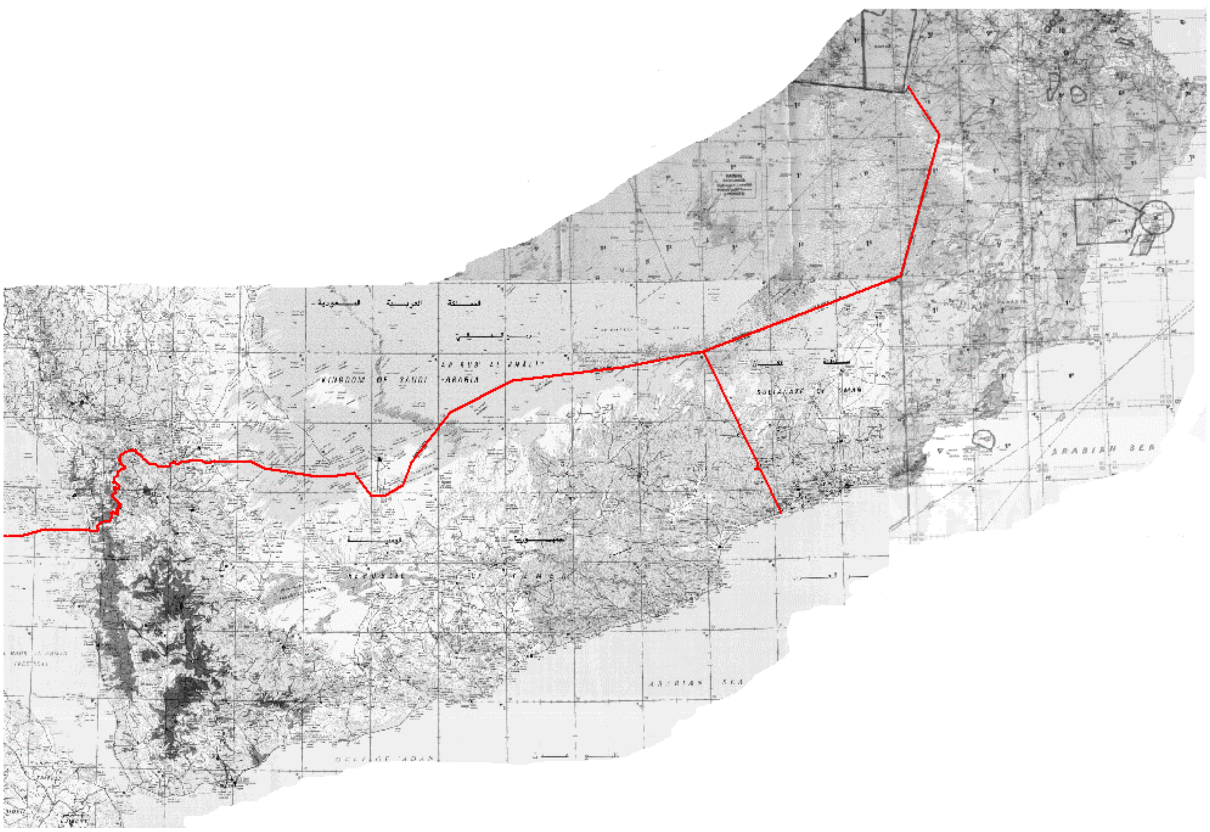

Fig. 1: Project areas on the Arabian Peninsula

2. PREPARATION PHASE

2.1 Definitions

The basis of the border demarcation projects was in all cases a bilateral international treaty which defines among others the exact course of the border line by geographical coordinates and their geodetic reference system.

The technical specifications were agreed on different proposals presented by the general contractor. So the number, the type and the design of the various border points were defined. Depending on the terrain situation these border points are based on several steel pipes drilled up to 40 meters into the soil to guarantee a safe and long lasting stability. All border points had to be built up in situ. The borderline between the first order points was defined as a geodetic line. In between second and third order points had to be established so that the average distance is about 2 till 5 kilometres and an inter-visibility in most cases is possible.

For documentation purposes the border areas had to be mapped at different map scales. Photogrammetric and remote sensing techniques should be used together with GIS and digital cartography.

Fig. 2: Signature ceremony between two states

2.2 Reconnaissance

Because the border lines are located in quite difficult terrain a thorough reconnaissance was necessary. The locations of the second and third order points had to be selected carefully especially for logistic reasons. Transportation of personnel, equipment and material in the remote areas must be possible in reasonable time. But also the locations for the base camps were selected carefully to optimise the distances for transportation.

GPS assistance to navigation and surveying, radio and later on also satellite telephones were absolutely essential for the small reconnaissance teams as well as for the whole logistic process. Very often locals helped for scouting the best tracks. But especially in the mountainous areas a helicopter mission was the only possibility to explore the terrain in short time.

Fig. 3: Reconnaissance trips in the mountains and the desert

2.3 General Contracting

The main idea behind the general contracting is to have one responsible counterpart, who has to coordinate all contractual and technical matters, guarantee the complete workflow of such challenging projects, keep the time schedule and steer all necessary subcontractors. The project periods were running between 3 and 5 years each. During this time a fully operational project organisation was established (see figure 4). This organisation is responsible for:

- Contractual and legal affairs
- Finances and taxation
- Book keeping
- Insurances
- General administration
- Technical controlling (schedules, reporting).

Up to 10 companies had to be coordinated by the general contractor Hansa Luftbild and more than 300 people were directly involved in the production process.

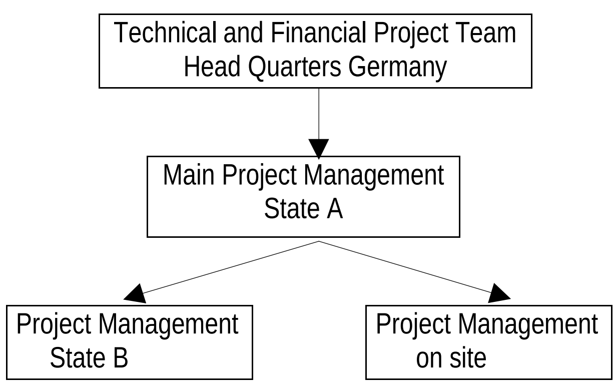

Fig. 4: Project organisation (steering group)

But also on the client's side several organisations were involved. There are joint teams be made up of each participating country for different level of the workflow. Beneath the responsible ministries a joint technical team for steering the project was established. This team had meetings on a regular basis to coordinate the permanent workflow and decide on open questions. On site a special technical field team was established for controlling and supervision. Issues on the survey and the monumentation had to be decided straight to the field works (cf. PETRING (1998)).

2.4 Logistics

The greatest part of the border lines are crossing very remote areas with adverse living conditions. The most critical issues were the high temperatures (up to 56° Celsius) and the water supply. So called base camps were established along the border lines (see figures 5 and 6). Those camps were chosen such a way as to assure that at least one water well was located within a distance of 300 km. Up to 200 people were living in those camps. The permanent catering, the medical assistance and the delivery of materials for drilling and monumentation as well as the whole communication was a great challenge. New tracks had to be established to allow the truck transportation (see figure 7).

Fig. 5: Aerial view of the base camp

Fig. 6: Mobile cabins and utilities

Fig 7: Establishment of a new track facing problems with salt lakes

The base camps existing mainly of mobile cabins were moving along the border line depending on the progress of works. To speed up the work several base camps were operated at the same time. From those camps the surveyors and the construction workers were operating with trucks and 4WD cars, but especially in mountainous areas helicopters were used for transportation of the people, equipment and materials.

3. GEODETIC LINKS

For surveying, the World Geodetic System 1984 (WGS 84) was used. This global Cartesian co-ordinate system is an earth-centred, earth-fixed reference system and represents the most accurate and modern geodetic system of international acceptance and use. It is also the reference system for the operation of the Global Positioning System GPS.

For the border surveying, in a first step in all projects a base network was established along the border line as a basis for all subsequent surveys. These base networks consisted of one datum point and a sufficient number of base survey marks along the border line. The datum points were observed and processed together with several IGS (International GPS Service)-stations to establish a precise GPS-network as a geodetic base network (cf. BEUTLER et al. (1998)), which had to be fixed to a geodetic datum like for example ITRF (International Terrestrial Reference Frame). Since all project areas were located on the Arabian Peninsula and the IGS-stations used were not all part of the same tectonic plate, even the velocity of different tectonic plates had to be taken into account during the data processing. To tie this base survey to each National Geodetic Datum of the two countries, a sufficient number of survey points in each country had to be used as part of the network. This facilitated later the necessary transformation of the base survey results (WGS 84) to each National Geodetic Datum of the countries. The measurements were all done by GPS-observations.

Due to sophisticated observation techniques and advanced processing strategies like the Bernese GPS-software the overall accuracies of the border points were in the range of a few millimetres (cf. ROTHACHER et al. (2001)).

Absolute reference of the height values to the mean sea level systems of each country was done by connecting the base survey network to bench marks of each country. For height measurements to determine the mean sea level height differences, a combination of GPS-measurements and astro-geodetic levelling was applied. In a second step after the base network, a densification network had to be established. The number of points for this network densification resulted from the condition not to exceed a maximum distance from the border line for accuracy reasons. Close to the border line temporary GPS-points were then established and used for the stake out of the border points. The border points, the network densification points and the GPS points were again measured with GPS-techniques.

4. DEMARCATION PHASE

The demarcation phase started after the final adjustment of the base survey and the network densification along the border lines. Each border point was staked out from several network points nearby by conventional surveying methods with total stations. To guarantee the necessary accuracy and reliability the redundancy for this local surveys was chosen high. The set off of the points was done over the whole construction time till the final establishment of the theodolite mounting plate on top of the pillars defining the central reference point.

The physical installation of the border points started with drilling holes down to the desired depth and the consecutive installation of stainless steel pipes. These steel pipes anchor each monument to the ground. The drilling depth and the diameter of steel pipes differ from sandy and mountainous areas. Different drilling techniques were necessary with respect to the geological conditions (see figures 8 and 9). For first and second order points 4 pipes at the corners and one pipe in the centre were brought down.

Fig. 8: Drilling in sandy terrain

Fig. 9: Transportation of drilling equipment in mountainous terrain

After the drilling and pipe installation for a border point was completed the monument could be built. Excavating the ground around the area of the installed pipes, blinding the ground, installing the reinforcement rods, concreting the monument foundation and concreting the monument pillar were typical construction steps (see figure 10). All concrete construction work was carried out in situ except for the reinforcement of the bases and the pillars which were pre-fabricated at the base camp. A typical first order point has the following dimensions:

Concrete base	2 m x 2 m x 0,5 m
Concrete pillar bottom	1 m x 1 m
Concrete pillar top	0,6 m x 0,6 m
Concrete pillar height	1,5 m

The corner pipes are connected with steel pipe hand rails and the forth corner pipe is extended vertically to a standard total height of 4,5 m above the ground to establish a steel sign sheet (see figure 11).

The first order border points are secured by 4 so called witness marks in the vicinity of about 500 m. So in total more than 1.300 points are established along those 2.300 km of border lines.

Fig. 10: Border point under construction

Fig. 11: Finished border point

5. CARTOGRAPHY

For the documentation of the border lines map series between the scales 1:10.000 to 1:1.000.000 were produced. The medium scale maps are based on photogrammetric survey flights and the small scale maps by satellite imageries and existing topographic maps. Most of the map series are so called orthophoto maps, i.e. the topographical information is composed with geo-referenced and rectified image data.

5.1 Survey Flight Missions

To cover all border project areas with its more than 100.000 km² 11 survey flight missions were planned. The image scales varied between 1:20.000 and 1:50.000. The aerial survey planes used for the projects were CESSNA 550 Citation II, CESSNA 404 Titan and ROCKWELL AC690 (see figures 12 and 13). The flight preparation and the navigation was done with the computer controlled navigation system CCNS4 (cf. HERMS (1991)). To avoid a large number of ground control points the principle of kinematic GPS determination for the photo exposure centres were used. So on board dual frequency GPS receivers and on the ground a GPS reference station were established (cf. FRIESS (1990)). In the area of the sea border in the western region the orientation of the images is done directly by a combined GPS and inertial system of type AEROcontrol II, because the establishment of ground control and the orientation by aerial triangulation is not possible (cf. HEIPKE (2001)).

The photogrammetric camera system used were of type ZEISS RMK TOP 15. To get for each country one original set of films two cameras were operated synchronized. The film processing was done in the photo laboratories of the national respectively military survey departments or at the Hansa Luftbild premises.

Fig. 12: Rockwell Aerocommander 690 Fig. 13: Cessna Citation II

5.2 Aerial Triangulation

To get the orientation of all images for the stereo plotting an aerial triangulation will be done. Ground control points (see figure 14) were signalised on the ground and measured by GPS with an accuracy of some centimetres to reference the photogrammetric block to the ground coordinate system. The bundle block adjustment for the aerial triangulation was done with the software PATB-RSG with gross error detection, self calibration and GPS determined camera positions.

14: Ground control point

5.3 Stereo Plotting and Field Verification

After the completion of aerial triangulation all basis information was available for the compilation of the topographic maps. It was performed by digital stereo plotting. The planimetric and height features to be mapped were specified by their data structure. However, not all features and their attributes to be shown in the topographical maps could be extracted from aerial photographs. Therefore information like classification of roads and tracks or water wells as well as all the geographical names was determined during the field verification phase. From the captured height information a digital terrain model was derived to compute the differential rectified images (orthophotos).

In addition to line work and orthophoto background, geographical names are an important component of topographic maps. The collection of these names in the area under survey took place simultaneously with the field verification. The verification of already recorded names (from existing maps) and the collection of unrecorded names was done in close co-operation with local authorities who allocated local inhabitants acquainted with their own localities to the field team. The names were recorded on tape which was utilised in order to avoid pronunciation mistakes and to facilitate transliteration. Each name was recorded three times and whenever possible by different speakers. Preliminary transliteration from Arabic to the Roman alphabet was performed immediately.

5.4 Cartographic Finishing

All border maps were compiled in terms of the Universal Transverse Mercator projection (UTM) with reference to the World Geodetic System of 1984 (WGS 84). During the cartographic compilation the following sources were used: field verified photogrammetric maps, names overlay for each map sheet, list of bilingual geographical names and the orthophoto mosaics. For each of the border map series a style sheet was designed to have an overall standard of the layout and the map content. Interactive editing, generalisation and final arrangements was done by digital cartographic processing with the INTERGRAPH map publishing system (see figure 15).

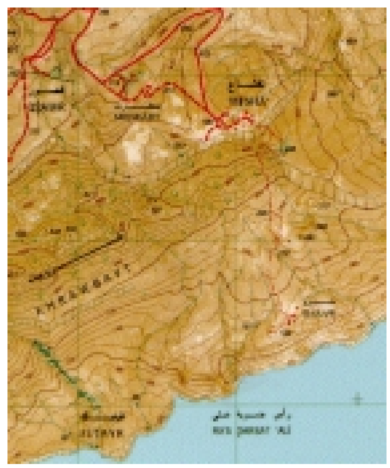

Fig. 15: Details of 1:50.000 map series in the dessert and mountain areas

5.5 Printing

From each map sheet a small edition of 1000 prints was produced at printers in Switzerland and Germany. A number of sheets were signed by both countries and delivered to the United Nations together with the treaty and the coordinates of the border points to register the border line as an international border.

6. CONCLUSION

The demarcation of three border lines on a total length of 2.300 km including the complete documentation is a great challenge. Two of the projects are finished nowadays, the last one is under good progress. Difficult terrain situations, an environment hostile to man and an enormously time pressure asked for strong organisational structures and the latest technologies. The method of general contracting is the right way to complete these projects successfully. The close co-operation between the client's organisation and the contractor is the only way to fulfil such an outstanding task.

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BIOGRAPHICAL NOTES

Ralf Schroth: Born 18.07.1953 in Berlin, studies of Geodesy at Stuttgart University, diploma degree 1977, legal surveyor 1979, scientific staff member at the Institute of Photogrammetry at Stuttgart University, Doctor thesis 1985, since 1984 with Hansa Luftbild Group, current position: managing director. Since 1991 part time lecturer at University of Hannover (Management and Business Administration).

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