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## Geographical Information in Delimitation, Demarcation and Management of International Land Boundaries

*Ron Adler*

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## Geographical Information in the Delimitation, Demarcation and Management of International Land Boundaries

by

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Dr Adler has been a Visiting Professor at Ohio State University several times and an Adjunct Professor at a number of Universities. He is the author of a textbook on Map Projections and of some 45 published articles.

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***Ron Adler***

*La caractère marquant de la notion de frontière est son universalité d'acception.*[1]

(de Lapradelle, 1928: 9).

## 1. Introduction

The number of international land boundaries is increasing. The crumbling of the Soviet Union, the disintegration of federal Yugoslavia, and the trend for independence all over the world have resulted in the emergence of 'new' states, many of them within new or undelimited boundaries. Add to this the legacy of ill-defined boundaries from the colonial period and the potential for disputes and conflict associated with boundaries is enormous.

Nevertheless, boundary creation can also contribute to the prevention of international conflict, or to its settlement, if such conflict has already arisen. Boundary creation is an interactive process involving politics, law, geography and socio-economic factors in negotiations between neighbouring countries. The architects of a boundary are the statesmen and politicians who negotiate and agree a boundary and define it within the framework of delimitation. They are supported by boundary engineers who are responsible for providing treaty negotiators with the most comprehensive and reliable information concerning the potential boundary site, and subsequent to delimitation, for the transfer of the defined boundary to the terrain.

This *Briefing* provides an overview of the state-of-the-art of boundary making on land. *Boundary Making* by S.B. Jones (1945) was an important milestone in bringing the technical aspects of boundary making closer to the boundary negotiators and decision makers. Some of the contents are as valid today as they were when the book was written, but Jones wrote before the computer era, before satellites and remote sensing, global positioning systems and geographical information systems. The technological potential available today in boundary engineering is very considerable.

The aims of this *Briefing* are twofold:

1. To present a model for the incorporation of the scientific and technological advances of the last fifty years into boundary making, and thus contribute to bridging the gap between boundary architects and boundary engineers and to show the latter (surveyors, cartographers and geographers), who have these skills, how they can be used in boundary creation and management; and,

2. To present the architects of boundaries with a review of modern technical services which are an essential part of boundary making.

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1 "*The notable characteristic of the idea of a frontier is its universality*."

The technical aspects of international boundary delimitation and demarcation are considered, including what a boundary consists of, what a boundary agreement involves, what demarcation involves and the role of the boundary engineer at all stages.

The technologies of boundary engineering are described in detail, including boundary coordinates, maps, remote sensing applications, and global positioning systems. The nature and importance of geographical information systems is considered in depth.

Two case studies of modern demarcation and recording surveys – the Iraq-Kuwait boundary and the Israel-Jordan boundary – provide comprehensive examples of the considerations and techniques described in the *Briefing* being put into practice.

## 2. Technical Aspects of International Boundary Delimitation and Demarcation

### 2.1 Introduction

There are three political consequences of delimiting a boundary:

- *Peace*. The boundary delimitation treaties concluded between neighbouring states are in most cases peace treaties or agreements stressing the peaceful permanence of the delimitation as opposed to the provisional character of armistice lines.
- *The reaffirmation of the independence of the states.*
- *Security* created by a line which is quasi-sacred, quite apart from political guarantees or military arrangements.

The American Institute of International Law in its *Declaration of Rights and Obligations of Nations*, of 6 January 1916, stated that every nation has the right, within the territory it possesses, within defined boundaries, to exclusive jurisdiction over its territory, applicable even to foreign persons. In other words, exclusive sovereignty exercised over its territory, within delimited boundaries.

The architects of a boundary are the statesmen and politicians who negotiate and eventually reach an agreement on the choice of the boundary site and its definition within the framework of delimitation. In this process they are aided by diplomats, lawyers and political advisors whose backgrounds may be in political science, law, history and economics, characteristic of boundary architects, rather than in geography, geodesy, cartography and computer science, characteristic of boundary engineers.[2]

It could be said that boundary engineers are responsible for providing the treaty negotiators with the most comprehensive and, above all, reliable information concerning the potential boundary site and, subsequent to delimitation, for the transfer of the defined boundary to the terrain.

[2] The term *"boundary engineers"* was suggested by W. D. Rushworth in a private communication, dated 13 May 1993.

The interpretation of the negotiated location on the ground and laying down the infrastructure for the administration of the boundary are often too readily relegated in importance as mere technical matters, only to re-emerge as issues of major political importance, the settlement of which is essential to avoiding conflict. It is at this stage also that boundary engineers have another important role to play.

> ...[the] *exact boundary could not be determined until the sciences of geography, geodesy and cartography had reached the point where they could furnish the data for delimitation and demarcation.*
>
> (Cukwurah, 1967: 81).

The principal objective of an international boundary must be its universal acceptance. This means that the concept is principally political in character. In its symbolic and formal aspect, the boundary is a set out line, defined by delimitation, representing separation of authority and influence in a frontier zone in such a way as to permit coexistence in the spirit of détente. Thus the delimitation has to define the location of the boundary and the procedures to be employed in the transfer of that definition to the terrain. It must also take into consideration the consequences of the delimitation on life in the area.

In the definition of the separating line between the authorities of the two states, there is often the temptation to create a 'no man's land' rather than a definite line, a zone of transition from one sphere of influence to another, avoiding disagreements over the precise location of the line. However, the concept of 'no man's land' is contrary to the nature of the sovereign state. In the words of East (1937: 259): *"States have always sought frontiers which foster separation, rather than assimilation with their neighbours."*

Delimitation is not a simple or a short process. It consists of three identifiable stages:

- *Preparation*, which includes the political as well as the technical plans for the anticipated operations.
- *The decision*, which is the actual working basis for the formulation of the treaty, which becomes the delimitation.
- *The execution* of the agreed upon and accepted treaty, namely the demarcation.

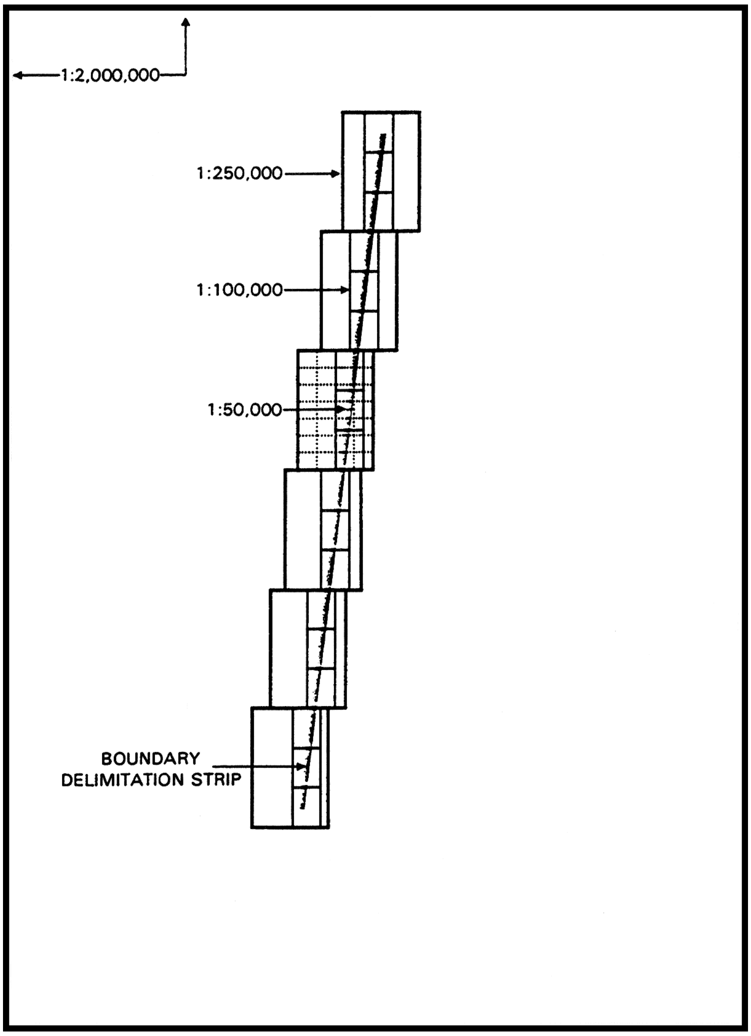
## 2.2 Preparation for Delimitation

In the preparation stage, the boundary engineer should serve as the technical adviser to the statesmen and political scientists in negotiating the treaty. The statesmen and treaty negotiators should be provided with the geographical background of the intended boundary[3] zone, and the best available topographical maps should be made available, respecting the principle 'from the whole to the part' as applied to the map coverage, beginning with a small-scale map covering the intended boundary area in one sheet and showing as much as possible of the surrounding areas. This would be followed by progressively larger-scale topographical maps, subject to

[3] The term *"boundary"* should be used for the actual boundary *line* as opposed to the term *"frontier"* which indicates a *strip* of land.

availability, the increased scale accompanied by smaller terrain coverage. Using the example of an imaginary boundary under negotiation, approximately 1,000km long and its direction predominantly north-south, the ideal coverage would be as shown in Figure 1.

**Figure 1: Map Coverage at Various Scales of the Anticipated Boundary Zone**




If maps are not available, or only partly available, in the preparation stage, satellite images or aerial photographs are a possible alternative. Satellite images of the earth are commercially available from a variety of sources such as SPOT Image, LANDSAT, and Priroda. These images, taken or sensed from a great elevation above the earth, are of limited value to the treaty negotiators, since they require interpretation, do not carry names of features and have no reference lines, such as meridians and parallels or plane rectangular grids.

It should be noted that satellite images and particularly aerial photographs contain much information missing from the map, such as details of agricultural cultivation, density of trees and bushes, dry-bed water courses, temporary structures such as ditches and fences and often traces of features no longer in existence, such as dismantled railway lines or destroyed buildings.

A field reconnaissance in the intended boundary area is essential to provide the treaty negotiators with as clear an overview as possible, updating maps if necessary, annotating satellite images and aerial photographs, noting prominent features and verifying or ascertaining their names and making note of areas which the negotiators may wish to visit because of their sensitivity such as built-up areas to be crossed by the boundary. Field reconnaissance is very desirable as a preliminary preparation for demarcation, considering possible locations for boundary points, checking intervisibility, potential reference features, approaches to the future boundary from both sides for supplies, emergencies and maintaining security arrangements.

## 2.3 The Decision Stage

Almost the same kind of technical support that is required for treaty negotiators in the delimitation preparation stage is required for arbitrators during the negotiation and decision stage. It should be noted that whatever technical data is provided by the geodetic scientist, surveyor or mapper, it should be accompanied by a statement of reliability and accuracy. The boundary negotiators have a right to expect their surveying experts to provide them with maps and/or satellite imagery, annotated with the location of prominent features along the prospective boundary zone, including point features such as peaks, walls and wells as well as linear features such as rivers, crests, prominent lines of change in cultivation, roads etc. These prominent features, verified on the ground, would not only provide the negotiators with a better background for their decisions, but would also permit the use of this information in the text of the treaty, decreasing the potential for difficulties in interpreting the intent of the signatories. A quotation from Jones (1945: 54) is very much in order here:

> *Because boundary making is in principle a continuous process, from preliminary bargaining to ultimate administration, errors at one stage have effects at later stages. For this reason, exact information about the borderland in question should be sought as early as possible in the boundary making process. Much of this information can best be obtained in the field, by direct investigation.*

### *2.3.1 Boundary definition*

The delimitation of a boundary in a treaty should be complete, accurate and precise. Jones (1945: 58) advances several methods of boundary definition, specifying that, *"a single document may employ several of them for different parts of the line."* They are:

- *Complete definition*, which is an attempt to describe the line so thoroughly that demarcation is merely a matter of routine surveying.

- *Complete definition, with power to deviate*, describing the line as completely as possible from the data at hand, but including a clause authorising the demarcators to make changes or recommend them, in order to facilitate setting out the boundary line in view of the situation on the ground.

- *Definition by turning points* is the most common and the most logical method because any line can be defined by sections, varying in length, in order to express the shape of the line. It is an accepted practice in surveying to set out a curve by creating a sequence of chords approximating the desired curve. Intervisibility between turning points is no longer a technical necessity, but it remains a most desirable feature from the point of view of boundary administration.

The directive for demarcating turning points, contained in the delimitation document, cannot be adhered to without a certain power to deviate in view of the situation on the ground. If the turning point is a mountain summit or another precisely definable feature on the ground, the location should present no difficulty, but trying to locate points not identifiable on the ground but indicated on the map can be a frustrating experience.

Attempts to define turning points by latitude and longitude or by coordinates in a plane rectangular coordinate system could also be a source of ambiguity due not only to the limitations of the instrumentation, but particularly to the datum to which the observations are referred to. Only the most modern Global Positioning System (GPS) receivers are suitable for location by pre-specified coordinates, but these problems will be considered within the documentation of a demarcated boundary.

- *Definition of a zone* within which the boundary is to be demarcated is again an undesirable method because the chances of it being successful are very low, except between countries having a friendly and particularly close relationship.

- *Natural features* appear attractive for the purposes of delimitation, as in the case of say a river as a natural dividing feature. However a more detailed definition of where exactly along the river the delimitation occurs may be difficult to apply and maintain. Jones describes these difficulties in detail, as well as giving examples of faulty delimitations.

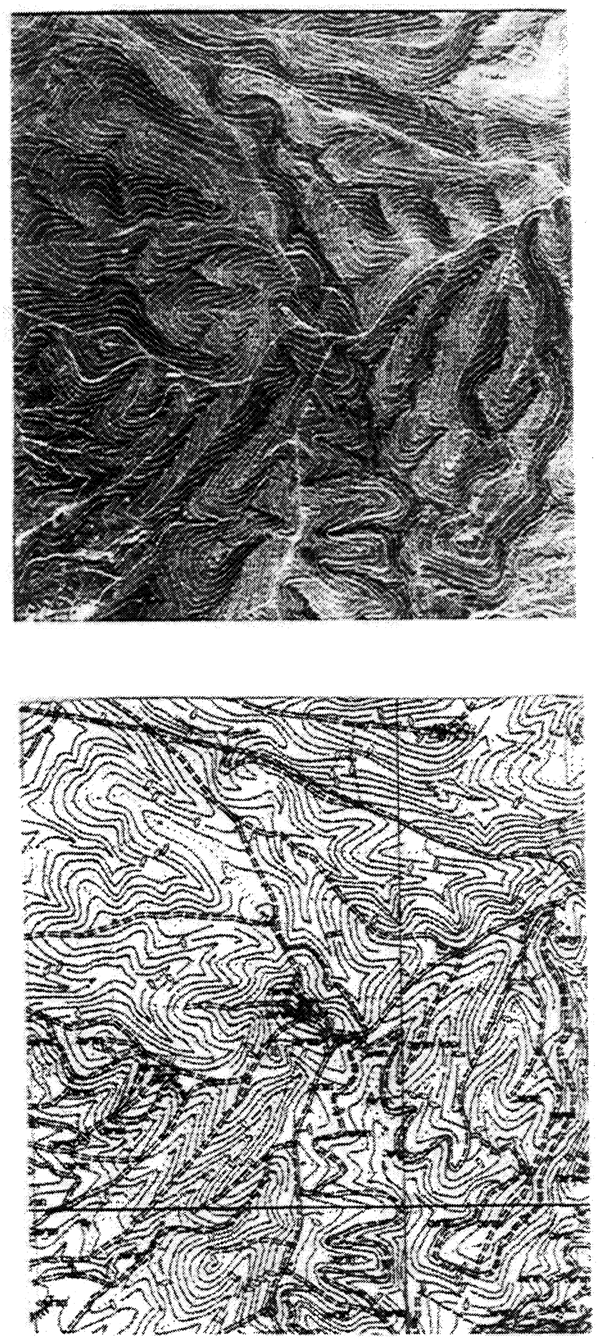
Prescott (1987) recognises only two delimitation methods, namely, the method of turning points combined with directions and distances, and the method of natural features.

### *2.3.2 Technical support from boundary engineers*

The wording of a treaty or an agreement should include anticipation of the demarcation stage and therefore boundary engineers should be represented amongst the treaty negotiators. Any deviation from the concluded treaty or agreement during the subsequent demarcation stage carries with it a potential for future disputes, minor or major, but always in danger of erupting depending on the political climate.

The use of stereoscopic views of the terrain, as recorded on aerial photographs or satellite images, parallel to the study of maps, is another way that boundary engineers can assist negotiators. One of the principal advantages of this technique is the possibility of simultaneous viewing and discussion by the negotiators of both parties. One can see in Figure 2 that the image conveys the character of the terrain better than the map. Viewing the image in such an instrument is like viewing it from a low-flying aircraft, with local water-parting lines and water-flow lines easily identifiable.

**Figure 2: An Image, Stereoscopically Observed, with Contour Lines Superimposed and a 1:50,000 Map of the Same Area**



One of the best aids to the negotiators, particularly at the stage of formulating the delineation text, is an orthophoto map or an orthophoto (for a detailed discussion see Section 3.3.6), annotated with geographical information. This is probably the best means to ensure that the decisions of the negotiators are faithfully transferred to the ground in the demarcation stage. Another product, which brings the terrain to the negotiating table, is a combination of a photograph and a map, as shown in Figure 3.

**Figure 3: Combination (photomontage) of a Map, a Model and a Photograph**
(Courtesy of Bayerischen Landvermessungsamt).

### *2.3.3 The structure of a typical boundary agreement*

> *The precise limits to the exercise of territorial sovereignty can only be determined by knowledge of the location of alignments enclosing a state on all relevant sides.*
> (Kaikobad, 1983: 119).

There is, of course, no set recipe for drafting a treaty or an agreement on an international boundary. Each case requires a set of specific references, taking into consideration the background circumstances and the geography of the boundary region. The preparation of an agreement is in the hands of politicians, the drafting in the hands of legal experts and only some salient points will be mentioned here regarding a fairly typical treaty. These include:

- The reaffirmation of peace between the contracting parties, the contribution of the agreement to the peace between the neighbours, and to regional and world peace.

- A statement regarding the principle of mutual consultation in the spirit of mutual accommodation, as well as a clear statement that the delimitation will be a milestone in preserving friendly relations and cooperation between the parties.

- A detailed description of mutual accommodations – withdrawals, exchanges of territories, straightening of lines, consideration of agricultural cultivation and of population centres, etc.

- Definition and description of the boundary agreed upon, detailed as much as possible, on the basis of the information available to boundary architects.

- The treaty delimits the boundary and also specifies the provisions for its demarcation.

### *2.3.4 Delimitation by reference to a third party*

The resolution of boundary disputes is attempted in the first instance through diplomatic means. Such disputes often include disagreements regarding the meaning of terms, expressions or clauses in a treaty, or incompatibility between the definition and the reality of the terrain. The diplomatic effort may result in negotiation, mediation and conciliation,[4] with the characteristic of a diplomatic settlement being that the parties retain control of the disagreement. Should this fail, the parties are free to choose international adjudication on the basis of international law. For the principles governing judicial settlement the reader is referred to Cukwurah (1967) and Merrills (1991) among others.

Many boundary disputes have been settled by an arbitration award or by judgment of the International Court of Justice. For details of some of the disputes settled by arbitration and judgments the reader is referred as follows:

- The *Case Concerning the Temple of Preah Vihear (Cambodia v. Thailand), ICJ Reports* (1962).

- The *Argentine-Chile Frontier Case (Palena), Arbitration Award of HM Queen Elizabeth II* (1966).

- *Case Concerning the Frontier Dispute Burkina Faso/Mali*, *ICJ Reports* (1986).

- *Rann of Kutch Arbitration, (India v. Pakistan), International Legal Materials*, Vol. 7 (1968).

- *The Taba Award (Egypt v. Israel)*, *International Legal Materials*, Vol. 27 (1988).

- *Case Concerning the Land, Island and Maritime Dispute (El Salvador/Honduras: Nicaragua intervening), ICJ Reports* (1992).

The above list is by no means comprehensive. It should be stressed that an Arbitral Award or Judgment of the International Court of Justice are in essence delimitations, with demarcations following. The demarcations can be executed by the parties concerned, by the arbitrating body or by a third party, all according to the specific circumstances of the case.

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4 *Conciliation* – a kind of institutionalised mediation or inquiry.

There is no doubt in the author's mind, that the best way to execute a successful demarcation is through the active participation of the boundary engineers of the countries concerned. Even a most successful demarcation from the purely technical point of view is not, in the author's view, a satisfactory substitute for bilateral demarcation by the parties concerned.

## 2.4 Demarcation

*Demarcation is the crux of all boundary making.*
(Cukwurah, 1967: 78).

*La démarcation, si elle est utile, n'est pas, en droit, nécessaire.*[5]
(de Lapradelle, 1928: 143).

Delimitation provides the definition of the separating line between the authority of the neighbouring states through a verbal description of the location of the boundary, sometimes accompanied by maps or sketches. This verbal definition contained in a treaty, an agreement, or an arbitration award has to be transferred to the terrain, a process termed demarcation. The mission of demarcation is certainly non-political in character, its functions are technological and its decisions limited to the transformation of the verbal, graphical and digital definitions to the terrain surface. The great importance of demarcation as the application of the delimitation on the ground was expressed in the *Taba Award* (International Legal Materials, 1988: 1,466):

> *If a boundary line is one demarcated jointly by the parties concerned, the demarcation is considered as an authentic interpretation of the boundary agreement even if deviations may have occurred or if there are some inconsistencies with the maps.*

In some of the professional literature and in a number of treaties, the demarcation is considered to be part of delimitation, although there is a clear difference between the two. The principal task of the demarcation is to set out on the ground, as exactly as possible, the *line* of the boundary as defined in the delimitation document. It is inappropriate and dangerous to dismiss the demarcation as a purely technical operation of minor importance. The difference between delimitation and demarcation is defined in Oppenheim (1992: 20):

> *The common practice for land boundaries is, in a boundary treaty or award to describe the boundary in words, i.e. to delimit it; then to appoint boundary commissions, usually joint, to apply the delimitation to the ground and if necessary to mark it with boundary posts or the like, i.e. to demarcate it.*

There are those who feel that although the demarcation is useful, it is not strictly necessary from the legal point of view. This may perhaps be true in the cases where the line of the boundary follows well defined and recognisable natural features such as rivers or canals. Only a definition of where the demarcation is, within the feature, is necessary in order to symbolise and preserve the 'sanctity' of the boundary and to aid the maintenance of the boundary regime. Furthermore, in some places demarcation is not feasible, for example in areas of swamps or flying sands. Indeed, many delimited boundaries were not demarcated in the past for a variety of reasons such as: the expense and logistic effort involved; the emotions of local inhabitants as

5 "*Demarcation, although useful, is not necessary in law*."

to the erection of monuments; adverse climate, or major difficulties in the interpretation of the delimitation document causing the matter to be returned to the diplomats or even submitted to arbitration. In general, however, every effort has to be made to demarcate the boundary wherever possible, particularly in cases where the boundary does not follow natural features.

### *2.4.1 Personnel – Commission of Demarcation*

Assuming that the formulation of the delimitation document is clear and based on preliminary knowledge of the terrain in the area of the frontier in which the actual boundary line is to be set out and documented, the demarcation operation is technological in character and should be entrusted to a commission composed mainly of boundary engineers. The appointment of the Commission of Demarcation should be specified in the Delimitation Treaty or Agreement, its terms of reference stated and its composition bilateral and based on equality of representation of the parties on both sides of the boundary. The extent of work delegated to the Boundary Demarcation Commission is a function of the quality of the delimitation and the geographical reliability of the definition. The agreement should clearly state the degree of freedom given to the Boundary Demarcation Commission to apply its own judgement in transferring the delimitation to the terrain, according to the situation encountered on the ground.

Cases are known where the accumulation of delimitation imperfections was such that the Boundary Demarcation Commission was unable to successfully conclude its mission and returned the matter to the political level. It is at this stage that conflicts arise, which could have been avoided if the geodetic-geographic information were available to the treaty negotiators. The seeds of conflict are sown in all cases where a discrepancy arises between the line defined and the line demarcated on the ground.

Study of the various writings on the subject of demarcation strongly suggest that the head of the commission should be an official whom the treaty negotiators and signatories regard as their representative, and often the choice falls upon high ranking military officers. The commission usually feels that a legal expert should be available for consultation and therefore a lawyer, experienced in international law, should be a member of each national team.

The real demarcation work will undoubtedly fall on the boundary engineers and each party should appoint a chief engineer who will be in charge of all surveying, demarcating, recording and mapping operations, with a number of survey teams available to him, their number depending on the length of the boundary to be demarcated and the terrain characteristics along the boundary. There is a possibility of course that the chief engineer would also be head of the commission, but this depends on whether he/she is of sufficient personal calibre, whether he/she is known to the boundary architects and whether the other party has a person who would also fulfil these conditions. Once again the need for bilateral parity should be stressed; persons of equal standing and similar qualifications, an equal number of delegates in the field, meeting places rotating between the parties – all these contribute to the quality of cooperation during and after the demarcation.

### 2.4.2 Demarcation in practice

An ideal boundary would be a line that follows a well-defined natural feature or a series of straight lines between inter-visible points. In reality boundaries are often difficult to demarcate and maintain, simply because they are not logical in terms of physical geography. This is perhaps an over-pessimistic perspective on boundary making, but one which reminds all boundary makers not to add to existing problems by ignoring the geographical and geodetic aspects in boundary delimitation and demarcation.

A useful approach is to define the boundary as a line composed of points, remembering the following terms:

*Point* *"that which has position but no magnitude"*
(Concise Oxford Dictionary, Fourth edn., 1954).

*"a specific, narrowly localised place having no relevant size or shape"*
(Webster New International Dictionary, Vol. 2, 1966).

*Line* *"limit, boundary", "straight or curved continuous extent of length without breadth", "track of moving point"*
(Concise Oxford Dictionary, Fourth edn., 1954).

Given the challenge of transforming a verbally and/or graphically delimited boundary to the terrain, points have to be used, which can then be joined to form a line. The problem arises then of selecting points which represent, as truly as possible, the delimitation. The selected points then have to be monumented, in other words, marks placed at the location, so as to make them easily identifiable and visible. From the purely economic point of view, there should be as few points as possible, saving on demarcation and maintenance costs. This however is a consideration which cannot always be followed in practice.

Ideally, from any point along the boundary one should be able to see two boundary monuments, implying that the monumented points should be prominent features. In addition, during the delimitation and demarcation stages, inter-visibility between the monumented points is a most desirable property, even if not an absolute requirement. Intervisibility means the physical ability to observe point B from point A and vice versa. The principle of inter-visibility was essential during the pre-GPS era when the location of a new point was fixed by measuring a distance and direction between the new and an already fixed point. This principle is no longer essential since the advent of GPS positioning, which is independent of inter-visibility and does not require a direct measurement between points. Thus the question of density of markers can be considered independently.

A useful monumentation principle is included in Article 6 of the *Treaty between Poland and Germany concerning legal relations at state frontier and cooperation and mutual assistance in frontier matters*, signed in Berlin on 28 October 1969 (United Nations Treaty Series, 1972: 240):

*(1) in land sectors the frontier line shall be marked by the following frontier marks:*

1. *By two concrete posts, each placed, as a rule, 2.5 meters from the frontier line, and a boundary stone placed between the posts directly on the frontier line;*

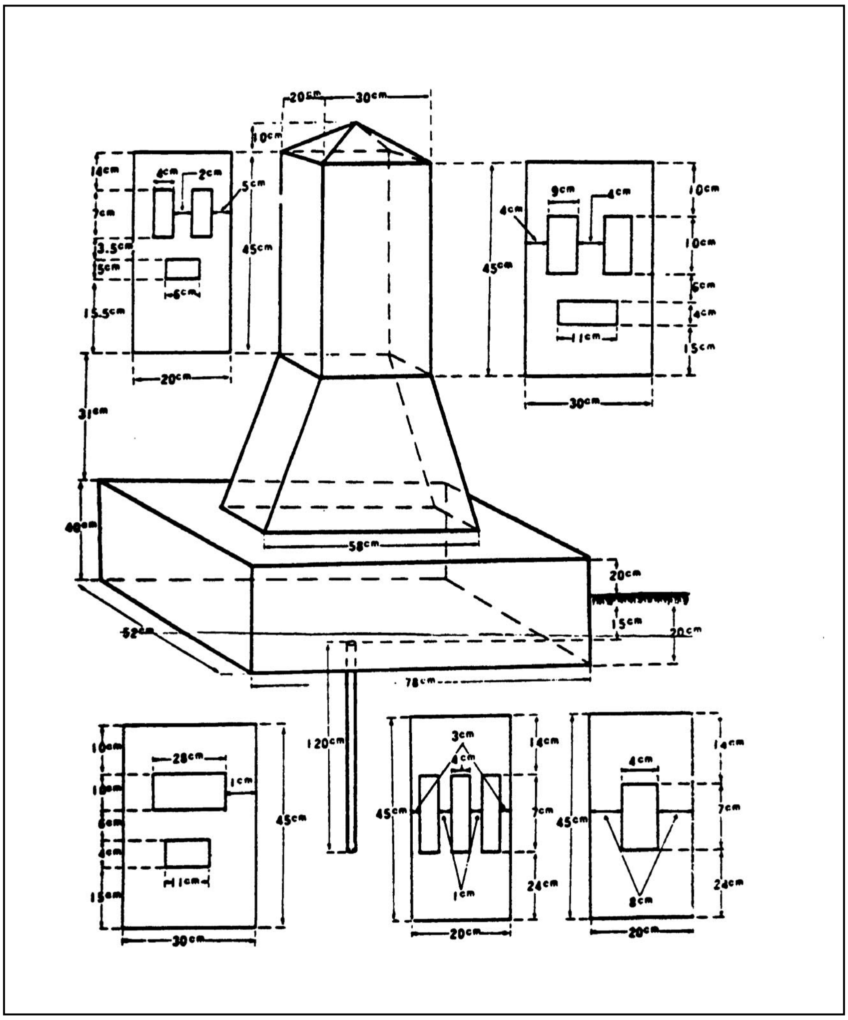
2. *At the basic turning points of the frontier line and at distinctive places thereon, by two concrete posts and by a concrete pillar placed between the posts and on the frontier line itself.*

This is of course only an example of a monument mark and each boundary treaty or agreement may choose its own form of monuments. Figure 4 provides an example of a boundary pillar. Another example of a boundary marker specification can be found in the *Burma-China Protocol* (UN Treaty Series, 1976, Vol. 1011) (Figure 5).

**Figure 4: A Boundary Pillar between Canada and the USA**
(By courtesy of the USA-Canada Boundary Commission).


In the GPS era, when practically all present and future surveys are likely to be executed by this method, it would be a good idea to place a mounting plate on top of the monument or pillar, so that the GPS antenna can be placed on it directly, automatically centred.

**Figure 5: A Specification Diagram of the Boundary Marker between China and Myanmar**




### *2.4.3 Specification*

A general specification of demarcation can be found in the Poland-Germany treaty mentioned above, where the specification of frontier demarcation documents is as follows:

1. *The description of the course of the frontier line contained in the Protocol;*

2. *Maps of the course of the frontier line;*

3. *Sketches of the geodetic grid (network) and measurements (survey) of the frontier line;*

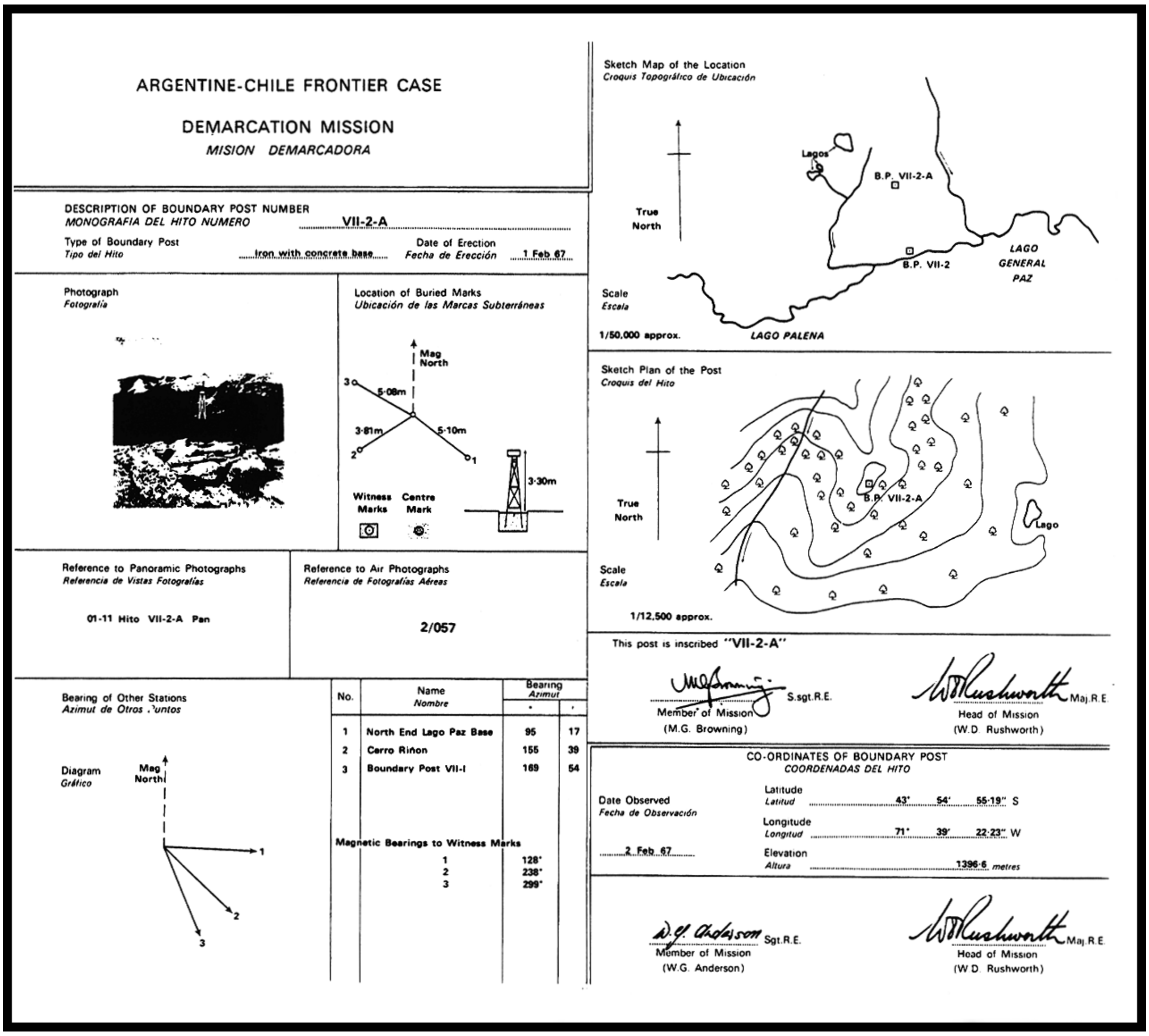
4. *A list of the coordinates of the frontier marks and geodetic points situated on the frontier line;*

5. *Protocols relating to placement of the frontier marks, together with sketches; and,*

6. *Protocols relating to the placement of auxiliary frontier marks, together with photographs.*

It is extremely important to have all the demarcated boundary points properly described, including witness marks which are essential to reconstruction or replacement of a lost or damaged marker. These marks are usually buried in the ground.

**Figure 6: Boundary Point Description Example**
(reduced from original size).


ARGENTINE-CHILE FRONTIER CASE
DEMARCATION MISSION
MISION DEMARCADORA
DESCRIPTION OF BOUNDARY POST NUMBER / MONOGRAFIA DEL HITO NUMERO: VII-2-A
Type of Boundary Post / Tipo del Hito: Iron with concrete base
Date of Erection / Fecha de Erección: 1 Feb 67
Photograph / Fotografía
Location of Buried Marks / Ubicación de las Marcas Subterráneas
Mag North
5·08m
3·81m
5·10m
3·30m
Witness Marks
Centre Mark
Reference to Panoramic Photographs / Referencia de Vistas Fotográfias: 01-11 Hito VII-2-A Pan
Reference to Air Photographs / Referencia de Fotografías Aéreas: 2/057
Bearing of Other Stations / Azimut de Otros Puntos
Diagram / Gráfico
Mag North

| No. | Name / Nombre | Bearing / Azimut ° | ′ |
|---|---|---|---|
| 1 | North End Lago Paz Base | 95 | 17 |
| 2 | Cerro Riñon | 155 | 39 |
| 3 | Boundary Post VII-I | 169 | 54 |

Magnetic Bearings to Witness Marks
1 128°
2 238°
3 299°

Sketch Map of the Location / Croquis Topográfico de Ubicación
True North
Lagos
B.P. VII-2-A
B.P. VII-2
LAGO GENERAL PAZ
Scale / Escala 1/50,000 approx.
LAGO PALENA
Sketch Plan of the Post / Croquis del Hito
True North
B.P. VII-2-A
Lago
Scale / Escala 1/12,500 approx.
This post is inscribed "VII-2-A"
S.sgt.R.E. Member of Mission (M.G. Browning)
Maj.R.E. Head of Mission (W.D. Rushworth)
CO-ORDINATES OF BOUNDARY POST / COORDENADAS DEL HITO
Date Observed / Fecha de Observación: 2 Feb 67
Latitude / Latitud: 43° 54′ 55·19″ S
Longitude / Longitud: 71° 39′ 22·23″ W
Elevation / Altura: 1396·6 metres
Sgt.R.E. Member of Mission (W.G. Anderson)
Maj.R.E. Head of Mission (W.D. Rushworth)

A very good example of boundary points description is taken from the demarcation by a British Military Survey team, following the arbitration award in the *Argentine-Chile Palena Frontier Case*. The following elements should be included in all demarcation descriptions:

- Name and number of the boundary point.
- Description of the marker, including a photograph.
- Reference measurements to witness marks.

- Reference directions to prominent features in the vicinity.
- Sketch map of the vicinity (approach map).
- Detailed sketch of the immediate vicinity.

The quality of the description reproduced (reduced in size) in Figure 6 is so good that it can be regarded more as a model than what one sees in surveying practice. The documentation of demarcation is of such importance that no effort should be spared to ensure that the descriptions are clear and properly preserved.

### *2.4.4 Boundary datum*

Another aspect of documentation is the expression of position of the boundary markers (after the post-demarcation survey) within a well defined coordinate system. It is suggested that the boundary partners decide on a separate boundary datum and on a boundary coordinate system independent of the geodetic control system existing in the two neighbouring countries.

A boundary datum to which all the computations of position are referred includes the following parameters:

- Two parameters defining the ellipsoid representing the earth, one of which must be linear. It is an accepted practice to define the ellipsoid by the length of its major semi-axis and the flattening.[6]
- Longitude and latitude of the datum point.
- An initial azimuth to another boundary point.
- The geoidal distance at the datum point, which shows the separation between geometric (ellipsoid) and physical (geoid) surfaces.

These rather complex problems are treated in Vanicek and Krakivsky (1982), Bomford (1980), Rapp (1989) and others and are outside the scope of this *Briefing*. This unique coordinate system defined for documenting the boundary avoids the necessity of using the control systems of the parties, which is often a sensitive matter with security conscious countries.

Considering the fact that the position of boundary defining points is likely to be obtained from GPS observations, it seems to be becoming a standard practice, to express the boundary position by geographical coordinates of latitude and longitude.

[6] *Flattening* is expressed by the formula f = a-b/a in which 'a' and 'b' are the semi-axes of the 'a' ellipsoid, 'a' being the major semi-axis and 'b' the minor.

### *2.4.5 Boundary Geographical Information Systems*

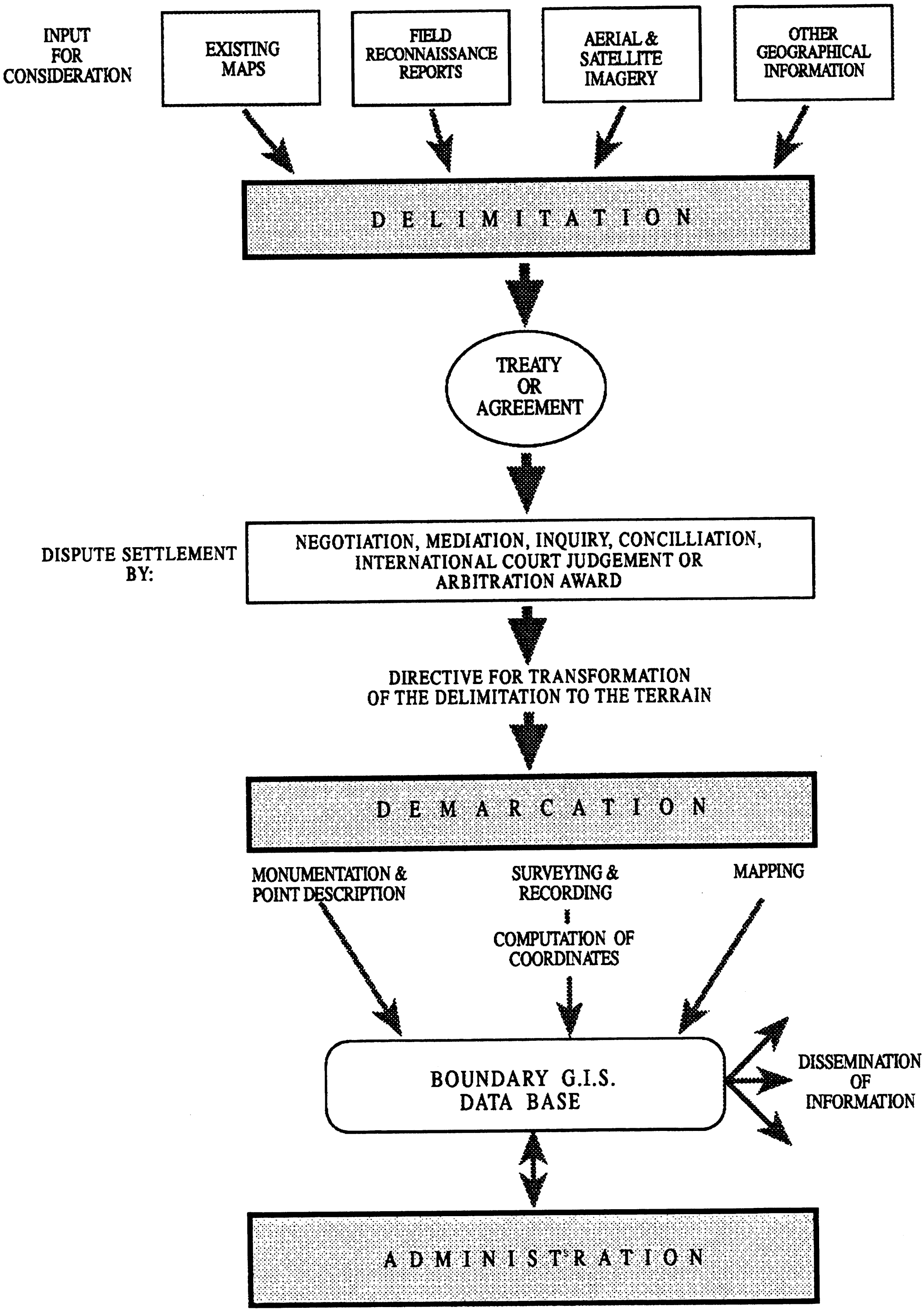
Demarcation records are usually voluminous. In the case of the 460km of the demarcated boundary between Poland and Germany, there are 646 pages of protocol in Polish and 584 pages in German, 34 maps, 143 pages of coordinate lists and 169 pages of frontier mark descriptions (UN Treaty Series, 1959, Vol. 319: 112).

The very volume of the boundary records speaks for conversion of data into digital form in order to create a boundary Geographical Information System (GIS) from which information can be easily disseminated.

### *2.4.6 Summary*

In order to summarise the technological services to delimitation and demarcation, the whole boundary creation process is shown schematically in Figure 7, starting with negotiations leading to delimitation and ending with routine administration of the delimited and demarcated boundary.

**Figure 7: Schematic Diagram of Boundary Creation**



# 3. The Technologies of Boundary Engineering

*As for the future, your task is not to foresee it, but to enable it.*
(Antoine de Saint Exupery, *Time*, June 1976).

## 3.1 Introduction

There is a range of technical resources available to the boundary engineer in support of boundary preparation, delimitation and demarcation activities. Maps have always been used in boundary making but technological advances in the past 50 years have improved the range and quality of resources and services available to international boundary makers. Remote sensing, aerial photography, global positioning systems and other surveying systems together with computer applications have both increased the range and quality of data available, and improved the means of its interpretation and application.

## 3.2 The Use and Abuse of Significant Figures – Accuracy Estimates of Digital Data

International agreements and treaties, awards, judgments and demarcation records, include, in most cases, coordinates – plane rectangular or geographical (longitude and latitude) – azimuths and distances, in order to define boundaries. All those responsible for the formulation of these documents have to be aware of the importance of significant figures.[7] They also have to be aware of the term *accuracy*, which expresses the closeness to the true value and the term *precision*, which expresses the consistency of the measurement procedure and its degree of refinement. In real life no true value or absolute accuracy exists and therefore the term *accuracy estimate* is used, which is obtained from the precision of procedures employed to produce a value. Whenever accuracy is mentioned, an estimate of accuracy is meant.

Consider a measured distance of 5,306 metres (4 significant figures). This means that the distance was measured with an estimated accuracy of ±0.5m. If the measured distance is 5,306.5m (5 significant figures), it means that the estimated accuracy is ±0.05m.

If the coordinates are given as Y = 688,723.4m, X = 546,375.5m, the estimated accuracy is ±0.05m and if Y = 688,723.41m and X = 546,375.53m the estimated accuracy is ±0.005m (5 millimetres).

In geographical coordinates given as latitude 35°20’N and longitude 55°10’E, the implied accuracy estimate is ±0.’5 or ±30”. Remembering that 1 second of arc is equal to approximately 30m on the earth’s surface, the estimated accuracy is ±900m in each coordinate or ±1,273m in position!

If, however, the coordinates are given as 35°20’24”N and 55°10’17”E the implied accuracy estimate becomes ±0.”5 which equals ±15m on the ground and ±21m in position. Finally, with

[7] The number of significant figures in a measured or computed value depends on the precision of techniques employed. It has to be assured that precision estimates were made by experts.

the given coordinates of 35°20'24".12N and 55°10'17".27E, the implied accuracy estimate is ±0.15m in each coordinate and ±0.21m in position.

### *3.2.1 Implications of Significant Figures*

Architects of treaties have not always been aware of the implications of significant figures. One of the many cases of delimitation of a boundary by coordinates, which was particularly common in Africa, is the boundary between Uganda and Tanzania, west of Lake Victoria. The boundary was delimited as a line following 1° South latitude. McEwen (1971) expressed surprise that the demarcated line is 400m north of the line stated in the treaty. However, the implied accuracy of the delimitation was ±0.5° of latitude, corresponding to ±50km on the ground! McEwen arrived quite correctly at the conclusion that the demarcated line represents the position of the boundary, without explaining that the original delimitation of 1°S was so lacking in accuracy, that only a very approximate position was expressed. If the delimitation were expressed as 1°00'00" S, the accuracy implied would have become ±15m.

Brownlie's (1979) work on African boundaries includes many cases where a complete lack of awareness of the meaning of significant numbers can be found. A much better approach can be found in the protocol between Myanmar and China (UN Treaty Series, 1976: 265) describing the boundary pillar No. 1:

> *Single pillar of medium size, placed in latitude N 25°32'46".31 and longitude E 98°09'18".03 on top of a conical shape hill. In magnetic azimuth of 149° and at a distance of 5.4m measured on the spot, there is a rectangular concrete block and in magnetic azimuth of 55°30' and a distance of 202 meters, measured on the spot there is a high peak...*

The accuracy estimates for position are realistic, ±0".005 = ±0.15m in each coordinate, 0.05m for a measured distance and ±30' for a magnetic azimuth.

The lack of attention to significant figures is evident even in relatively modern treaties. In the *Treaty to Resolve Pending Boundary Differences and Maintain the Rio Grande and the Colorado Rivers as the International Boundary between Mexico and the United States of America* (UN Treaty Series, 1973: 87), the table of coordinates is given in metres: Station 1, North 209,008.07 and East 81,418.18, with a statement that these are coordinates in Texas State Lambert Projection, South Control Zone, implying an accuracy of ±0.005m in each coordinate. Further on in the Treaty however, there are areas, computed from coordinates, given as 7.75 acres = 3.13 hectares, implying an accuracy of ±50 square metres. This is an example of incompatibility of significant figures. Either the traverse coordinates are too precise or the areas are given with insufficient precision.

To summarise this topic for boundary applications, it should be remembered that accuracy estimates are expressed as ± half the last significant figure. The estimate, and consequent decision on the number of significant figures, has to be made by an expert in the analysis of the measurement and computational procedures. In all analysis of boundary treaties in which numerical values are mentioned, attention must be paid to significant figures in each value.

## 3.3 Maps

A map is a scale model – a two dimensional (plane) representation of the three-dimensional surface of the earth, showing a selection of material or abstract features. It is a portrayal of geographical facts, but also of political facts associated with them (Hyde, 1993). Maps are heavily relied upon in all stages of boundary making and map evidence plays a major part in questions concerning boundary alignment (Akweenda, 1990). Maps illustrate the course of the boundary in different stages of boundary making:

- As a background to negotiations leading to delimitation.
- As an aid to the instrument of delimitation, becoming a directive for demarcation.
- Showing the boundary 'as made', as demarcated, or, if the boundary is not demarcated, as an expression of the recognised alignment.

One should be aware, however, that *"a map has probative value proportionate to its technical qualities"* (Brownlie, 1979) and it would therefore seem appropriate to consider some of these cartographic qualities. A map should have its own technical authority, some of which is often acquired through the professional reputation of the mapping agency which produced the map. The real authority, however, is achieved only through analysis of the map content, through examination of its generation process and through awareness of the map's limitations. It should also be remembered that the alignment of a boundary is seldom an integral part of the cartographic process and its incorporation in the map has to be carefully examined.

### *3.3.1 The technical qualities of maps*

Cartography is the art, the science and the technology of making maps, each one of these aspects contributing to the quality of the final product. In the analysis of map quality, the following factors have to be considered:

- Distortion due to projection.
- The source of data acquisition.
- Geodetic control for the mapping process.
- Map accuracy standard or an error balance of the mapping process.
- Deterioration of map quality through revisions.
- Correctness and completeness of non-quantitative information.

***Distortion due to projection***
In the representation of the curved surface of the earth, two projections are involved, namely, from the physical surface to the geometrical reference surface (ellipsoid or a sphere) and from the reference surface to the plane.

Distortion due to the transformations from the physical surface to the reference surface at sea level, can be considered errorless for all practical purposes, because all surveying and mapping methods take care of this problem in such a way as to eliminate its influence on the map quality.

The projection from the ellipsoid or a sphere, representing the earth, to the plane of the map involves distortions of shape (direction), area and distance. The theory of map projections is a separate topic of geodetic science and has been treated by a number of authors – Richardus and Adler (1972), Maling (1973), and others. The distortion due to map projection can be regarded as distortion of scale, which in the case of major map projections, such as Transverse Mercator, Universal Transverse Mercator and Lambert Conformal, does not exceed 0.2%. The scale distortion is a ratio of distance measured on the map and converted to ground distance, as compared with the true distance between the same two features.

All coordinates and distances measured on a map carry a distortion due to the map projection, in addition to the error of the measurement itself.

***The source of data acquisition***

Most topographical mapping produced in the last fifty years is based on aerial photography. The source of data acquisition is, of course, important in setting up a quantitative error balance of the mapping process, but from the point of view of qualitative accuracy, it is a question of interpretation and classification, in mapping land use, roads, buildings, power and communication lines. The errors of interpretation are regarded as *"errors of commission"* whilst the errors in classification are regarded as "*errors of omission*" (Maling, 1989: 172), and methods exist for quantifying both types.

It is safe to assume that photogrammetric operators responsible for compilation from aerial photographs are excellent photo interpreters, and therefore for boundary making applications, mapping from aerial photographs by an agency of professional reputation, accompanied by field verification procedures and followed by appropriate compilation, is the most reliable procedure.

Mapping from satellite imagery, which has made great strides in the last decade, is less reliable as far as interpretation and classification are concerned, but the panchromatic imagery has improved as far as resolution is concerned and thus this source of data acquisition cannot be ignored. It should also be remembered that satellite imagery, properly annotated and interpreted, is an alternative to mapping in cases when suitable scale, good quality, up to date maps are not available.

***Geodetic control for the mapping process***

All mapping has to be based on a geodetic control network – a network of points physically marked on the earth's surface, the position of which is known with great accuracy, relative to each other within the network – and the whole network positioned accurately within an earthwide system. These conditions are necessary because the geodetic control network defines the coordinates to which positions of all mapping detail are subsequently related. It is the position of geodetic control points on the earth's surface that defines the position of lines of geographical coordinates, the meridians and the parallels, and not vice versa. Many users of the coordinate systems are not aware of this most important principle.

A geodetic control network must also refer to a specified geodetic datum, a definition of the reference surface and the network's connection to it. The reference surface of the earth is an ellipsoid of revolution, a three dimensional geometric figure, created by turning an ellipse around its minor (smaller) axis. An ellipsoid is most often defined by the length of its semi-major axis and its polar flattening.

The true figure of the earth is the geoid, an equipotential surface at the mean sea level, which cannot be expressed by a mathematical formula. The geoidal surface is represented by an ellipsoid, in accordance with the principle that the best fit between the geoid and the ellipsoid has been achieved, i.e. the sum of the undulations of the geoid above and below the surface of the ellipsoid tends to zero. Many earth ellipsoids were and still are in use in different parts of the world, but today only a small number are relevant. Table 1 shows the most commonly used ellipsoids.

**Table 1: Most Commonly Used Ellipsoids**

| *Date* | *Name of ellipsoid* | *Length of semi-major axis in metres* | *Flattening* | *Remarks* |
|---|---|---|---|---|
| 1940 | Krassovsky | 6378245 | 1/298.3 | Used in the former Soviet Union and the former 'Eastern Block' |
| 1980 | Geodetic Reference System | 6378137.0 | 1/298.25722101 | The system approved by the International Union of Geodesy and Geophysics |
| 1984 | World Geodetic System | 6378137.0 | 1/298.257223563 | The system used for GPS positioning |

***Map accuracy standard or an error balance of the mapping process***

Some countries have a National Map Accuracy Standard, which expresses accuracy requirements, or a map accuracy standard which a mapping agency or a private company uses to monitor the quality of its products. These accuracy standards enable the map user to have confidence that the map product satisfies the requirements of the envisaged specialised map use.

The map accuracy standard, both planimatric-positional and altimetric-elevational, depends on a quantitative evaluation of the balance of errors involved in the map data acquisition and in the cartographic and printing processes.

A positional error is the difference between the location of points of map detail and their true location on the ground, both measured with respect to the same coordinate lines – Eastings and Northings of the plane rectangular grid, or meridians of longitude and parallels of latitude of the geographical graticule. The comparison between the map values and ground values has to take into consideration the scale of the map. A height error is the difference between the elevation of a point ascertained from the map and the elevation of the same point on the ground.

In order to obtain a statistical evaluation of map accuracy a sample selection of points has to be made. Usually, in positional evaluation, points representing well-defined detail features are selected, such as intersections of road and railway lines, corners of walls and centres of wells. Denoting the error vector by 'v', which signifies the distance between the map position and the ground position of features in the selected sample, we can compute the root mean square error of position 'Mrms' in the map by:

$$\text{Mrms} = \pm\sqrt{\frac{[vv]}{n-1}}$$

where 'n' is the number of points in the sample and 'v' the vector of an individual positional error.

An inspection of a simple plot of the error vectors would ensure that the vectors are random in character, as they should be. 'Mrms' is an expression for standard deviation (sometimes erroneously identified with standard error) at the one sigma level, that is at a 68% probability.

The US National Map Accuracy Standard in Thompson (1981: 104) reads as follows:

> Horizontal accuracy. *For maps on publication scales larger than 1:20,000, not more than 10 percent of the points tested shall be in error by more than 1/30 inch measured on the publication scale; for maps on publication scales 1:20,000 or smaller, 1/50 inch. These limits of accuracy shall apply in all cases to well defined points only.*

In metric units, for the 1:20,000 and larger scales, the tolerance is 0.85mm at the publication scale and for 1:20,000 and smaller scales, the tolerance is 0.5mm at the publication scale.

An important addition to the definition was given by Vogel (1981: 55):

> *...90 percent of all well-defined planimetric features, except those unavoidably displaced by symbolic exaggeration...* [and] *with reference to a prescribed datum*.

Symbolic exaggeration is a standard cartographic procedure and one can expect symbolic exaggeration in the vicinity of major roads and in the representation of buildings in small scale maps. The reference to a prescribed datum means that the position is referred to a geodetic control network, as previously mentioned.

Turning to the "*not more than 10 percent of the points tested...*" requirement. This 90% probability is expressed by 1.645 sigma level or 1.645 standard deviation, so when judging compliance of a map with the National Map Accuracy Standard, one has to remember that the 'Mrms' computed has to be multiplied by 1.645 in order to adjust it to the 90% probability level.

This topic can be summarised by saying that the American approach, although not free of imperfections, provides a viable criterion and a map carrying the statement "*This map complies with National Map Accuracy Standards*" is of a known quality.

The same simplicity in defining a criterion can be found in the US National Map Accuracy Standard for heights:

> *Vertical accuracy, as applied to contour maps on all publication scales shall be such that not more than 10 percent of the elevations tested shall be in error more than one-half the contour interval* (Thompson, 1981: 104).

A new National Cartographic Standard for Spatial Accuracy has been prepared (Morrison, 1994) and is much more demanding than the old one. The positional error converted from the map to the ground, is approximately 10m, the elevation error varies between 2m and 5m.

At the same time, one should be aware of the fact that the estimates of errors are on the conservative side and in fact most maps produced by the national mapping agencies have accuracies better than the above-mentioned estimates. It is therefore necessary to analyse quantitatively the various types of errors that combine to result in the total error of the map.

### *Types of Error*

*$m_1$ = The error of geodetic control*
Geodetic control is established today almost exclusively by means of GPS. This technology has the ability to furnish position with a conservative estimate of accuracy of 2m, which at the scale of 1:50,000 is 0.04mm, a totally insignificant quantity from the point of view of its contribution to the total map error. For old maps however, the error of position of the geodetic control could be estimated as 30m, which at the 1:50,000 map scale is 0.6mm.

The error of plotting the control network has to be considered only where the plotted control is used for the survey of detail. In modern mapping, the plotted control is of no significance, since the control of locational and elevational data are used directly in orienting the aerial photographs from which detail is surveyed.

*$m_2$ = the error of mapping of detail*
Maling (1989) estimates the root mean square error in mapping (horizontal position of detail) in a 1:50,000 map to be 10-15m and in altimetry (height) as 2.2-3.8m, which appears to be a realistic estimate, although in modern digital mapping better accuracies can be expected for well defined points of detail.

*$m_3$ = the error of cartographic plotting*
The source of this type of error is the drawing, or in most cases scribing of map detail. This error is estimated to be 0.2 mm at the map scale, which for 1:50,000 is 10m on the ground.

*$m_4$ = the error of reproduction*
This is an error caused by the photo-mechanical processes involved in preparation of the map for printing and the printing itself by offset methods, including the stability of materials. This error is estimated to be 0.2mm which is 10m on the ground in the case of a 1:50,000 map.

*M = estimate of total map error*
This estimate is arrived at by summing up squares of the individual errors and taking the square root of the sum:

$$M = \sqrt{m_1^2 + m_2^2 + m_3^2 + m_4^2} = 0.7\text{mm}$$

at the map scale, which for a 1:50,000 map would be 35m on the ground. It could be argued that this is a very conservative estimate, which is probably true. The author's estimate is supported by Maling (1989), who estimated the total error to vary between 0.42mm and 0.73mm, i.e. 20-24m.

All the above considerations are applicable as a root mean square error at the one sigma (68%) level. If one wishes to increase the probability to 90% which is approximately two sigma level, the total estimated map error for a 1:50,000 map may reach 70m. This must be taken into consideration when evaluating the quality of delimitation and its limitations.

However, when using maps for treaty negotiation or for the purpose of aid to delimitation, which is a directive for demarcation, one must be aware of the limitation of the medium used, which in most cases is not a modern digitally surveyed-data set disseminated in a map form, but a map conventionally surveyed from aerial photographs and reproduced by a conventional cartographic process.

***Deterioration of map quality through revisions***

It has been a conventional cartographic procedure to partially revise maps, particularly the roads and built up areas, before reprinting. These revisions were often made by approximate methods directly on the graphical database, resulting in gradual deterioration of map quality, as a function of the number of revisions. It would be almost impossible to estimate the actual magnitude of errors caused by revisions, but one should be aware of the danger of gradual deterioration of a map repeatedly revised. Nowadays revisions are made to the digital database, causing no significant deterioration of the map quality.

***Correctness and completeness of non-quantitative information***

Names are typical non-quantitative information in a map. The incorrect naming of features, or incorrect transliteration, are common examples of errors in maps used in boundary making. Particular attention should be paid to correct recording and verification of all non-quantitative information gathered.

In the last few years, we have seen a gradual transformation in the concept of a digital database for mapping, which means a digital storage of collected data, including updates. This approach will result in reference to data accuracy in the database, rather than the accuracy of maps. The present comparison between the two shows that the digital data accuracy is better than map accuracy by a factor of four.

***Conclusions***

Having discussed the quantitative error estimates and having recognised the fact that qualitative errors exist, one might be tempted to come to the conclusion that the cartographic records are apt to mislead the negotiators of treaties of limits, and that they are unworthy of incorporation in a formal international agreement (Hyde, 1933: 312).

The author does not recommend a conclusion rejecting the cartographic evidence, but does, however, recommend that boundary architects, negotiators, judges and arbitrators should be aware of the map's limitations regarding its quantitative and qualitative accuracy. Many countries map at medium scales only up the their border. Joining maps along the border may be inconvenient because of datum shifts. If such awareness does not exist, or the reliability of map evidence is in question, the boundary architects should request a professional evaluation of the map accuracy and its sources.

The lack of credibility in maps of doubtful or unknown quality is well understood. It is difficult, however, to accept the opinion of the arbitration tribunal in the *Beagle Channel Award* (ILR, 1977, Vol. 52: 82):

> *The map evidence cannot per se be preferred over a description or definition in an agreement, even if the definition was uncertain or ambiguous...*

This sweeping disqualification of maps is too general to someone who devoted most of his professional career to making reliable maps.

Another example of disregarding a doubtful quality of a map on the grounds of its *"acceptance by acquiescence"* is a legal consideration which it is difficult to appreciate. In the *Case Concerning the Temple of Preah Vihear* (ICJ Reports, 1962), the International Court of Justice preferred a map which in the eyes of the court was a part of an agreement despite the fact that its quality was doubtful. Similarly in the *Rann of Kutch Case* (ILM, 1968) the arbitration tribunal found the cartographic evidence *"convincing"* but insufficient to prove the claim of India.

The author has not seen a settlement of conflict based on an estimate of map accuracy or on a quantitative evaluation of map evidence. We are still far away from changing the status of maps from the legal point of view. A considerable improvement in map quality will no doubt increase its weight, particularly through the incorporation of reliable maps in boundary treaties.

### *3.3.2 Maps as a background to delimitation*

In this application, maps serve the purpose of familiarising the boundary architects with the terrain in the area where the boundary is to be delimited by treaty or adjudication. The scale and quality of the map are important at this stage, but seldom can a map successfully bring the terrain into the negotiating room or the courtroom.

The scale of the map is of primary importance. A 1:1,000,000, or World Map scale, is acceptable as a general guide, but one should remember that at this scale a millimetre on the map is equivalent to one kilometre on the ground, and the map det ails suffer from the effects of generalisation, within which details are selected, lines smoothed, symbols used instead of features, names omitted and so forth. A map produced at or close to publication scale is much more reliable and suitable for the purpose.

The choice of scale is also very important because it determines the clarity of the map and the degree of detail of the contents, as illustrated in Figures 8 and 12. Fortunately maps can be augmented by aerial photographs and satellite images, both containing a wealth of information not available on a topographical map. An image station combines hardware and software solutions involved in a stereoscopic examination of aerial photography and satellite imagery and a precise measurement of positions and elevations. Liquid crystal glasses permit high quality stereo viewing of the display provided by a large size monitor (Figure 8).

**Figure 8: Output of a Stereoscopically Viewed Image with Contour Lines Superimposed**
(By courtesy of Advanced Digital Mapping Ltd.).

Several people can view the stereo display simultaneously and have a free discussion on the three-dimensional terrain model displayed, which is invaluable in the delimitation stage, particularly when a watershed or cultivation details are involved. If control points are provided by GPS, the course of the intended boundary can be delineated in terms of measured coordinates.

Vector data, such as map details of various kinds, as well as name labels or other annotation can be superimposed on the displayed image to provide comprehensive information. This new technology is a powerful tool to achieve unambiguous delimitation of the boundary, especially in view of the fact that the image displayed with the decided upon alignment can be outputted in order to accompany the delimitation text.

### *3.3.3 Maps incorporated into or annexed to delimitation documents*

Maps are used as an integral part of the treaty, judgment or arbitration award by incorporating the map(s) into the text to which they are annexed. If a map is incorporated into the text, it serves as part of delimitation, if it is not, it serves merely as an illustration of the text.

One must always remember that maps, solely by their existence, cannot constitute a title to land which establishes legal rights. The legal force of the maps can only be acquired by their incorporation into the text of the treaty, or judgement, otherwise they remain merely a piece of information, the accuracy of which varies as a function of the technical quality of the maps. Perhaps the most extreme reservation regarding maps is contained in the order of 10 January 1986 of the International Court of Justice in the *Burkina Faso v. Mali Case*:

> *...maps can still have no greater legal value than that of corroborative evidence endorsing a conclusion at which a court has arrived by other means unconnected with the maps.*
>
> (ICJ, 1986: 562).

The very same document however contains the decision of the chamber:

> *(1) From a point with the geographical coordinates 1°59'01" W and 14°24'40" N (point A), the line runs in a northerly direction following the broken line of small crosses appearing on the map of West Africa on the scale 1:200,000 published by the French Institut Geographique National (IGN) (hereinafter referred to as 'the IGN line')...*
>
> (ICJ, 1986: 624).

The chamber was favourably impressed with the quality of the map and the reputation of the mapping agency, without unreservedly relying on it:

> *The chamber cannot uphold the information given by the map where it is contradicted by other trustworthy information concerning the intentions of the colonial power. However, having regard to the data on which the surveys were made and neutrality of the source, the chamber considers that where all other evidence is lacking, or is not sufficient to show an exact line, the probative value of the IGN map becomes decisive.*
>
> (ICJ, 1986: 625).

It should be noted that the judgement usually becomes a delimitation incorporating a map. The delimitation however contains seeds for further disputes, namely, the geographical coordinates do not specify the geodetic datum to which they are referred and the map is on 1:200,000 scale, where 0.2mm (the limit of graphical accuracy) is equivalent to 40m on the ground and 0.8mm (a less optimistic graphical accuracy) becomes 160m, the two sources of error combined being capable of producing discrepancies varying from tens of metres to hundreds of metres on the ground.

In a later case before the International Court of Justice, namely the case concerning the *Land, Island and Maritime Frontier Dispute, El Salvador v. Honduras: Nicaragua intervening*, the judgment of 11 September, 1992, recognises the fact that discrepancies of the order 9”.2 (equivalent to approximately 276m) can result from the choice of datum and the judgment (delimitation) is given in terms of a text incorporating maps and coordinates derived from maps (ICJ, 1992).

The judgment incorporates maps and marks made upon them in the delimitation of the boundary, but the coordinates given in the judgment serve to assist in locating the boundary points rather than to express their position. The map (Figure 9) being of very good quality, it would serve as a directive to demarcators who would have no problem in transferring the judgment to the terrain.

This in fact is one of the very few cases where the delimitation is of such quality that the demarcation would not be strictly necessary, or when it could be delayed and executed only as circumstances make it essential, or could be carried out in sections only, or dispensed with altogether.

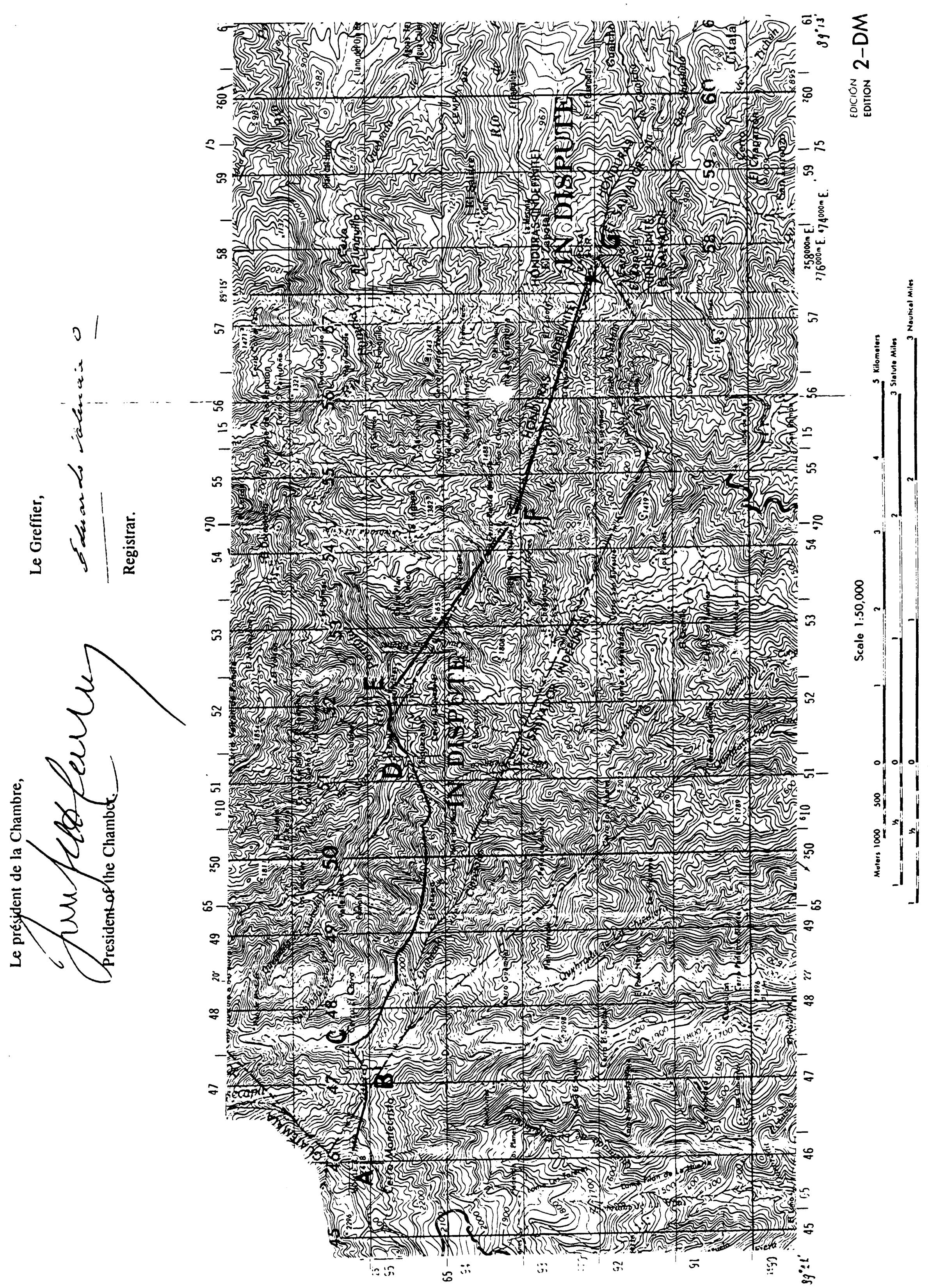
Demarcation may also be considered unnecessary or prohibitive from the point of view of the expense involved. This may have been the case for major parts of the boundary between Egypt and Sudan delimited originally as an administrative line by the Agreement between Britain and Egypt, signed in 1899. Some 800km of the boundary running along the 22° parallel of latitude were left undemarcated. There are, however, indications (Brownlie, 1979), that eventually demarcation will be necessary, with local adjustments being made during the course of demarcation.

### *3.3.4 Maps as background documents to demarcation*

This is an application where maps serve as an aid in transferring the delimitation to the terrain, although one must remember that the delimitation text prevails over the map in all cases where a discrepancy between the two exists. This in no way detracts from the value of the map as an aid to demarcation. The map has to be of a sufficiently large scale to provide the detail and the portrayal of the terrain by contour lines, essential for following the delimitation on the ground. In fact, the points to be monumented can be preliminarily marked on the map before the actual demarcation begins, with the final decision as to where to place the mark or the monument made in the field.

A good quality topographical map at a scale of 1:50,000 or larger would be excellent for the purpose, but sometimes, especially in sparsely populated areas, a smaller scale map can serve the purpose. The demarcation is by nature a bilateral operation, and unless the map used is incorporated or annexed to a treaty, the parties concerned have to agree on the map to be used as an aid to demarcation.

**Figure 9: Part of the Map Used to Express the Judgment of the ICJ of September 1992**
(reduced in scale).



This, however, should not present a difficulty, since a demarcation which consists of monumentation, description of the points marked, including photographs and the measurement of position within a defined system, is a non-ambiguous and finite act of transferring the delimitation to the ground. It is almost irreversible since the demarcated boundary points, if properly documented, can always be restored.

An example of a combined application of maps and aerial photographs is in the arbitration of the *Argentine-Chile Frontier Case*, known as the *Palena Case*. A specially ordered 1:50,000 map was produced as well as aerial photographs and a field visit was made by the arbitrators. Enlargements of aerial photographs were used in the delimitation contained in *HM Queen Elizabeth II Award* in 1966. Rushworth (1968) comments that the photograph was much more comprehensive in details and easier to read than a map in specifying discrete points.

Should a difficulty arise in obtaining aerial photographs acceptable to both sides, satellite imagery, suitably enlarged can be used. They will be less sharp than air photos, but much easier to acquire (see Section 3.4).

### *3.3.5 Maps showing the boundary 'as made'*

This is an application following the actual boundary making process, a display of the boundary 'as made' to the general public and an aid to the boundary regime for administration and maintenance. Map scale permitting, all demarcated boundary points ought to be shown, joined by a line symbol representing the exact course of the boundary between the points. One could say that a 1:250,000 and larger scale map would usually be able to show the demarcated points as well as the line. It should be stressed that although the 'as made' map would not usually be used for the restoration of the lost or destroyed monumented points, care should be taken in showing the correct alignment of the boundary, within the limitations of the map (Figure 10).

The proper way to show the demarcated points would be to compute their geographical coordinates on a defined datum and then to transform the computed position to the plane rectangular projection system on which the map is plotted. The positioning of the line symbol of the boundary would present no difficulty in those sections of the boundary where it runs as a straight line between the monuments.

Where the boundary follows a well-defined feature, such as a stream, the accuracy of portrayal would be equal to the accuracy of the mapping of the feature concerned and this applies also to cases where the boundary follows the centre or the *thalweg*[8] of a river. It would be more difficult to portray on the map those sections of the boundary which follow, for example, the watershed. The accuracy of the portrayal would depend not only on the accuracy of the contour lines, but also on the ability of the cartographer to ascertain the course of the watershed from the map concerned.

It would be safe to assume that once the boundary is properly shown on the map, its position will be preserved in future editions of the map, or in the maps derived cartographically from it.

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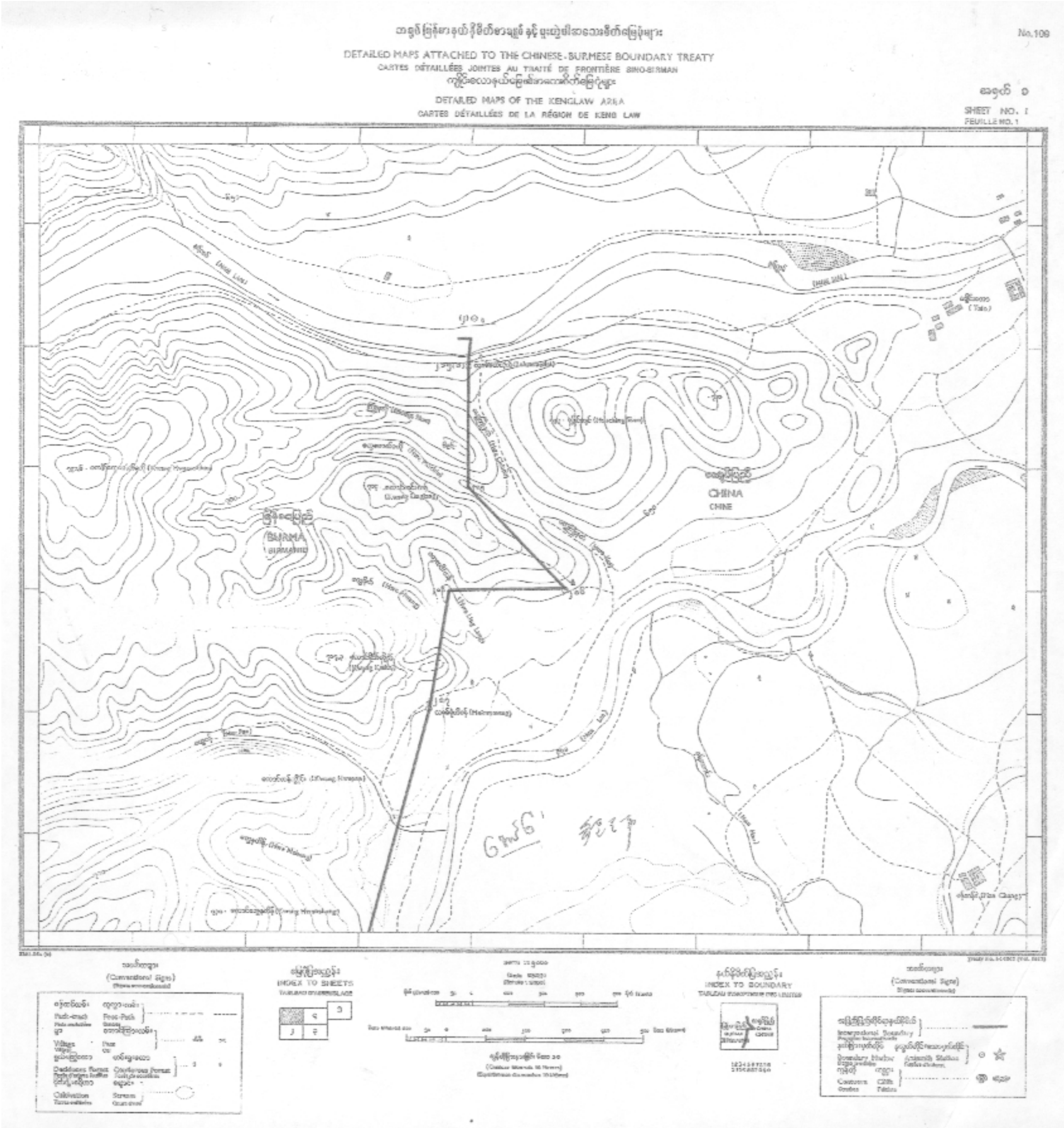
8 A principle, traditionally applied to river boundaries, usually referring to a division along the deepest part of the deepest navigable channel. For a more detailed analysis of this term see Deeley (2001).

**Figure 10: Map Showing the China-Myanmar Boundary 'As Made'**



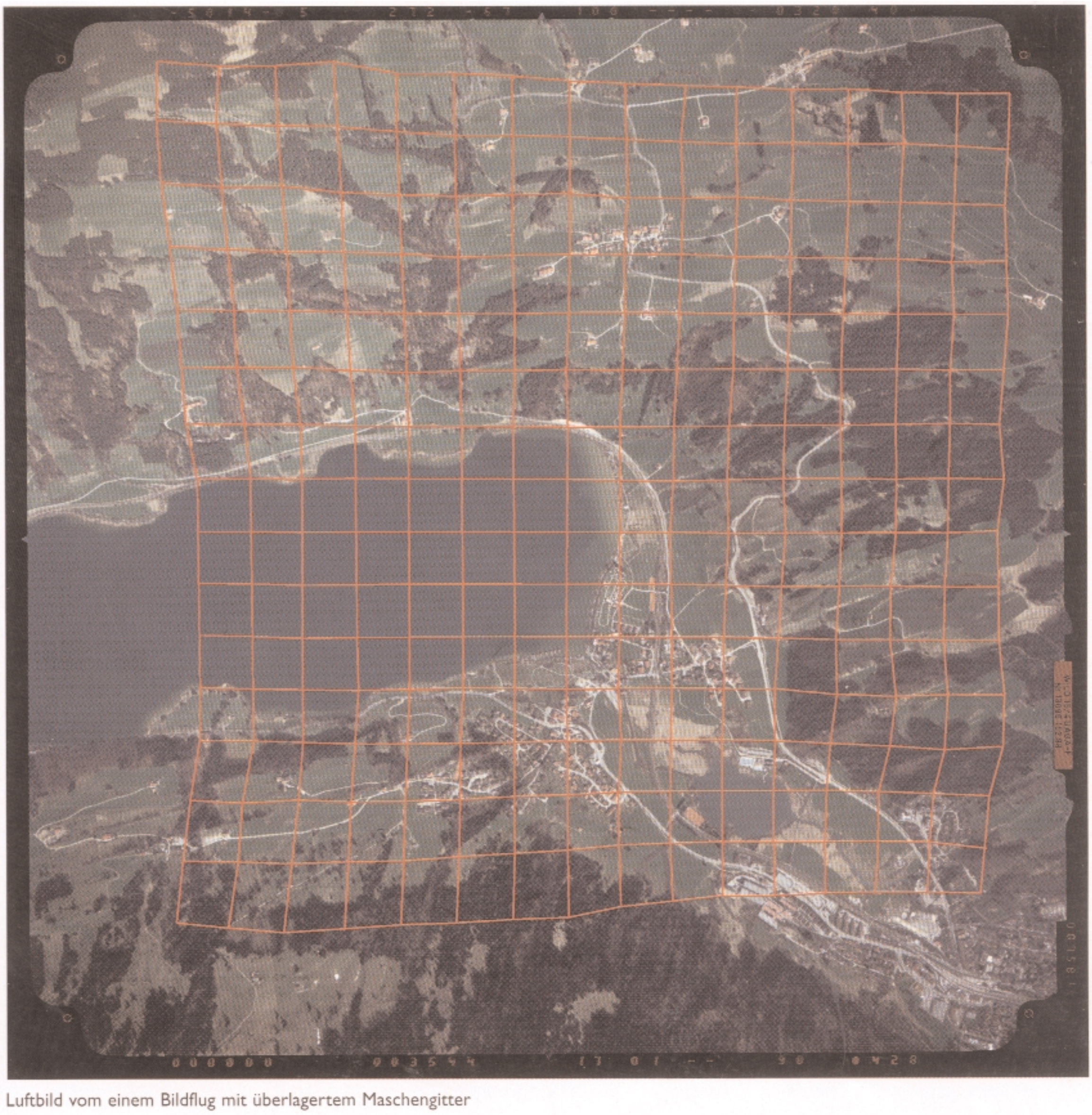

### *3.3.6 Orthophoto as an aid to delimitation and demarcation*

A map is an orthogonal (right angle) projection of the earth surface onto a plane. The projection is achieved by parallel rays, as if viewing the earth from an infinite distance. A photograph, including an aerial photograph is a central projection, all rays passing through one point, the centre of the lens and onto the plane of the film. The image formed on film suffers from deformations, but there are methods, with the aid of which a central-projection photograph can be converted into a *"correct photo"* or an *"orthophoto."*

The deformations in the photographic image are caused by the tilt of the camera during the flight, by lens distortions and by the central projection resulting in image displacement of details caused by their elevation, and so forth. These problems and their rectification are presented in *Photogrammetry* (Kraus, Ferd. Dummler Verlag, 1993, Vol 1: 300-334).

Rectification is achieved with the aid of an instrument called a differential rectifier, the product of which is an orthophoto. The data required for the rectification is a reliable model of the ground surface (digital deviation model), which is today often available in Geographical Information Systems (GIS). The result is most impressive, especially when rectifying colour photography (Figures 11 and 12).

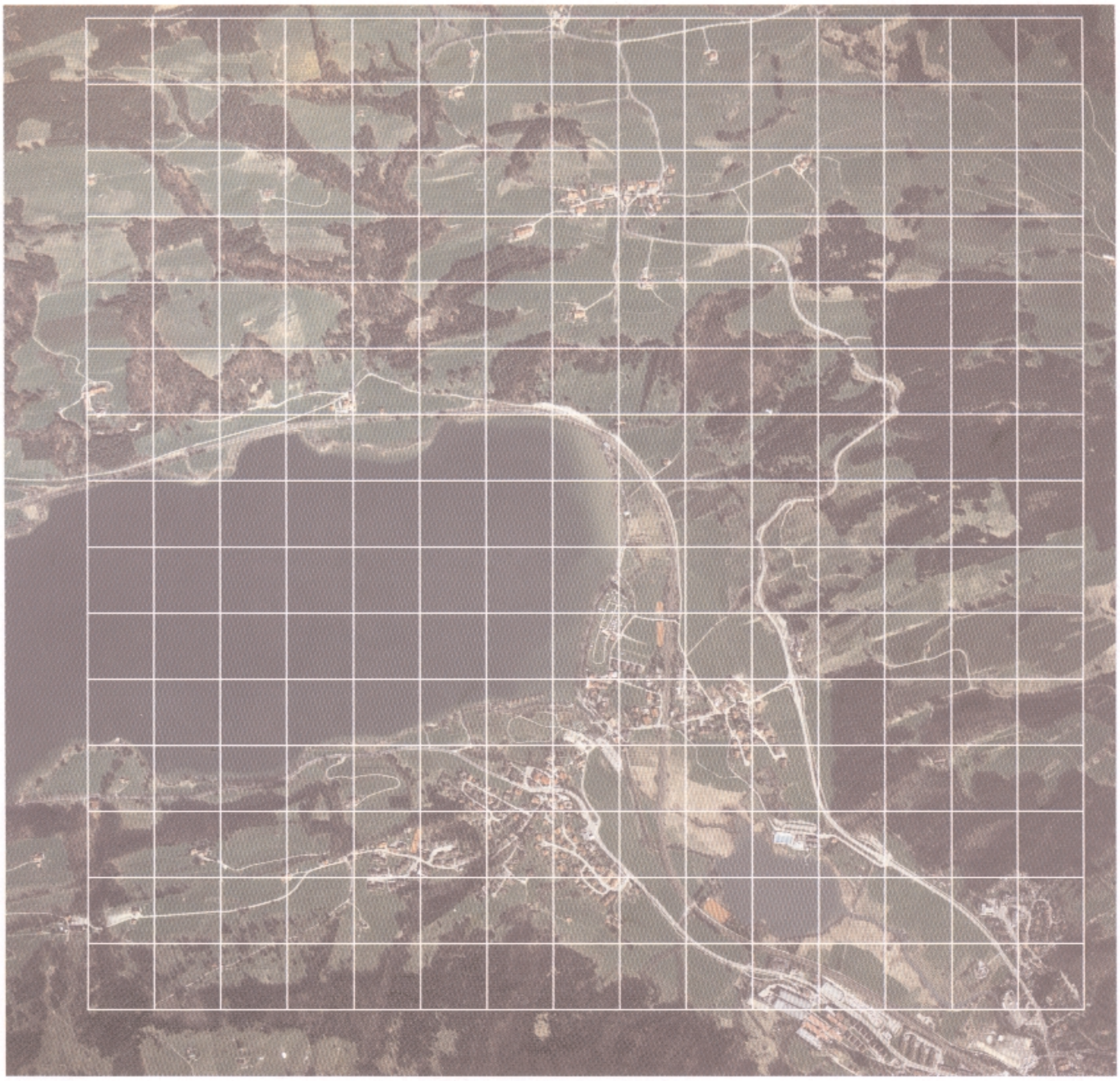
**Figure 11: An Aerial Photograph Overlaid with a Distorted Grid**
(Courtesy of Bayerischen Landvermessungsamt).



Luftbild vom einem Bildflug mit überlagertem Maschengitter

An orthophoto can be enhanced by the introduction of a map grid, the most important topograhic details, names of larger settlements and perhaps even contour lines, the enhancement resulting in an orthophoto map. An orthophoto map is an invaluable aid to the boundary architects negotiating a treaty which delineates the agreed upon boundary. An orthophoto map delineating the boundary should become a part of the treaty or the agreement. Needless to say it would be an invaluable aid to the boundary engineers in demarcation, since there would be no room for misinterpretation of the written word. An orthophoto with the boundary on it is easy to apply to the ground by experienced demarcators. If an orthophoto is not available an enhanced map may be used

**Figure 12: An Orthophoto produced by Differentially Rectifying the Distorted Photo in Figure 11**
(Courtesy of Bayerischen Landvermessungsamt).



Orthophoto, abgeleitet aus einem Luftbild

## 3.4 Remote Sensing Applications

> *...through the ages man's greatest technologic breakthroughs have resulted from his curiosity about a phenomenon he could not experience directly with his senses.*
> (Holz, 1985: 9).

Aerial photographs and satellite imagery are important technical means for bringing the terrain to the negotiation table, as products which complement maps or serve as alternatives to them. Aerial photographs have been an acceptable product for approximately the past 75 years, whilst satellite imagery is a relatively new product, in use for only the last 10-15 years.

Aerial photographs are taken at heights between 500 and 10,000m, whilst the satellites, which serve as image sensing platforms, move in orbits between 200 and 1,000km above the surface of the earth. An aerial photograph stands out from the point of view of sharpness and the wealth of fine detail pictured, with the potential of discerning features the dimensions of which are 10 centimetres or even less. A satellite image[9] is capable of a resolution of 2m and expected to improve to 1m. It is easier to control aerial photography parameters: the flying height and the focal length[10] of the camera. A satellite orbit is planned in advance of the launch and is almost impossible to change substantially subsequent to that.

It might be concluded that the natural preference would be towards air photographs. In practice however it is difficult to acquire aerial photography for boundary applications with the full participation of the two parties in the flight and the laboratory handling of the film and prints, in sharing the expenses and in overflying the territory of neighbouring states. Satellite images are available commercially, without logistic and administrative difficulties, at a reasonable cost.

The following considerations should underly the decision whether to use aerial photography or satellite imagery:

- The size of the area within which the boundary is to be delimited.
- The technical characteristics of the respective products.
- Availability and cost of the data required.

### *3.4.1 Aerial photographs*

One may assume that all modern aerial photography cameras have excellent lenses, an automatic film advance feature, and automatic exposure control in accordance with prevailing light and speed of the aircraft. There are two parameters which can be controlled, namely the focal length and the flying height.

The choice of focal length is usually limited to three:

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9 The reference here is made to earth observation satellites and not intelligence satellites.
10 *Focal length* is the distance between the centre of the lens and the film plane.

- *Normal* angle (210mm approximately).
- *Wide* angle (152mm approximately).
- *Superwide* angle (88mm approximately).

The terms *normal*, *wide* and *superwide* refer to the opening angle (looking angle) of the camera.

The size of the film remains constant (usually 23 x 23cm) and therefore the shorter the focal length, the wider the looking angle and the greater the area covered by the photograph. The relationship between the flying height and the scale of the photograph (Table 2) is expressed by the following formula:

Scale of photo = 1/S = f/H - h = focal length/flying height above the terrain

Where: f = focal length.
H = flying height above sea level.
h = average height of the terrain above sea level.

From a certain scale of an aerial photograph, maps at different scales can be produced. This is shown in Figure 26. It is easy to be tempted into larger scales because of the clarity of the map. However, it should be noted that the larger the scale of the map, the smaller the area covered.

**Table 2: The Scale of the Air Photograph as Function of the Focal Length and the Flying Height**

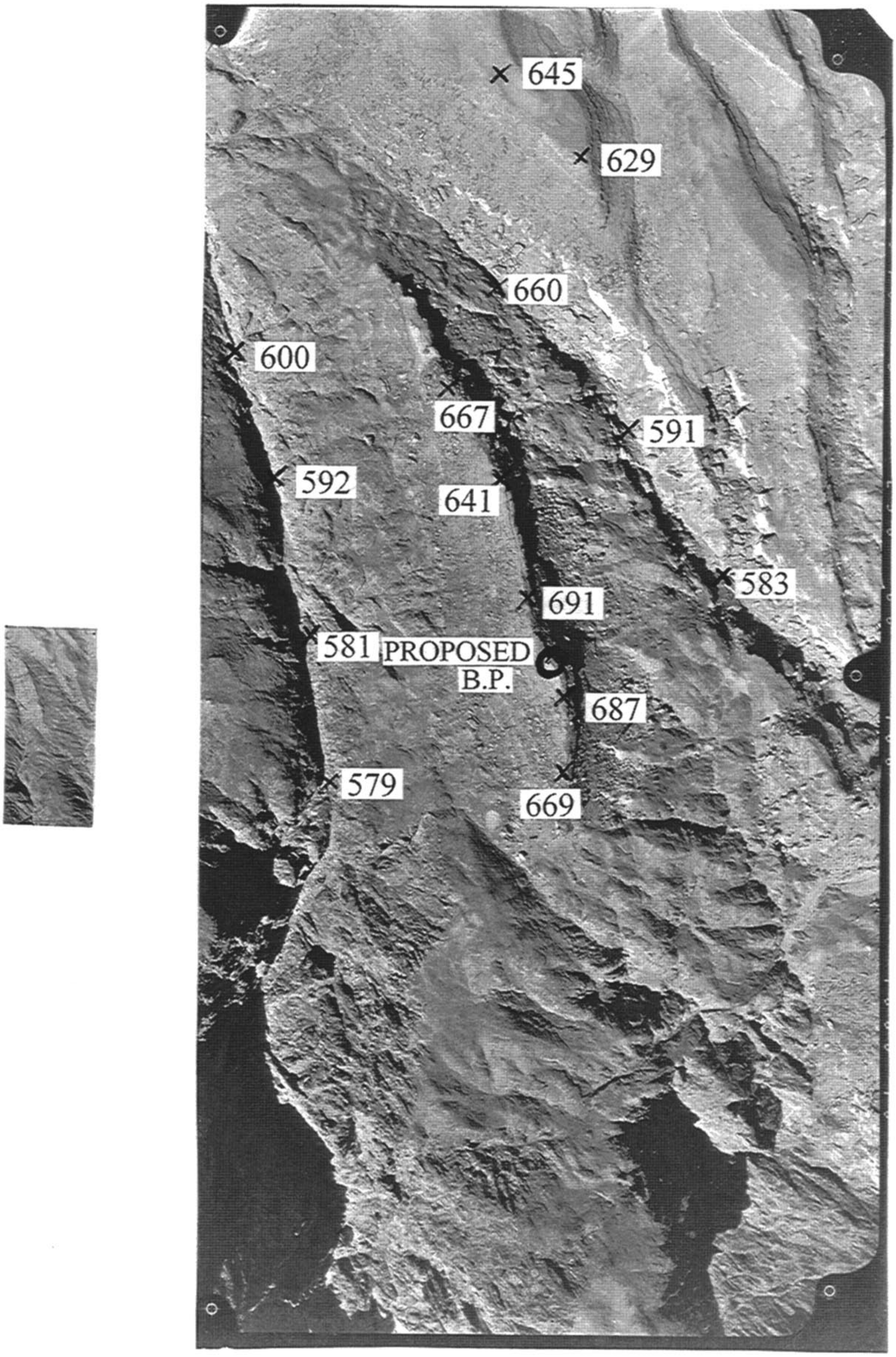
| **Focal Length** | **Flying Height Above Ground** | | | |
|---|---|---|---|---|
| | 500m | 2,000m | 5,000m | 10,000m |
| 210mm | 1:2,400 | 1:95,000 | 1,23,800 | 1:47,600 |
| 152mm | 1:3,300 | 1:13,100 | 1:32,900 | 1:65,800 |
| 88mm | 1:5,700 | 1:22,700 | 1:56,800 | 1:113,600 |

Figure 13 shows half of an aerial photograph at an approximate scale of 1:4,000 and the area covered is approximately 432,000 square metres (less than half a square kilometre). On the left is the same area covered by part of an air photo at a scale of approximately 1:30,000. It is obvious that in the 1:4,000 scale photo one can see every large stone and every undulation of the terrain, whilst at 1:30,000 scale one can see only the main features of the area.

If this image were used for the purpose of preparing a proposal for delimitation, and a number of elevations were measured to enhance the photograph and the values annotated as in Figure 13 (one can see easily that the small ridge on which it is proposed to position the boundary pillar marked B.P. is a logical location), then it is clear that the annotated photograph is almost as effective as a field visit.

Aerial photographs are an almost unsurpassed medium to inspect and interpret the terrain as shown in Figure 14.

**Figure 13: Aerial Photographs at 1:4,000 and 1:30,000 Illustrating Differences in Clarity**



This is not an appropriate forum for an in-depth study of photogrammetry,[11] which is a separate field of specialisation in geodetic engineering; it is however easy to see its potential in delimitation and demarcation of boundaries. For more specific information about photogrammetry, the reader is referred to the American Society of Photogrammetry and Remote Sensing (ASPRS) Manual (1982), and Kraus (1990).

### *3.4.2 Satellite photographs*

Satellite photographs are conventional photographs, like aerial photographs, except that the camera-carrying platform is an artificial satellite, which raises the camera to an elevation exceeding 200km above the surface of the earth, instead of the 10km ceiling of an aeroplane. Being real photographs taken on film, they are sharper than almost all other satellite images, the resolution of 5m comparing favourably with 10m for the satellite images. The camera is a Russian development and the products are commercially available. The focal length of the KFA 1000 camera is 1009.13mm and the format (size of the photographs) is 30 x 30cm. Scanned photographs are available also in digital form. The scale of the photographs is approximately 1:220,000 and their quality permits enlargement to 1:50,000 or even 1:25,000. In Figure 15 an enlargement of the photograph to 1:100,000 is presented.

### *3.4.3 Satellite images*[12]

Satellite images are an important product, applicable in all stages of boundary creation and its subsequent maintenance, especially as a complement to a map. The term *image* instead of photograph is used because the image is obtained without components characteristic of a photograph – lens, film, shutter etc.

The principal advantage of satellite images in boundary applications is their ready availability on a commercial basis, without problems of overflying certain territories or censorship of any kind.

The satellite era started in 1960, but the first satellite for scientific purposes and product applications was launched in 1972, with the beginning of the first LANDSAT series which ended in 1978. Two additional satellites were added in 1982 and 1984, which orbit the earth at an elevation of 705km.

From the point of view of international boundary applications, the most suitable images are those obtained by the French satellite SPOT. The first SPOT satellite was launched in 1986, the second one (still active) in 1990 and the third one in 1993. The height of the orbit is 822km. The image is created through two observation devices called HRV, each one composed of 6,000 sensors arranged in a straight line, perpendicular to the direction of the satellite motion. Each sensor covers 10m on the ground, hence one observation device covers 60km on the ground. Some platforms today carry sensors covering 1m on the ground.

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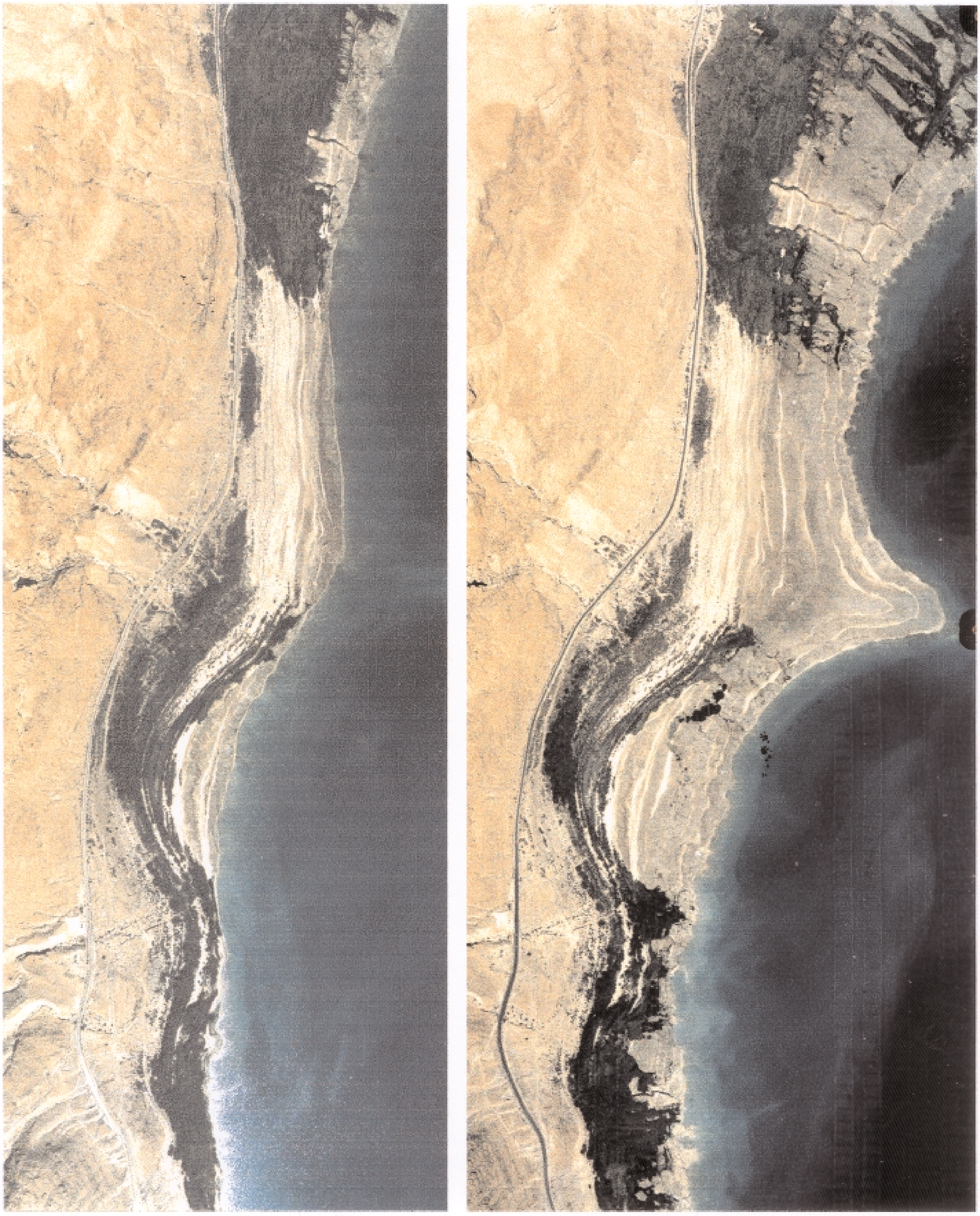
11 *Photogrammetry* – the science of measuring photographs.

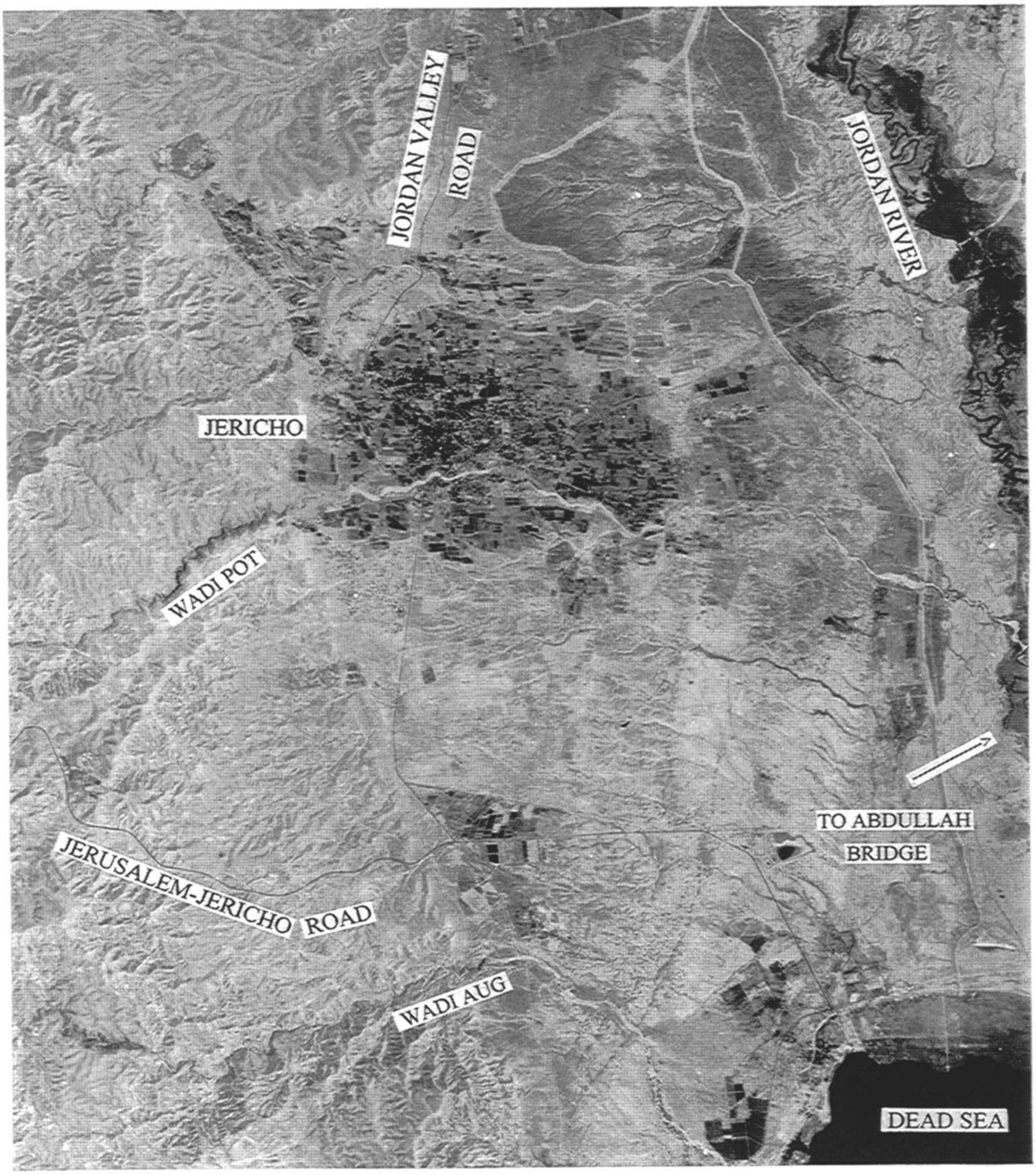
12 A *"satellite image"* is a picture of the earth's surface obtained from a satellite through the use of sensors.

**Figure 14: Two Aerial Photographs, Taken Five Years Apart, showing Changes in the Shoreline**



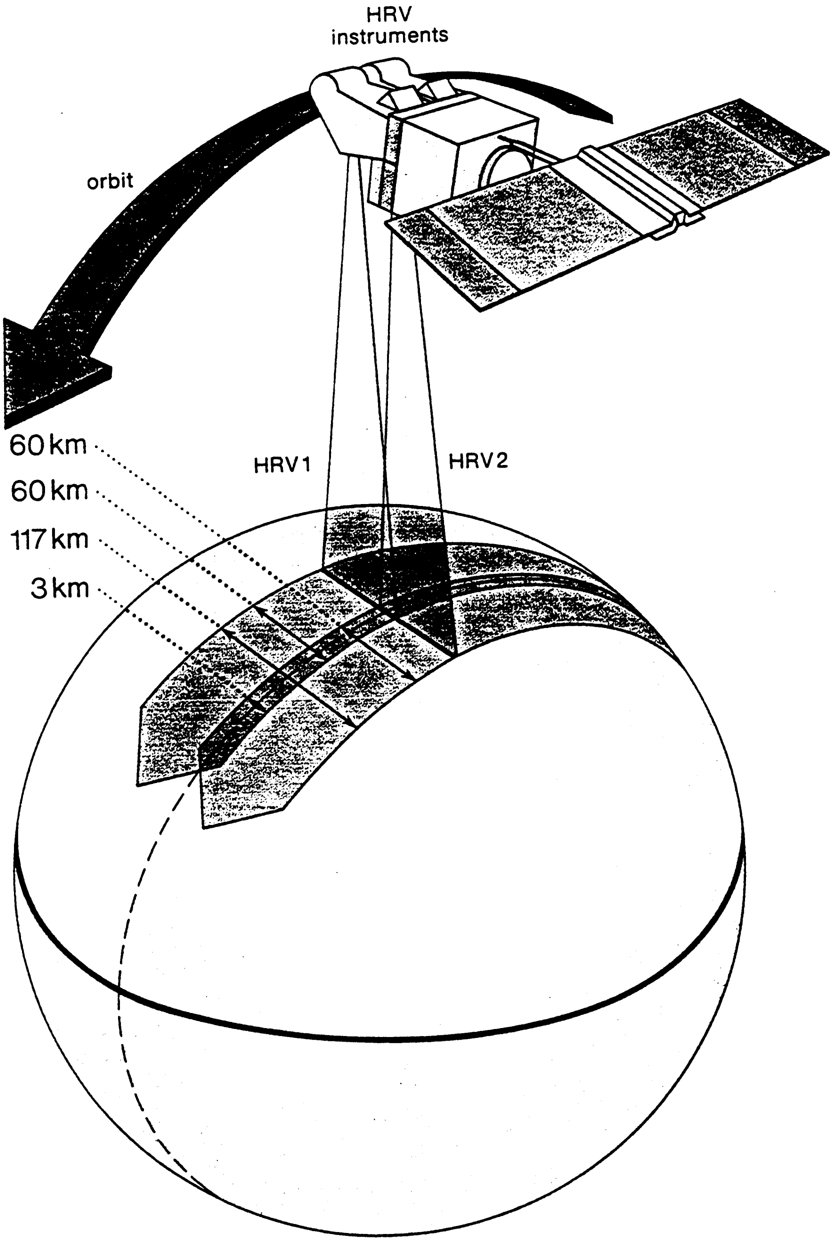
The satellite motion is arranged in such a way that in 1.5 milliseconds the satellite moves 10m in its orbital path and hence each sensor covers an area 10 x 10m – called a 'pixel' and the whole observation device of 6,000 sensors covers an area of 60 x 60km – called a 'scene'. This arrangement is valid for a panchromatic (black and white) image. In a multispectral (colour) image, the size of the pixel is 20 x 20m and the image is less sharp (has a lesser resolution) compared to the panchromatic.

**Figure 15: Part of a KFA 1,000 Photograph Enlarged to Approximately 1:100,000**
(Some annotation is added to facilitate orientation.
Courtesy of *Priroda*, Russian Scientific Research and Production Center).



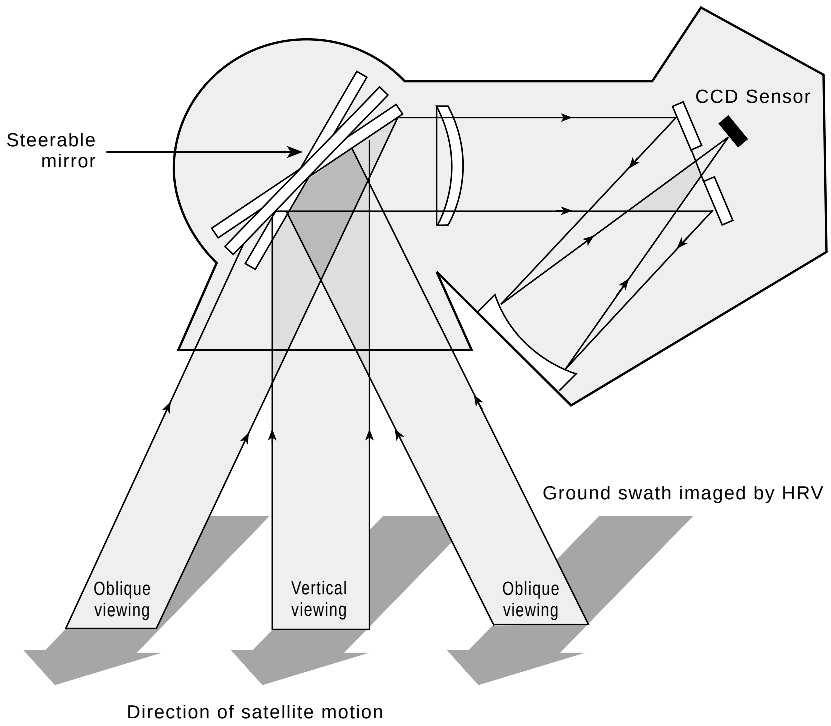
In Figure 16 one can see the principle of sensing through two sensing devices. Note the 3km overlap between the coverage by each of the two devices. This type of sensing by a straight line array perpendicular to the satellite motion is called 'pushbroom' sensing. The SPOT satellite executes 1,436 orbital revolutions of the earth per day and thus obtains a complete coverage of the surface of the earth every 26 days.

**Figure 16: Earth Coverage by Two HRV Devices**
(Courtesy of SPOT Image).




The HRV device can be tilted by 27° from the vertical. This capability facilitates a repeated coverage more often and also permits the viewing of the area stereoscopically through overlapping coverage obtained from different angles (see Figure 17).

**Figure 17: A Cross-section View of the HRV Telescope**
(Courtesy of SPOT Image).




The light reflected from the earth's surface enters the HRV telescope and is focused on the Charge Coupled Device (CCD) sensor, which is miniature in size (13 x 13 micrometres). An example of a SPOT satellite image is given in Figure 18.

A very special product can be obtained by merging 28.5m data from NASA's LANDSAT 5 satellite with the French SPOT satellite. The result is an accurate, true-colour, photo-realistic satellite map, such as the one shown in Figure 19.

To summarise, remote sensing applications for international boundaries – aerial photography, satellite photography and satellite imagery – are important products, which bring the terrain to the negotiating room and enhance existing maps or can even replace them, especially in non-mapped or poorly mapped, sparsely populated areas. The complete replacement of maps is difficult but annotation of images can certainly help.

**Figure 18: A SPOT Satellite Image of Sant Feliu de Guixols, Enlarged to 1:50,000 from the Original 1:400,000**
(Courtesy of Institut Cartografic de Catalunya).

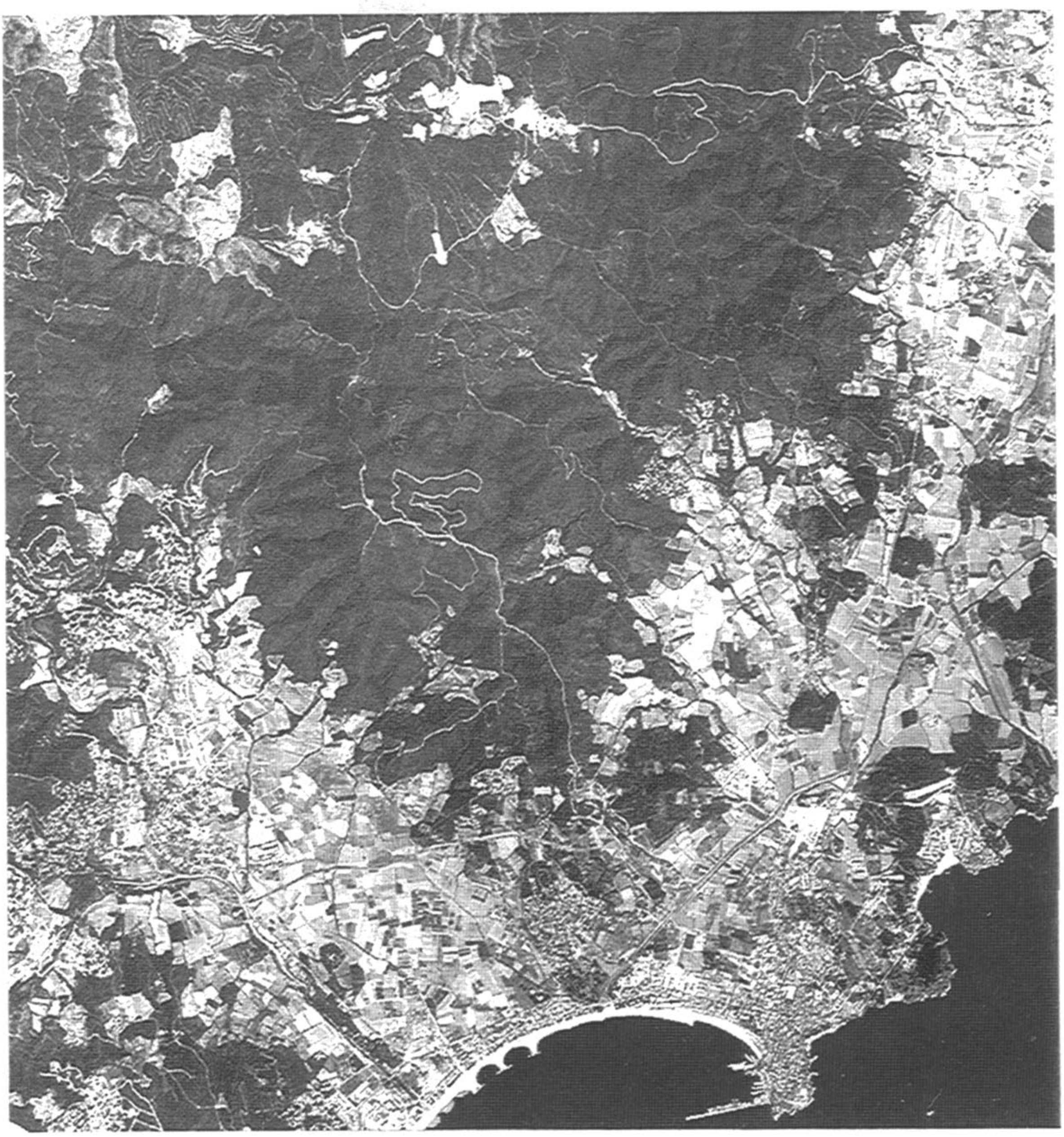


**Figure 19: Part of a 1:100,000 scale LANDSAT/SPOT Satellite Map of the area North of the Dead Sea**
(Courtesy of Dr John Hall, GSI).

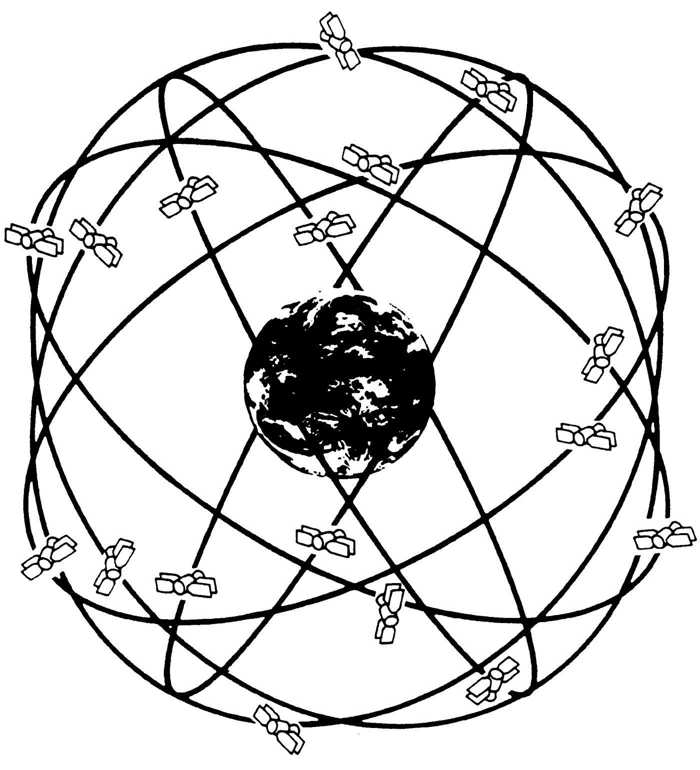
## 3.5 Global Positioning System (GPS)

*The future uses of GPS are limited only by one's imagination.*
(Hofmann-Wellenhof *et al.*, 1993: 13).

The task of precise measurement and computation of the position of points on the earth's surface was, since time immemorial, a challenge to navigators, geodesists and cartographers. For centuries the challenge was answered by astronomical methods, which in the second half of the twentieth century, using advanced observational and computation methods, achieved an absolute accuracy of 10m approximately and a relative accuracy of 3-5m. It remained a slow intensive process, however, requiring a great deal of specialised knowledge and skill as well as favourable atmospheric conditions. It can be stated confidently that today, astronomical positioning is 'out' and its chief merit is in developing an understanding of space celestial coordinate systems. It certainly cannot be considered a method for positioning and documenting international boundaries. It has been superseded by Global Positioning System (GPS).

GPS supplies positions of points, relative to a regional datum and within seconds, independent of weather conditions, day and night and without intervisibility between points being fixed. It is the only efficient method for positioning international boundaries and their documentation for posterity – a real technological revolution in the sphere of boundary engineering. GPS was conceived as a worldwide positioning system and was developed by the United States Department of Defence, to serve the navigational requirements of the armed forces on land, sea and in the air.

**Figure 20: A Reference Network of 24 GPS Satellites in Six Orbits**



GPS is based on a reference framework of 24 satellites; orbiting the earth in six orbits, four satellites per orbit, at an elevation of 20,000km (Figure 20). The positions of satellites in orbit at any time are precisely known with relation to a network of control points on the earth's surface and the orbital data is constantly monitored. Positioning with the aid of GPS is based on precise measurement of distances to at least four different satellites.

GPS methods have several great advantages:

- Can be used day or night in any weather.
- There is no intervisbility requirement.
- Produces results with very high accuracy.
- More work can be accomplished in less time with fewer people.

This is a truly wonderful capability for boundary positioning.

### *3.5.1 The measurement of distance from a satellite*

Every satellite is equipped with an atomic clock. The satellite broadcasts signals at two frequencies[13] for positioning purposes namely L1 at 1,575.45 Megahertz[14] and L2 at 1,277.6 Megahertz. Radio waves travel in vacuum at the speed of light, which is known with great accuracy. If the time required for a wave from the satellite to arrive at the receiver set over an unknown point is measured, then we can multiply the time by the speed of the wave to obtain the distance:

$$\Delta t \times c = D.$$

In the above formula '$\Delta t$' is the delay of the signal broadcast by the satellite with reference to a replica of the signal broadcast at the receiver (Figure 21). The clocks at the satellite and at the receiver are synchronised, so the 't' expresses the time of travel of the signal from the satellite to the receiver. In addition, 'c' = velocity of light in vacuo, and 'D' = the distance from the satellite to the receiver. For example, let us assume that the delay measured is 0.07 seconds and the speed of light 300,000km per second, the distance 'D' = 0.07 x 300,000 = 21,000km.

This type of measurement does not solve the problem of position and it requires four distances to satellites in order to fix the position precisely on the surface of the earth. Three distances would be sufficient to position a point in space, but the fourth measurement is required to overcome the difficulty caused by the satellite clocks being more precise than the receiver clocks.

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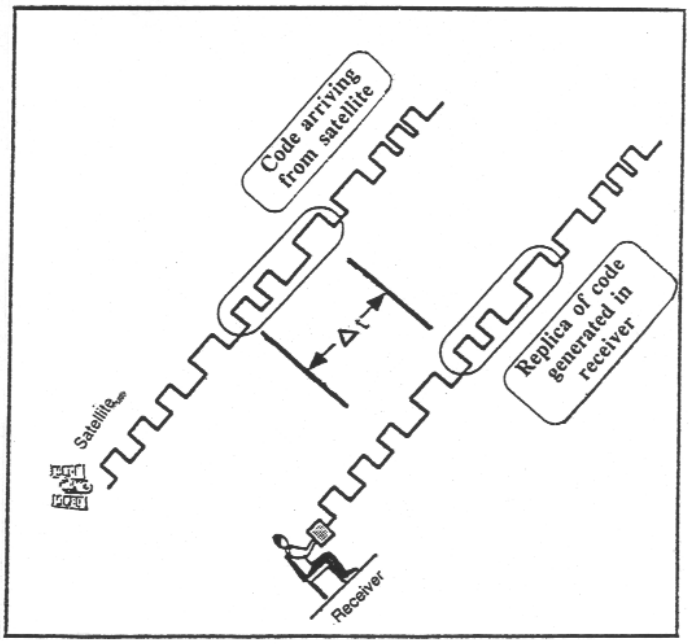
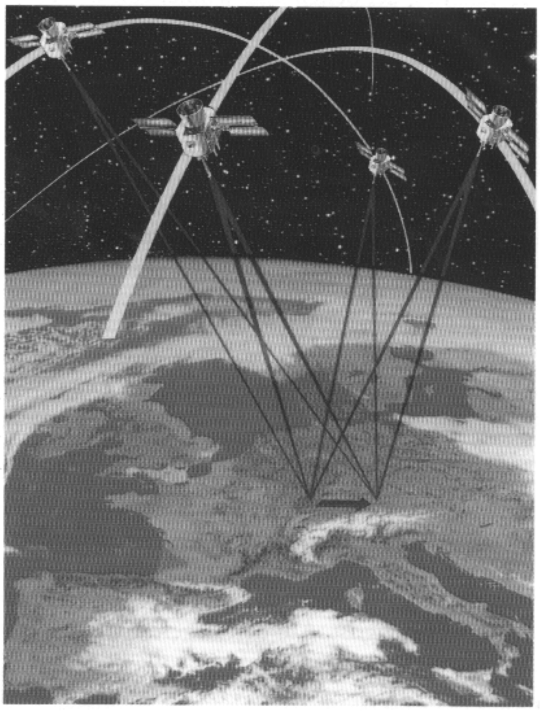
13 *Frequency* is the number of cycles of an electromagnetic wave per unit of time.

14 *Hertz* is a basic unit of frequency: one cycle per second. *Kilohertz* is one thousand cycles per second and *megahertz* is one million cycles per second.

Models of the atmosphere and of the ionosphere[15] enable the computation of the slowing down of the satellite signal caused by the passage through those layers. For more detailed reading on the subject, the reader is referred to Wells (1986) and Hofmann-Wellenhof *et al.* (1993).

**Figure 21: The Principle of Measuring the Distance, Satellite-Point Being Fixed, with the Aid of Time Signals**



[15] *Ionosphere* is a layer of electrically charged particles at the elevation of 130-190km above the earth's surface.

### *3.5.2 GPS receivers*

Modern receivers, such as those manufactured by Trimble, Leica and Ashtech among others, are capable of making measurements to nine satellites simultaneously (in two frequencies for each satellite). The extra observations, over and above the minimum required for determination of position, allow an increase in the estimated accuracy of positioning.

A typical GPS receiver weighs approximately one and a half kilograms, and models are getting lighter and lighter each year. Adding a backpack and including nickel-cadmium batteries the weight approaches six kilograms. In addition to an antenna a controller is needed, a portable device permitting operation of the instrument, storage and display of results and guidelines for continuing the measurement process. The antenna, which has to be set up over the point being positioned, can either be set up on a tripod or mounted on a portable staff. Figure 22 shows a backpack mounted instrument with a portable antenna mounted on a staff, together with a controller which can be hand held. The inset shows (top to bottom) various output forms of the controller: coordinates X, Y of the positioned point, the estimated precision and the number of satellites used in the determination and the direction and distance to the next point as well as the current deviation from the line leading to it. These GPS receivers are known as geodetic survey receivers, as distinguished from the hand held receivers capable of lesser precision, although improving all the time.

In general, the receivers can be divided into two groups: those capable of measurements at two frequencies – L1 and L2 – and those capable of measurements on one frequency only – L1. There are basically two observational techniques, suitable for different purposes. Table 3 summarises the techniques applicable in boundary surveys.

### *3.5.3 GPS measuring techniques*

There are several measuring techniques that can be used with most GPS Survey Receivers. The surveyor should choose the appropriate technique for the application.

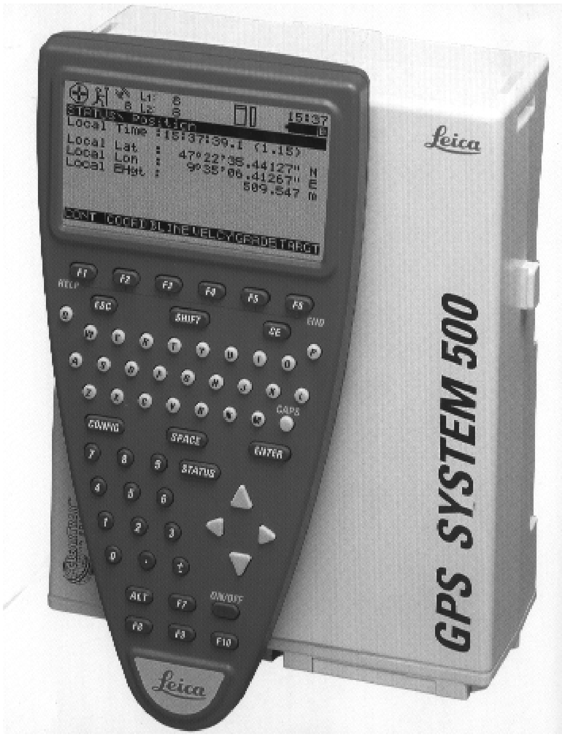
**Static** – Used for long lines, geodetic networks, tectonic plate studies, and so forth. Offers high accuracy over long distances but is comparatively slow.

**Kinematic** – Used for detail surveys and measuring many points in quick succession. A very efficient way of measuring many points that are close together. However, if there are obstructions to the sky such as bridges, trees, tall buildings or similar, and less than four satellites are tracked, the equipment must be reinitialised which can take 5-10 minutes. A processing technique known as On-the-Fly (OTF) has gone a long way to minimise this restriction.

**RTK** – Real Time Kinematic uses a radio data link to transmit satellite data from the Reference to the Rover. This enables coordinates to be calculated and displayed in real time, as the survey is being carried out. Used for similar applications as Kinematic. A very effective way for measuring detail because results are presented as work is carried out. This technique is however, reliant upon a radio link, which is subject to interference from other radio sources and also line of sight blockage.

**Figure 22: A Portable GPS Receiver with Antenna and Controller**
(Courtesy of Trimble Navigation).

**Figure 23: Two Examples of Read-out from a GPS Receiver: satellites available for observation in the sky (left) and the computed latitude, longitude and elevation (right)** (Courtesy of Leica Corp).



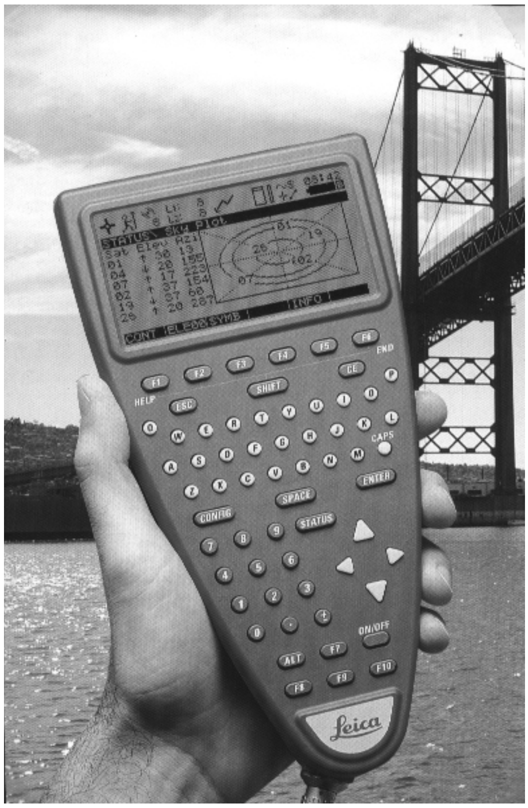




**Table 3: Typical Accuracies Achievable and Observation Times for the Two Techniques**

| Type of Receiver | Distances Between Points | Measurement Technique | |
|---|---|---|---|
| | | *Static (several hours[16])* | *Kinematic (several seconds)* |
| **Dual Frequency** | Up to hundreds of kilometres | 5mm plus 1ppm[17] of distance | 2cm plus 2ppm of distance |
| **Single Frequency** | Up to 30 kilometres | 1cm plus 2ppm of distance | 2cm plus 2ppm of distance |

In the above table Kinematic technique includes RTK (Real Time Kinematic), which in boundary applications is particularly valuable in searching for lost or buried points. It is recommended that in international boundary applications, Dual Frequency instruments should be used.

[16] Measurement time depends on the number of satellites observed and their geometric configuration.

[17] 1ppm = 1 part per million of the distance, which for 100m = 0.1mm, for 1km= 1mm, for 10km = 1cm and for 100km = 10cm.

### 3.5.4 *Applications of GPS technology to boundary making*

GPS technology revolutionises technical services to boundary creation in all its stages. Its principal advantages are speed and efficiency of work, ease of operation and uniformity of data in the frontier zone, and independence of the national control networks of the neighbouring countries. The following table summarises GPS applications in the various stages of boundary creation.

**Table 4:** ***Summary of GPS Applications to International Boundaries***

| | **Data Acquisition for Delimitation** | **Demarcation and Documentation** | **Routine Administration and Maintenance** |
|---|---|---|---|
| 1 | Location of prominent features in frontier zone | Location of demarcation sites after delimitation | Location of occurrences along the boundary line and in the frontier zone |
| 2 | Annotating air photos and satellite images with position data | Location of witness marks | Densification of boundary markers |
| 3 | Aid in defining local water parting | Survey for boundary documentation purposes | Maintenance of marks and replacement as necessary |
| 4 | Survey of proposed boundary line | Producing a comprehensive set of boundary points | Definition and demarcation of administrative zones |
| 5 | Clarification of matters raised during negotiation | | Assistance in construction and development projects |

During the data acquisition stage as background to delimitation, the accuracy of the order of several tens of centimetres or even single metres is sufficient and, therefore, no particular observational procedure is recommended. Almost any method is acceptable on condition that the negotiating parties are aware of the coordinate system used and the accuracies involved. Figure 24 shows a static observation situation.

This is not the case at the demarcation and documentation stage. Here, the accuracy of single centimetres is essential. It would be a good idea to work with two survey parties when observing according to static or kinematic techniques, with an overlap of two points for every six measured by a single party. It would also be a good idea to plan the boundary markers in such a way as to permit setting up of the GPS antenna on top of the marker without the need for centring, or to devise a way of setting up two antennas, one on each side of the marker.

Recording the positions of boundary markers by GPS methods seems to be preferable to any other method. It should be stressed, however, that in the era of rapidly developing and often unexpected technologies, it is difficult to forecast more than several years ahead.

In the past decade, and in the foreseeable future, boundary surveys are likely to be based on GPS determinations of locations, with the final computed coordinates entered into a geographical information database.

**Figure 24: Static GPS Observation with the Antenna set up over a Boundary Pillar**
(Courtesy of Leica Corp).

# 4. Geographic Information Systems as Applied to International Land Boundaries

*...the emphasis is on query and response rather than display.*
(Clarke, 1995: 3).

## 4.1 The Importance of Information on the Boundary

The long process of the creation of a boundary begins with negotiations by boundary architects, continues, through the formulation of the delimitation and conclusion of a treaty or agreement, the demarcation and recording of the boundary position, and ends with the transition to peaceful management and coexistence on both sides of the line. This is the culmination of a lengthy international political process and the beginning of cooperation in protection, maintenance and administration of the created boundary, with the emphasis on its permanency and stability.

Throughout this process, both sides need a smooth flow of information: at the beginning each side, separately to its negotiators, together to and from the demarcators recording the infrastructure of the boundary for posterity, and to and from the bilateral authority which constantly evaluates all matters pertaining to the measures necessary to achieve a smooth administration of the frontier. This information is one of our most important resources, not the least aspect of which being the easy availability of the relevant information to the public directly or through the media.

This cannot be realised without assembling all the relevant data from which information about the boundary can be easily retrieved as required. The concept of a boundary information system is eminently applicable in this context. The following kinds of data should be included in any envisaged system:

- The text of the treaty, agreement, judgment, or award, with all the relevant protocols, on which the location of the boundary is based.

- The principles on which the boundary line over land is based, for example, that it runs in straight lines between marks, except where the line follows a terrain feature such as local watershed, or where it follows watercourses.

- The principles on which the boundary line following watercourses is based, namely, the middle line of a watercourse, or a bank of a watercourse, or a thalweg, including clear definitions of these terms.

- The principles applicable in cases of natural changes in boundary watercourse bed.

- Description of the marks and monuments used to mark the course of the boundary and the principles governing their placement, relative to the boundary line.

- The numbering of the marks.

- Any special provisions or arrangements along the boundary line, such as clearing a strip of defined width on both sides of the line, or prohibition of construction of installations within a prescribed strip along the boundary.

- Principles governing inspection and maintenance of the boundary including restoration of markers where necessary. A specification for records of these operations.

- Measures appropriate to protection of boundary markers.

- The bilaterally agreed upon coordinates of the boundary markers, referred to a stated datum and expressed within a well-defined coordinate system.

- The principles governing the recording of boundary incidents, such as illegal crossings, fires and damage to boundary fixtures.

- Principles governing the dissemination of information about the boundary.

## 4.2 Boundary Digital Databases and GIS

A database[18] is at the heart of a Boundary Information System. While a database can take several forms, the range and volume of information that ideally should be maintained about a boundary tends to promote the use of a computerised database system. One widely used system for establishing and maintaining a database on a boundary is a Geographic Information System (GIS). GIS is an organised collection of computer hardware, software and geographic data, designed to efficiently capture, store, update, manipulate, analyse, retrieve and display all forms of geographically referenced information. Such systems exist at many national mapping agencies and are an excellent model for a dedicated boundary information system.

In a GIS, geographic features in a data bank are classified into three feature classes: points, lines and polygons. Typically, layers are organised so that feature types are stored in separate layers: boundaries, roads, land use, streams, etc. A code scheme would emerge through which various features can be stored and retrieved as necessary. For example, the following range of Feature Types might be assigned certain codes:

| Number Layer | Feature codes | Feature types |
|---|---|---|
| 0 | 0-99 | Geodetic control and boundaries |
| 1 | 100-199 | Roads |
| 2 | 200-299 | Infrastructure and utilities |
| 3 | 300-399 | Water features (linear) |
| 4 | 400-499 | Water features (polygonal) |
| 5 | 500-599 | Hypsography (elevations) (points, lines) |
| 6 | 600-699 | Land use (polygonal) |
| 7 | 700-799 | Structures (buildings) (polygonal) |

18 A systematised collection of data that can be accessed immediately and manipulated by a data-processing system for a specific purpose.

| | | |
|---|---|---|
| 8 | 8011-8999 | Other features (points) |
| 9 | 9100-9999 | Other features (linear) |
| 10 | 1000-1999 | Other features (polygonal) |

Now let us look at the examples of codes allocated to different features under this coding scheme.

| Feature Code | Feature |
|---|---|
| 10 | International Boundary point – pillar |
| 11 | Geodetic control point |
| 14 | Benchmark – levelling |
| 34 | International boundary point – unmonumented |
| 51 | Cadastral block boundary |
| 55 | Cadastral parcel boundary |
| 73 | District boundary |
| 79 | Territorial waters boundary |
| 85 | Statistical district boundary |
| 100 | Road axis |
| 114 | Path axis |
| 122 | Road shoulder boundary |
| 141 | Railway |
| 156 | Ford |
| 159 | Footbridge |
| 191 | Runway axis |
| 201 | Electric power line (h.v) |
| 204 | Underground power line |
| 231 | Telephone line |
| 233 | Cable television line |
| 301 | River axis |
| 303 | Dry streambed |
| 310 | Canal axis |
| 424 | Reservoir |
| 432 | Lake shoreline |
| 438 | Area seasonably flooded |
| 443 | Salt pans |
| 501 | Contour line |
| 503 | Intermediate contour |
| 531 | Bathymetric contour |
| 608 | Cultivated area |
| 653 | Sports field |
| 660 | Orchard |
| 665 | Citrus grove |
| 703 | House under construction |

| | |
|---|---|
| 716 | Industrial building |
| 731 | Police station |
| 734 | Medical building |
| | |
| 8139 | Railway stop (4 figure code – appears also in transportation layer) |
| 8188 | Traffic light (4 figure code – appears also in transportation layer) |
| 8241 | Telephone pole (4 figure code – appears also in infrastructure layer) |

Each layer has its own format in order to achieve a structure which is easily accessible and as non-voluminous as possible. Let us consider an example of a record in the Zero (top) layer of the database:

78566096010353147217436250613841286113
7856/010/6096/3531472174/3625061384/1286113

| | |
|---|---|
| 7856 | Record number |
| 010 | International Boundary pillar |
| 6096 | Pillar Number |
| 3531472174 | Longitude 35°31'47".2174 |
| 3625061384 | Latitude 36°25'06".1384 |
| 1286113 | Elevation 1286.113 m. |

The above mentioned codes are only an example of how a coding system may be designed. Feature Codes are country specific or even boundary specific. The format has to be designed so that it should serve for a long time, but there is not a set recipe for the format and each database design team will make its own considerations and decisions. Many countries and even local authorities establish their own GIS as a multipurpose system for information storage, updating and dissemination in various forms. The level of detail gone into depends on the value and potential of the land.

## 4.3 A Boundary GIS Database

Given the facilities within a GIS to represent lines on the ground it is particularly suited to storing information about international boundaries. The top layer in Figure 25 includes an international boundary line. This line can represent several different kinds of boundary:

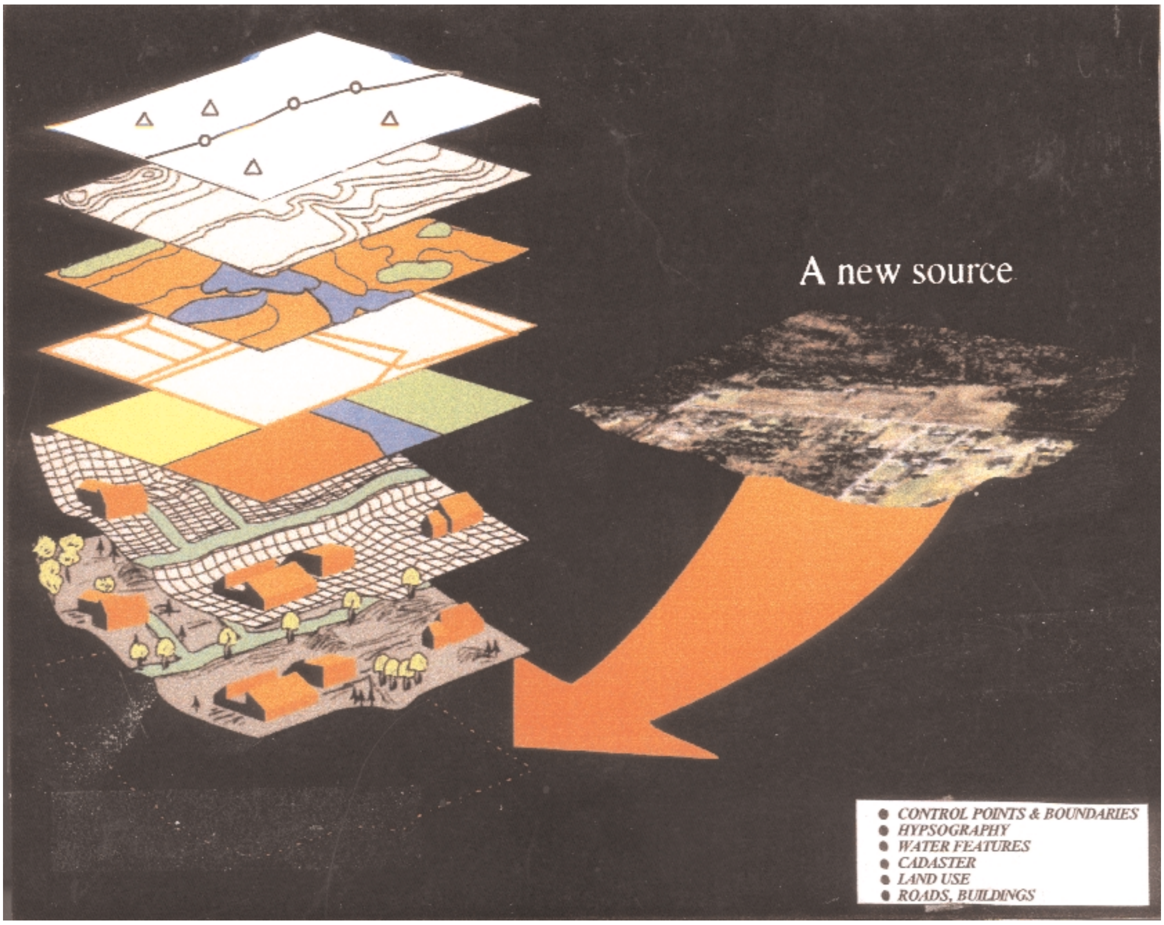
- A traverse of straight lines between monumented points situated on peaks of hills, all surveyed by GPS and some also by ground survey methods.

- A line along a local watershed, the watershed defined by a digital photogrammetric method, through stereoviewing inspection, recording coordinates from which the line can be marked as necessary.

- A line along a stream, the coordinates recorded by digital photogrammetry without marking envisaged.

- A line defined as the middle of a river, unsurveyed, but the approximate coordinates of the middle digitised from an existing map.

**Figure 25: The Layered Structure of a Digital GIS Database, representing the many geographies of the real world**




One of the demarcated points should serve as the boundary datum point at which static GPS observations were made. This point also becomes the central meridian of the plane rectangular projections system, Universal Transverse Mercator (UTM) – to serve the frontier area. All positional references would be given in this system, each country being free to incorporate the boundary system into its own national datum independently.

## 4.4 Main Features of a Boundary Information System based on GIS

A boundary information system has two principal objectives:

- To provide the authorities and the general public with a reliable information on the boundary.
- To facilitate the management of the boundary and the adjacent areas.

Ideally, such a system could be a joint venture for both neighbouring countries, this, however, depends to a large extent on the degree of friendly relations between the countries concerned. Even if each country establishes a Boundary GIS of its own, there is a common denominator between such separate systems provided by the framework of the delimitation formula and the joint demarcation survey related to the boundary datum and the boundary coordinate system. Unfortunately a boundary information system based on GIS is expensive to establish and maintain and not all countries, particularly those in the Third World, can afford such an investment. A good manual system though, can be an acceptable alternative in these circumstances.

### *4.4.1 Building up the system*

Much in the same way as the map coverage shown in Figure 1 covered the area adjacent to the actual boundary line, a Boundary GIS should be available within a strip of some 20km width, following the direction of the boundary. Whilst the foundations of a boundary GIS database are laid down during the negotiation stage, leading to the delimitation, the demarcation with the bilateral survey of the final boundary location, provides the infrastructure for a Boundary GIS.

The topographical database can be built up gradually, at the beginning by digitising maps or by producing an infrastructure for new ones, much as outlined in Section 4.2. Various outputs can be produced from the digital database, such as maps at various scales. If one prepares the data base for a basic map at the scale of 1:25,000, the same data base will serve for deriving maps at larger scales up to 1:5,000 as shown in Figure 26, as well as special products such as an orthophoto, which can be used on its own, or combined with a line map, as shown on Figure 27.

Figure 27 shows some of the map components and Figure 28 shows them combined into a map. A boundary GIS should contain as much information as possible on the frontier area, e.g. land use as shown in Figure 29.

Design and layout must be considered when producing output in the form of a map. A beautiful map will help to convey the intended message with greater impact. It is likely to increase the credibility of results, as well as their acceptance. The following points should be considered:

- Designing the components of a map;
- Using symbols effectively;
- Determining the purpose of a map;
- Defining the map parameters (size and scale);
- Designing the map layout;
- Preparing symbol data;
- Creating a final map; and,
- Generating tabular reports (such as a list of coordinates).

**Figure 26: Maps at Different Scales produced from the same Aerial Photographs**

Aerial Photography, scale 1:40,000, one of many data sources

Scale 1:25,000

Scale 1:10,000

Scale 1:5,000

## 4.5 Boundary Administration and Management

Once a boundary has been demarcated it is not unusual to administer the boundary through a joint Boundary or Frontier Commission, whose task it is to ensure security and order along the boundary and to monitor adherence to the treaty or agreement upon which the boundary is based. The structure and organisation of the bilateral Boundary Commission is a matter of agreement and would vary with the length of the boundary, the terrain characteristics and the character of relations between the boundary neighbours as well as the cost and the economic status of the countries. There is no recipe for the terms of reference for the activities of a Boundary Commission, but the maintenance of the boundary monuments is clearly a task for such a bilateral body. Meetings of the Boundary Commission can be held alternately in the territory of the contracting parties and at their respective expense. Good examples of the administrative tasks of bilateral boundary commissions can be found in the UN Treaty Series (1972).

A Commission should provide the means for discussing and resolving any problems that occur with the demarcation. For example the alignment of the boundary in navigable watercourses may vary with the natural displacement of the main navigation channel and should be jointly checked periodically by the parties and the changes recorded. In non-navigable watercourses, the alignment of boundary line may vary with gradual, natural changes in the configuration of the banks, e.g. a meandering river stream. The parties should decide by agreement whether the boundary should continue along the middle of the new course or whether it should be restored to the previous position by redemarcation. Where the line runs over water, its course may be marked by auxiliary border marks, such as buoys, the position of which should be recorded by a survey procedure.

The boundary can be subdivided into sectors of appropriate length and the responsibility for maintenance of the monuments divided equally between the parties, possibly on the basis of odd numbered sectors going to one party and even numbered sectors to the other, for the purpose of executing and financing the work required. A survey of land use along the boundary (Figure 29) is also a useful aid to boundary maintenance routine. It should, however, be made clear that all activities connected with the boundary maintenance must be coordinated between the parties. This applies also to any kind of a cleared strip on both sides of the boundary line, or fences or monitoring structures.

Administrative arrangements should be made and detailed in an agreement for the examination and settlement of incidents along the boundary (such as illegal crossings, firing, damage to boundary fixtures, illegal communications and other breaches of peace). Provisions should be made to refer the unsettled matters or matters beyond the bilateral commission competence, through diplomatic channels, to government authorities of the parties.

Provisions should also be made for informing the other party of any outbreak of contagious diseases in humans or animals or plants, danger of fires and so forth, to coordinate prevention of the spread of such occurrences into and across the frontier. A GIS based Boundary Information System can be a powerful tool in these instances. For example very exact answers can be provided to the following types of queries:

1. Time required for police/military force to arrive at point... from the base at...
2. The nearest hospital to point... is at...

**Figure 27: The Various Layers of Map Components Derived from the Database: roads (top left), water features (top right), contours and spot heights (bottom left), orthophoto (bottom right)**

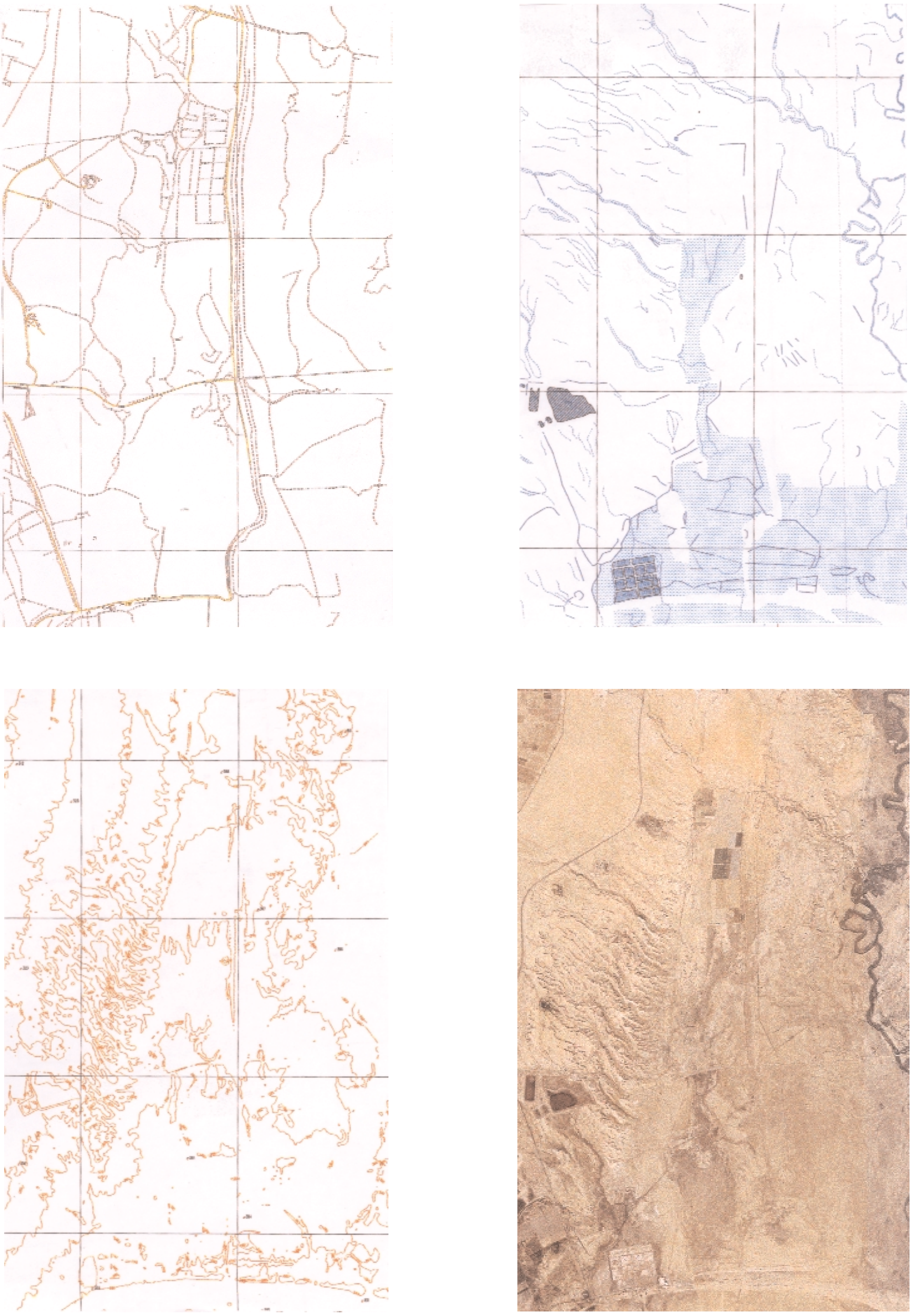
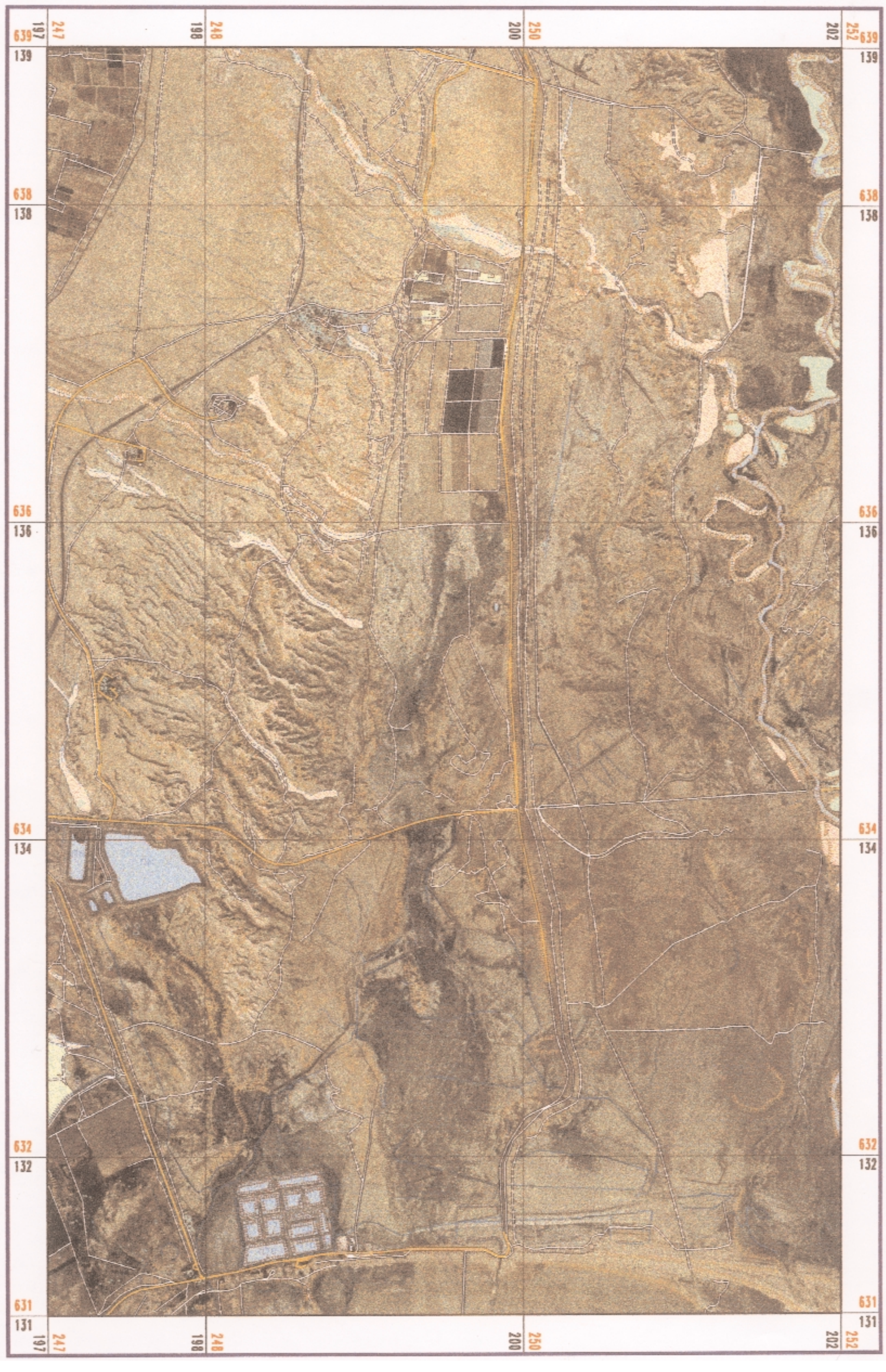


**Figure 28: The Components in Figure 27 Combined**



3. Water sources available nearest to point... are at...
4. Emergency at... Establish police/military road barriers at...
5. Children's busses within the radius of... from...
6. Helicopter available at... Estimated arrival at...

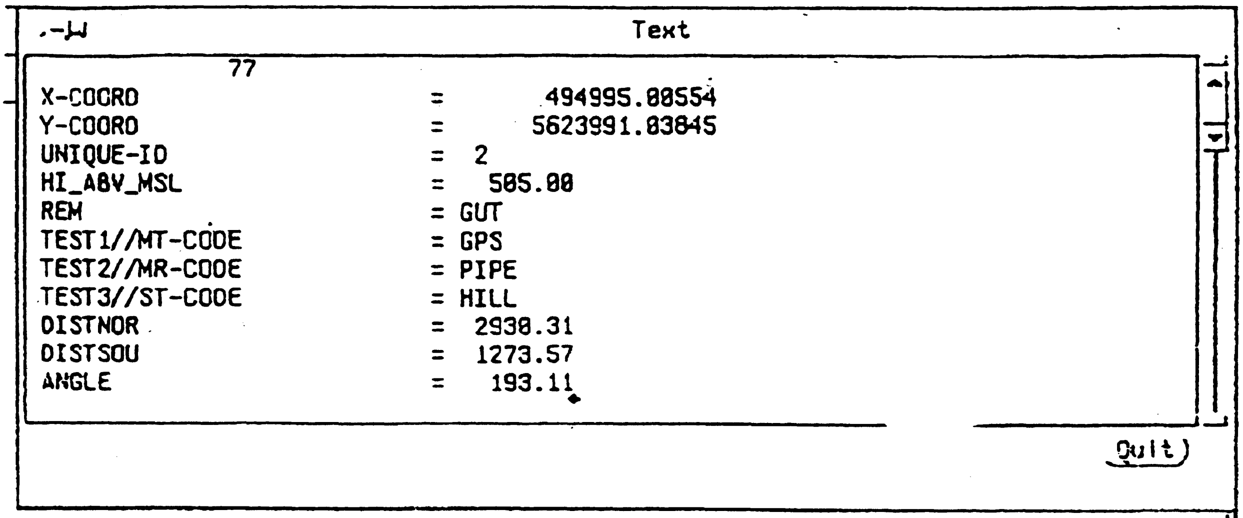
The ease with which emergency services equipped with a hand held GPS receiver could be directed to where their presence is required, should be noted. Equally important the information system can be used to locate precisely any occurrence of crime or breaches of security along the boundary.

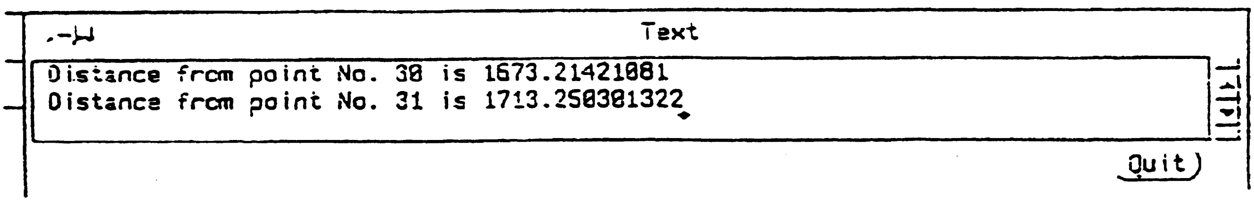
## 4.6 Conclusions

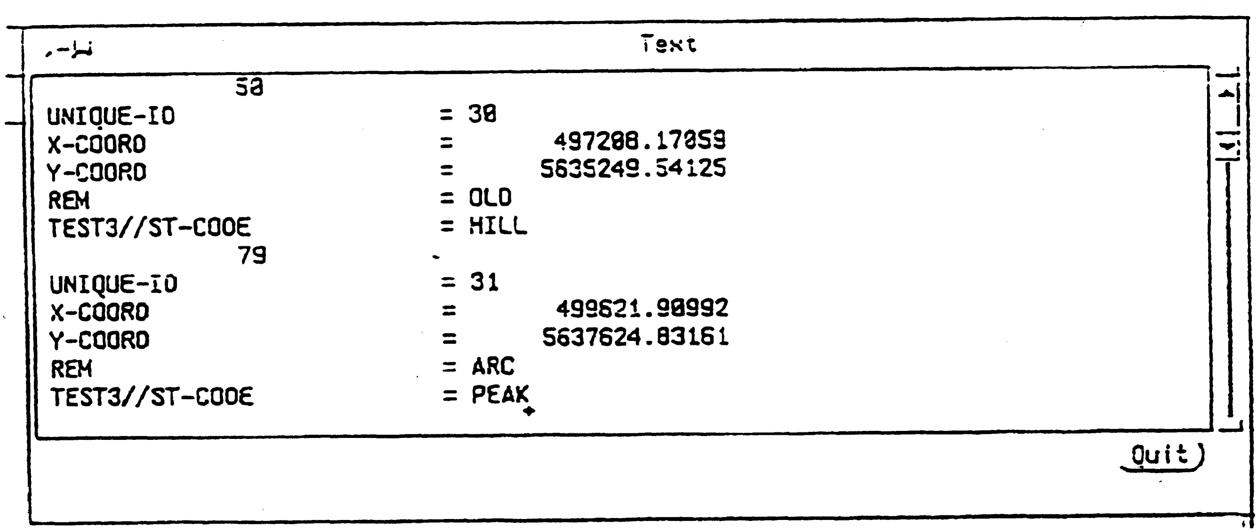
A great deal of information is assembled throughout the whole process of boundary negotiation, delimitation and demarcation. This information should be maintained by both parties to the agreement in, ideally, a joint database providing a Boundary Information System. Given the volume of data and the need to geographically reference much of it, a digital database, using a GIS approach would be the optimum approach, where resources allow.

**Figure 29: Land Use along the Boundary**
(Courtesy of Teldor Co.).

**Figure 30: An Example of Query Answers on the Computer Display**
(Top: Point No. 2 and its attributes.
Bottom: border crossing occurrence between points 30 and 31).



# 5. Modern Demarcation and Recording Surveys

Two demarcation and recording surveys from the last decade can serve as examples of the application of modern technologies to boundary making. The examples have a lot in common, although they were not connected with each other in any way. The first example is the demarcation of the international boundary between Iraq and Kuwait (ILM, 1993). The second example is the demarcation and recording survey of the international boundary between Israel and Jordan, delimited in the two states' *Treaty of Peace* (1994). It is worthy of note that both demarcations were preceded by previous inadequate delimitations some 70-80 years ago and never fully demarcated.

## 5.1 The Iraq-Kuwait Boundary

The background of the Iraq Kuwait boundary problems is ably presented in Schofield, (1993). Security Council Resolution 687 (1991) called upon the Secretary General of the United Nations "*to lend his assistance to make arrangements with Iraq and Kuwait to demarcate the boundary between them, drawing on appropriate material...*" After consultations with the Governments of Iraq and Kuwait, the Secretary General established the United Nations Iraq-Kuwait Boundary Demarcation Commission, composed of three independent experts, one of whom would serve as chairman plus one representative each from Iraq and Kuwait, to demarcate the boundary between the two countries.

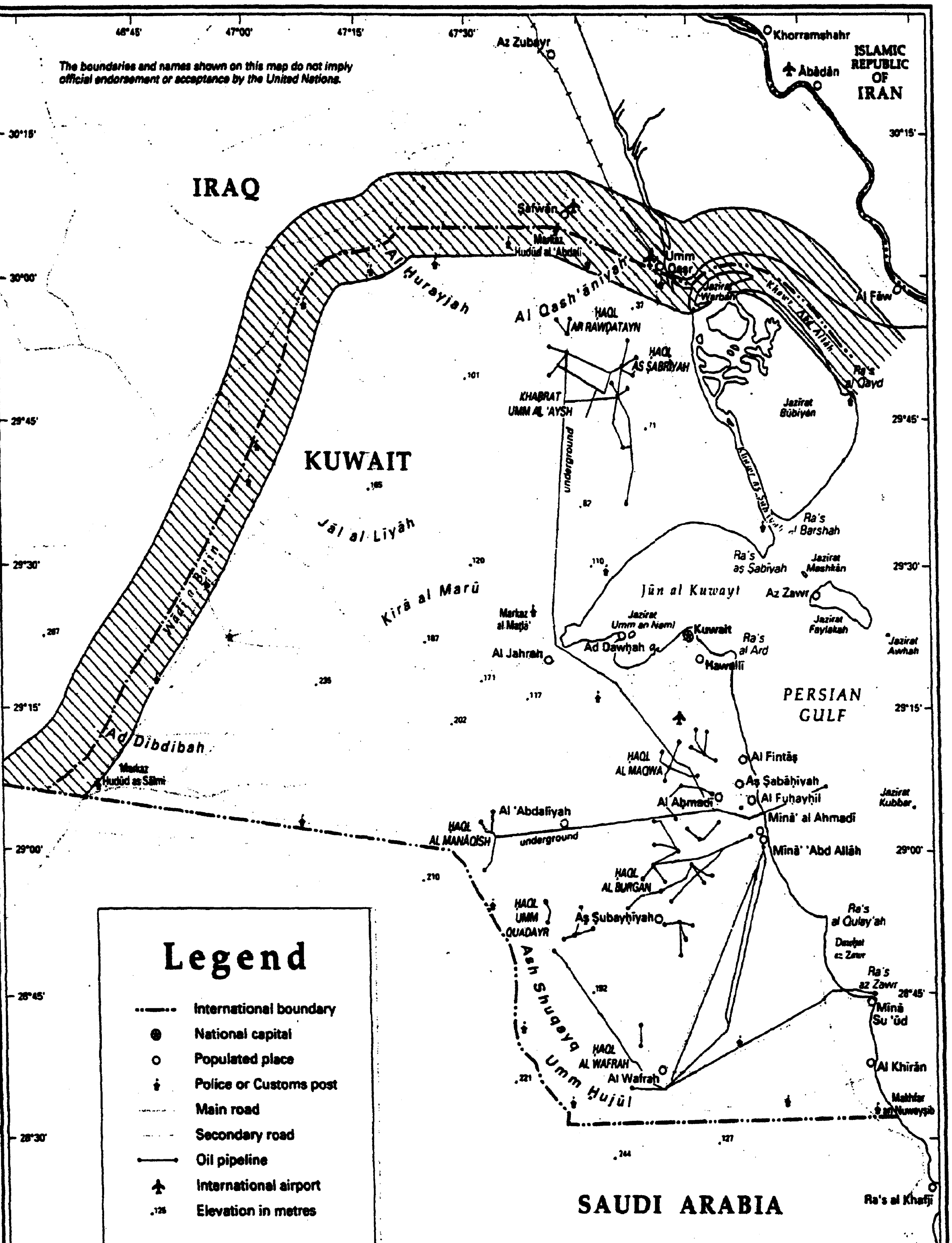
The terms of reference provided that the international boundary should be demarcated in geographical coordinates of latitude and longitude, as well as by a physical representation (on the ground). The delimitation formula was the 1932 *Exchange of Letters* between the Prime Minister of Iraq and the Ruler of Kuwait as follows:

> *From the intersection of the Wadi-el-Audja with the Batin and thence northwards along the Batin to a point just south of the latitude of Safwan; thence eastwards passing south of Safwan Wells, Jebel Sanam and Um Qasr, leaving them to Iraq and so on to the junction of the Khor Zobeir with the Khor Abdulla. The islands of Warbah, Bubiyan, Maskan (or Mashjan), Failakah, Auhah, Kubbar, Qaru and Umm-el-Maradim appertain to Kuwait.*

Pursuant to paragraph 3 of Resolution 687 (1991), the Secretary-General appointed Mr Mochtar Kusuma-Atmadja, former Minister for Foreign Affairs of Indonesia as Chairman; Mr Ian Brook, then Technical Director, Swedsurvey, National Land Survey of Sweden; and Mr William Robertson, Surveyor General/Director General of the Department of Survey and Land Information of New Zealand, as independent experts. Iraq was represented by Ambassador Riyadh Al-Qaysi and Kuwait was represented by Ambassador Tarek A. Razzouki. Mr Miklos Pinther, Chief Cartographer of the United Nations Secretariat, was appointed Secretary to the Commission.

With effect from 20 November 1992, Mr Kusuma-Atmadja resigned as Chairman of the Commission for personal reasons. Consequent upon the resignation of Mr Kusuma-Atmadja, the Secretary-General appointed as his successor Mr Nicolas Valticos, former Assistant Director of the International Labour Office, and member of the Institute of International Law, who assumed his functions on the same date.

**Figure 31: An Orientation Map for the Iraq-Kuwait Boundary**



In addition to the terms of reference, the Secretary General transmitted to the Commission a set of 10 topographic maps at the scale of 1:50,000 by the British Military Survey, on which the boundary is shown as *"undemarcated."* For a historical summary on the boundary, the reader is referred to *ILM* (1993: 1434-1437).

The boundary can be divided into three parts:

a. The section in Wadi-el-Batin.
b. The section between Batin and the Khowrs.
c. The section in the Khowrs.

The Commission held a general discussion on the three sections of the boundary as a whole on the basis of the discussion paper presented by the independent experts.

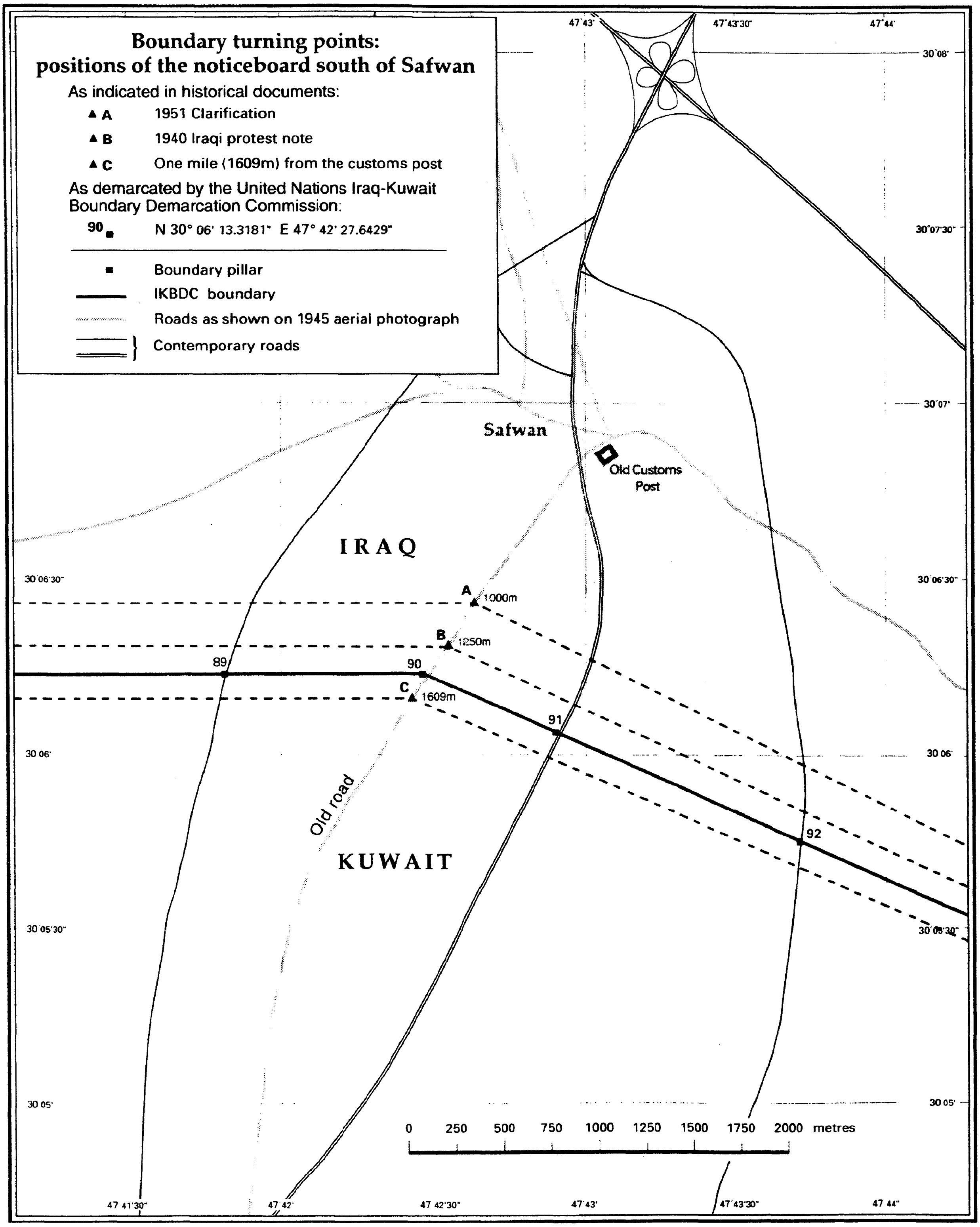
Considerable time was devoted on the investigation and discussion of the definition of the point south of Safwan, the general course of the boundary in the Batin, the position of the boundary south of Umm Qasr and the possible position of the boundary at the junction of Khowr Zhobeir and Khowr Abd Allah in 1932. The principles to be applied in the demarcation of the boundary beyond the junction of the Khowrs were also considered at length. The language of the delimitation formula was debated extensively. Of particular concern were whether it was technically possible to demarcate the boundary without a turning-point at Safwan, whether the thalweg or the median line concept should be applied in the northern part of the Batin to divide the grazing areas equitably and whether there had been a shift in the junction of the Khowrs over the past decades. With regard to the Khowr Abd Allah section, the principle of the median line, tempered by equity, was considered.

In the technical sections of the discussion paper, the independent experts proposed methods for new mapping of the border area to provide a proper basis for demarcation. The maps and the related spatial data were, in the opinion of the experts, a necessary supplement to the existing maps and documents and would be required before demarcation on the ground could be carried out, as there were no adequate maps of the boundary area for the purpose of demarcation.

To assist the Commission in its deliberations and to enable it to achieve a precise demarcation, the independent experts therefore proposed a new survey and mapping of the entire border area. The proposal included the establishment of a geodetic control network and ground control points for mapping, using satellite-based (GPS and Doppler) methods, combined with conventional survey techniques, aerial photography and the production of a set of large-scale orthophoto maps at the scale of 1:25,000. Included also were special maps to enable the Commission to study specific areas such as the Batin and the border areas at Safwan and Umm Qasr.

During the first stage of the field work, the Commission established its own geodetic datum called *IKBD-92* (Iraq Kuwait Boundary Datum, 1992), based on the WGS '84 ellipsoid and established geodetic network control for the purpose of demarcation of the boundary. It should be noted that the establishment of boundary datum and geodetic control network does not require their connection either to the Iraqi geodetic control, or to the Kuwaiti geodetic control. Four datum stations, 25 geodetic control stations and 137 photogrammetric control points were established towards the end of 1991, by GPS and Doppler survey methods.

## Figure 32: Turning Point of the Boundary South of Safwan




Initially, a series of 31 orthophoto maps (in English and Arabic) was produced at a scale of 1:25,000. In addition, separate orthophoto maps were produced at the scale of 1:7,500 for the Safwan and Umm Qasr areas.

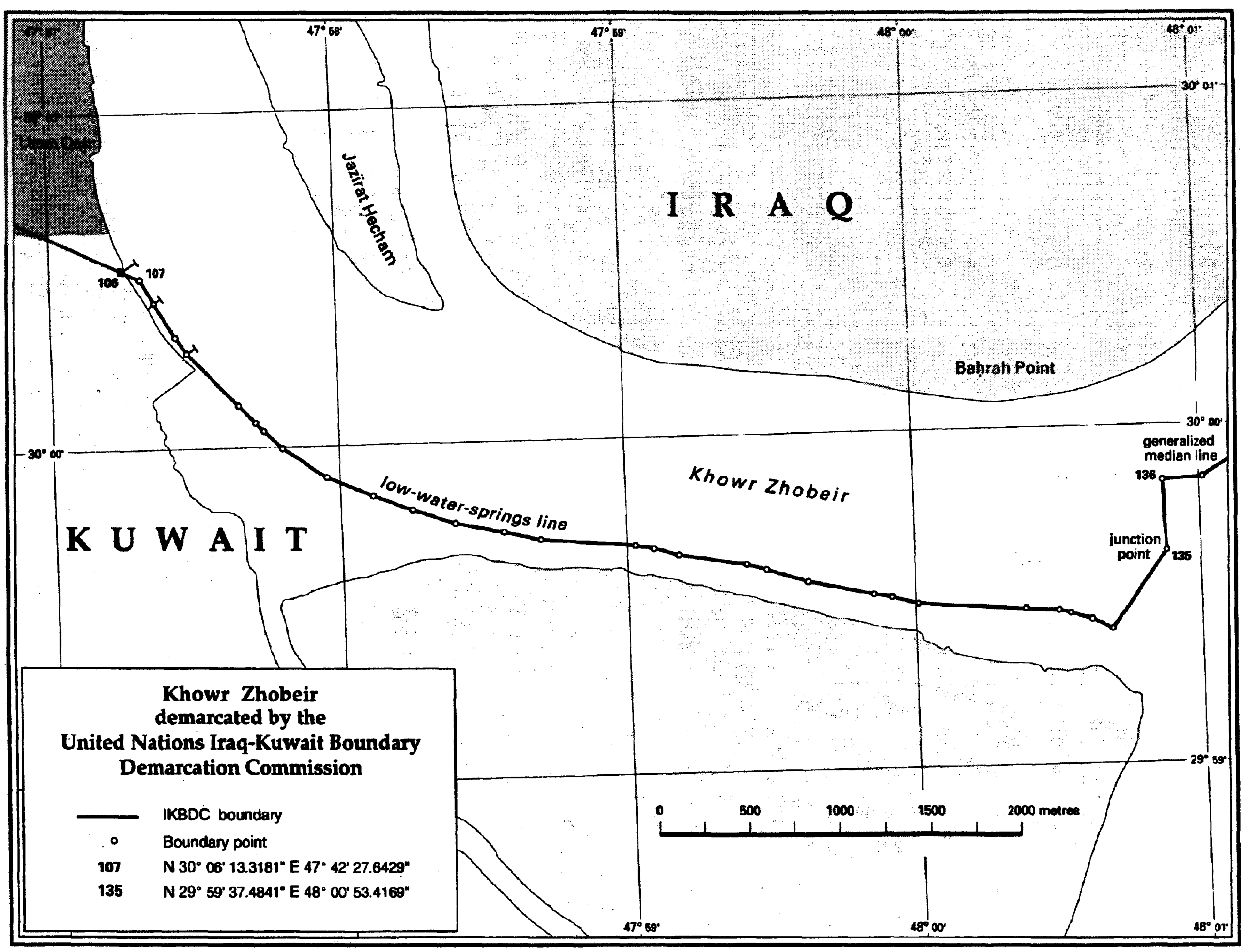
For the Batin, 1,420 transverse photogrammetric height profiles were produced. From these the lowest-point line in the Wadi was determined by examining the elevation contours, by measuring along the profiles and by generating three-dimensional digital terrain models.

At a later stage, the aerial photography was extended eastwards to the outer reaches of the Khowr Abd Allah, from which additional orthophoto maps were produced at the scale of 1:25,000. In order to reduce the final number of map sheets and to provide better coverage of the boundary, the size of the sheets was changed. The boundary from the trijunction (initial southwestern point) to the eastern end of the Khowr Abd Allah is thus covered by 18 map sheets.

The Commission dealt with the maritime sections of the boundary from Umm Qasr (boundary pillar 106 – the last land boundary point) eastwards, but this is outside the scope of this *Briefing*. The Wadi Al Batin section was demarcated along the line of the lowest points, by a series of straight lines of approximately 2km in length, balancing the areal departures from the lowest points line, between the two countries. This was achieved with the aid of terrain models and transverse elevation profiles.

The Commission decided that the western section of the boundary would terminate at the intersection of the line of the lowest points in the Wadi Al Batin with the line of the latitude of the boundary point south of Safwan. The northern section of the land boundary required the definition of the shore point south of Umm Qasr, at the eastern end of the section.

**Figure 33: The Non-land Boundary (beyond Pillar No. 106).**



On the old road south of Safwan there was a notice board marking the boundary, the position of which was apparently not measured, and two different versions regarding its location existed, namely 1,609m (1 mile) and 1,250m of the south west extremity of the customs post. A third version claimed that the position was 1,000m from the customs post. The Commission decided to establish the boundary half way between the two versions, which it considered most probable, at a mean distance of 1,430 meters from the southwest extremity of the old customs post and along the old road. This was done with the aid of several air photographs (from 1945 to 1992) and astronomical observations in 1942.

The location was determined by GPS observations and subsequent computation of coordinates producing a latitude of 30°06'13".3181 and thus fixing the parallel of latitude for the boundary between the end of boundary in Wadi-Al-Batin and the point south of Safwan (boundary pillar No. 72). Looking at the coordinate of the parallel, one notices that the estimate of the GPS location accuracy must have been in the order of single centimetres as compared with the hundreds of metres in estimating the location of the notice board! These, however, are the realities of boundary making, that the purely technological data of the present day are, as a rule much more accurate than any estimates relating to past positions.

The Commission determined the junction of Khor Zobeir with Khor Abdullah and used it to determine the intersection of the boundary with the shoreline at Umm Qasr, aided by the British 1:50,000 map and leaving Umm Qasr port and village as stated in the delimitation document (boundary pillar No. 106).

The section of the boundary between the turning point South of Safwan (boundary pillar no. 90) and the final land point (boundary pillar No. 106) was defined by the Commission as being "*along the geodesic.*" This perhaps is the first instance of using the term "*geodesic*" in boundary making, a geodesic being the shortest line between two points on the surface of the ellipsoid of reference. Only experts in geodetic science or geodetic engineering are capable of setting out such a line on the ground or defining it by geographical coordinates.

### 5.1.1 *Physical demarcation of the land boundary*

The coordinates for the land boundary are physically demarcated by 106 monuments, approximately 2km apart, and 28 intermediate markers. The first monument is the existing pillar marking the trijunction point of Iraq, Kuwait and Saudi Arabia. Each boundary monument site consists of a steel-reinforced, silica-mica aggregate concrete boundary pillar, painted yellow and black, 3m in height and measuring $45cm^2$ at the top and $90cm^2$ at the base. The pillars are sunk into the ground to an approximate depth of 1.5m. A $2m^2$ concrete collar is positioned over them flush with the ground. At each location one witness mark on the Iraqi side and one witness mark on the Kuwaiti side are buried in the ground to facilitate repositioning of the pillar should it become necessary. Small pointer pillars on either side provide a direction towards the site of the next pillar.

Before and after the pillars were emplaced, their positions were inspected and checked at each site. During this exercise it was found that intervisibility between pillars was not possible at every location, either because of the terrain or because of structures along the sightlines. Where the terrain interfered with intervisibility, intermediate pillars were emplaced during the final field session, in April 1993.

The final output of the United Nations Iraq-Kuwait boundary commission is the list of geographic coordinates (latitude and longitude) of the 106 boundary pillars, 28 intermediate boundary markers and the 56 points defining the position of the low-water line and the median line at sea.

## 5.2 The Israel-Jordan Boundary

The original delimitation of the boundary between mandatory Palestine and Transjordan was laconic and inadequate: "...[a] *line drawn from a point two miles east of the town of Akab ah up the centre of Wady Arabah, the Dead Sea and the River Jordan to the junction of the latter with the River Yarmuk, thence up the centre of the River Yarmuk to the Syrian Frontier*." One sentence in the order of the high commissioner, dated 1 September 1922, for a boundary almost 400km long, even if half the length is along natural features, such as rivers and the Dead Sea, where demarcation is not strictly necessary. The section of the boundary between the Gulf of Aqaba and the Dead Sea, running "*up the centre of Wady Arabah*" was considered by the British too expensive to demarcate, given the logistical difficulties associated with the remote boundary area at that time, as well at the complicated problem of interpreting what was the "*centre of the wadi*", which is a flat bed, several kilometres wide. It was only in 1945-1947, that the survey of Palestine, under the British mandate demarcated a short stretch of the boundary, of less than 4km, at the southern end of the boundary. The saving of expenditure for demarcation, became a source of friction between Israel and Jordan during the period of armistice and cease-fire between 1949 and 1994.

The *Treaty of Peace* between Israel and Jordan was signed on 26th October 1994, with the joint team of Experts (JTE) acting in an advisory capacity during the negotiations concerning the delimitation of the boundary.

The delimitation was unique in character, using an album of orthophotos, showing the boundary line, as Annex I, Appendixes I-VI, to the *Peace Treaty*. The boundary line as shown on orthophotos is the best possible way of expressing its intended location within the delimitation and a clear directive for demarcation, avoiding problems connected with the interpretation of maps.

The demarcation was carried out by the joint Team of Experts who worked together in all the professional activities, connected with establishing principles, reference frame, observations, computations, monumentation and the final set of coordinates. The survey task of the demarcators is then very clearly specified. It is stated that:

> *The boundary pillars shall be defined in a list of geographic and UTM coordinates based on the joint boundary datum (IJBD 94) to be agreed by the Joint Team of Experts appointed by the Parties using Global Positioning System measurements... This list of coordinates... shall be binding and shall take precedence over the maps as to the location of the boundary line of this sector*.

This approach is undoubtedly the ideal way ahead for boundary delimitation and demarcation.

Phase I of the demarcation was carried out by three Jordan/Israel field teams working in parallel. Every point was located on the ground, using the orthophoto maps for identification, and marked temporarily, with witness marks and ground measurements describing the location. In phase II, the monumentation took place, pillars replacing the temporary markers, 124 in all.

The Israel Jordan Boundary Datum (*IJBD '94*) was established using the WGS '84 ellipsoid and 12 boundary datum points, six in Israel and six in Jordan. The location of the 12 datum points was decided upon after a two day reconnaissance and the points were observed with 12 dual frequency GPS receivers, in two sessions of four hours each, so that each point was observed for eight hours (static observations) on the same day. The 12 datum points established the connection to the reference ellipsoid and one of them – IJ 09 was chosen for the boundary datum, using computed average value calculated by each side using broadcast ephemeris. Both sides agreed to use ellipsoidal heights.

IJ 09 Latitude 31°45'04". 37449 Longitude 35°36'13".70799 Height – 272.150m.

Using the UTM projection (Universal Transverse Mercator), grid coordinates were computed, using the appropriate mapping equations. Holding the datum frame coordinates fixed, the boundary pillar coordinates were computed for the 124 pillars between the Red Sea and the Dead Sea. A uniform accuracy estimated at sub-decimetre level was achieved by each side separately and in view of this an average value was accepted for the final coordinates of each pillar.

## 5.3 Conclusions

These case studies demonstrate that boundary engineers play a major part in demarcation and that demarcation is largely a surveyor's task, in sharp contrast to delimitation, where the principal players are statesmen, diplomats, international lawyers, political advisers etc., and the surveying and mapping experts act in an advisory capacity. Yet it is the demarcation which provides a permanent record of the boundary and an important component of the database, which serves as an infrastructure for managing, maintaining and preserving a boundary line.

The studies also highlight the professional cooperation between the experts of the countries involved is of the utmost importance. As Rushworth, (1993) quite correctly says:

> *Delimitation by diktat of the winner of a war, such as the recent UN decision on the Iraq-Kuwait boundary, tends not to stand the test of time. Agreed settlement of frontiers only occurs when relations between the states concerned are reasonably good and usually lags a considerable time behind any conflict.*

Another point which emerges from these examples is that orthophoto maps are an excellent aid to delimitation and are almost indispensable in avoiding disputes, which arise worldwide due to faulty delimitations. Equally, a boundary datum not only avoids problems of connecting boundary points to a national datum, but provides an important infrastructure for a geographic information system, which is of great assistance to managing and maintaining boundaries. It is clear from the two case studies that GPS observations, joint and simultaneous are the best way to define the location of boundary points within a very acceptable accuracy and a reasonable time. It can be seen that a GPS demarcated boundary line expressed in coordinates can always be restored by GPS means, without any other aids. Clearly, where resources exist to use this technology, it is recommended.

**Figure 34: An Example of an Orthophoto attached to the Israel-Jordan Peace Treaty**

## 6. Summary and Conclusions

Practically every existing boundary has its own specific background, which includes technical aspects, often dating back several centuries. It is often very difficult and perhaps unnecessary to modernise such boundaries by introducing modern technology, even though a boundary information system, ideally a computer database system, would be desirable in most cases.

It is strongly recommended that the boundary making technologies outlined in this paper be used, as far as possible, in all cases of newly emerging boundaries or in the reestablishment of old ones. The following aspects should be stressed:

- Technical experts should participate in the negotiating teams in order to provide the negotiators with the most reliable information available, in other words, to bring the terrain to the negotiating room.

- The boundary treaties and agreements should rely less on maps and more on recently acquired digital data. Great care should be taken in order not to misuse significant figures. All maps used should be evaluated by experts and the results of the evaluation recorded.

- Each boundary should have a geodetic boundary datum, which would provide a well defined reference system, independent of national datums and completely unclassified.

- All location surveys should be executed by GPS methods with each location given its estimated accuracy. Demarcation records should be meticulously prepared and digitally stored, permitting restoration of marks at all times.

- A computerised boundary information system as outlined in this *Briefing* should ideally be established for the purpose of efficient and peaceful administration of the boundary. Selected parts of the specific boundary database should be included in a worldwide database.

- Every effort should be made to bridge the gap between the boundary architects and boundary engineers.

It is hoped that the model of technological services for boundary creation and their administration detailed here will, through its implementation, become a contribution to preserving international peace.

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## Abbreviations

ICJ International Court of Justice

ILM International Legal Materials

ILR International Law Review

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