International Boundaries Research Unit

BOUNDARY & TERRITORY BRIEFING

Volume 2 Number 1

Positioning and Mapping International Land Boundaries

Ron Adler

Boundary and Territory Briefing

Volume 2 Number 1
ISBN 1-897643-19-5
1995

Positioning and Mapping International Land Boundaries

by

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Acknowledgements

This work was supported in part by the Charles Revson Foundation, New York, within the Jerusalem Research Institute, and by the Center for Mapping - Survey of Israel, Tel-Aviv.

Institut Cartografic de Catalunya, Barcelona, kindly provided the cartographic and geodetic basis for boundary simulation and the author's appreciation is expressed to its Director, Sr. Jaume Miranda i Canals.

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Positioning and Mapping International Land Boundaries

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"La caractère marquant de la notion de frontière est son universalité d'acception"
(de Lapradelle, 1928: 9).

1. Technical Aspects of International Boundary Delimitation and Demarcation

1.1 Introduction to Boundary Engineering

It is postulated that boundary creation, accompanied by more understanding of the technical aspects by the treaty negotiators and more understanding of the guiding principles of the international law by the technical experts, will contribute to prevention of international conflict and to its settlement if the need arises.

International boundary creation is a process of inter-action between politics, law, geography and the lives of state populations. The most important objective of the process is peace and the general acceptance of the boundary. In order to achieve it, the boundary has to be negotiated and agreed upon by the neighbouring countries.

The crumbling of the Soviet empire and the continuing trend for independence all over the world resulted in the emergence of new states, many of them within new or non-delimited boundaries, with a new potential for disputes and conflicts, many of them connected with boundary location. One of the principal aims of this briefing paper is to present the architects of the boundary with a review of modern technical services which are an essential part of boundary making.

History shows that imposed boundaries never achieved general acceptance. The architects of the 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 advisers whose background 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.[1]

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, subsequently to delimitation, for the transfer of the defined boundary to the terrain.

1 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 as technical matters, only to reemerge as matters of major political importance, the settlement of which is essential to avoiding conflict.

The book by 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 fifty years ago. It should be remembered however that Jones wrote before the computer era, before artificial satellites' application to remote sensing and to positioning, and before geographical information systems. The technological potential available today in boundary engineering applications is very considerable.

One of the principal objectives of this paper is to present a model for incorporation of scientific and technological advances of the last fifty years into boundary making, and thus contribute to bridging the gap between the boundary architects and boundary engineers.

1.2 Delimitation

> "...[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 separation of influence in a frontier zone in such a way as to permit a 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 the definition to the terrain. It must also take into consideration the consequences of the delimitation on the life in the area.

In the definition of the separating line between the authority of the two states, there is often the temptation to create 'no man's land' rather than a set-out 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"*.

There are three political consequences of delimitation of a boundary:

- *Peace*. The limiting treaties concluded between neighbouring states are in most cases peace treaties or boundary agreements stressing the peaceful permanence of the delimitation as opposed to the provisional character of armistice lines.

- *The reaffirmation of the independence of the state.*

- *Security* created by a line which is quasi-sacred, quite apart from political guarantees or military arrangements.

The American Institute of International Law in the 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.

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

- Preparation, which includes the political plan as well as the technical plan 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.

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[2] 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 availability, the increased scale accompanied by smaller terrain coverage.

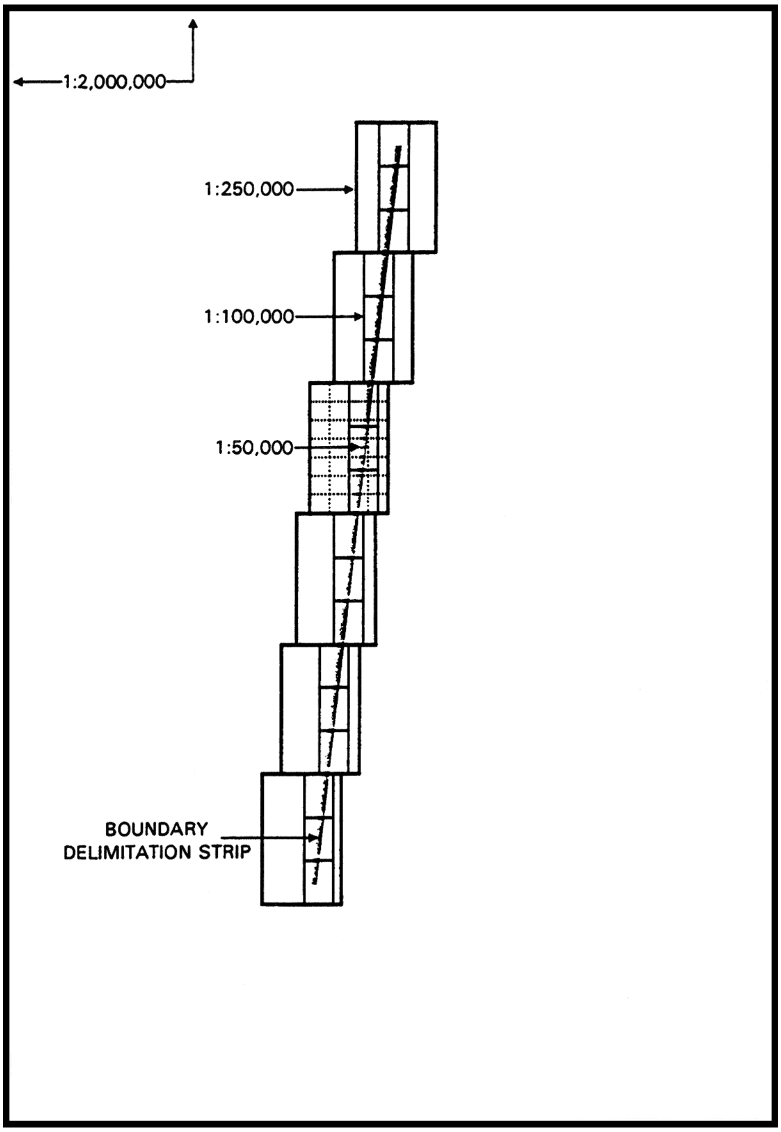
An imaginary boundary under negotiation can be considered, assuming that the boundary is approximately 1,000km long and its direction predominantly north-south. In an ideal situation, the coverage would be as shown in Figure 1.

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 grid s.

One should be aware of the fact 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.

2 The term 'boundary' should be used for the actual boundary *line* as opposed to the term 'frontier' which indicates a *strip* of land.

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



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 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.

Almost the same kind of technical support as required for treaty negotiators in the delimitation stage is required for adjudicators, remembering always that whatever technical data is provided by the geodetic scientist, surveyor or mapper, it should be accompanied by a statement of reliability and accuracy.

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."*

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 could be a frustrating experience.

  The 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 it has a chance to succeed only between countries having a friendly and considerate 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 may be difficult to apply and maintain. Jones describes these difficulties in detail, as well as 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.

Within the efforts of boundary engineers to bring the terrain to the negotiating table, it is possible to use the technology of stereoscopic viewing of the terrain by the negotiators as recorded on aerial photographs or satellite images, parallel to the study of maps. One of the principal advantages of this technique is the possibility of simultaneous viewing and discussion by the negotiators of both the parties concerned.

One can see in Figure 2 that the image conveys the character of the terrain more than the map. Viewing the image in an instrument is like viewing it from a low-flying aircraft, with local water-parting lines and water-flow lines easily identifiable.

1.2.1 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 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 the regional and world peace.

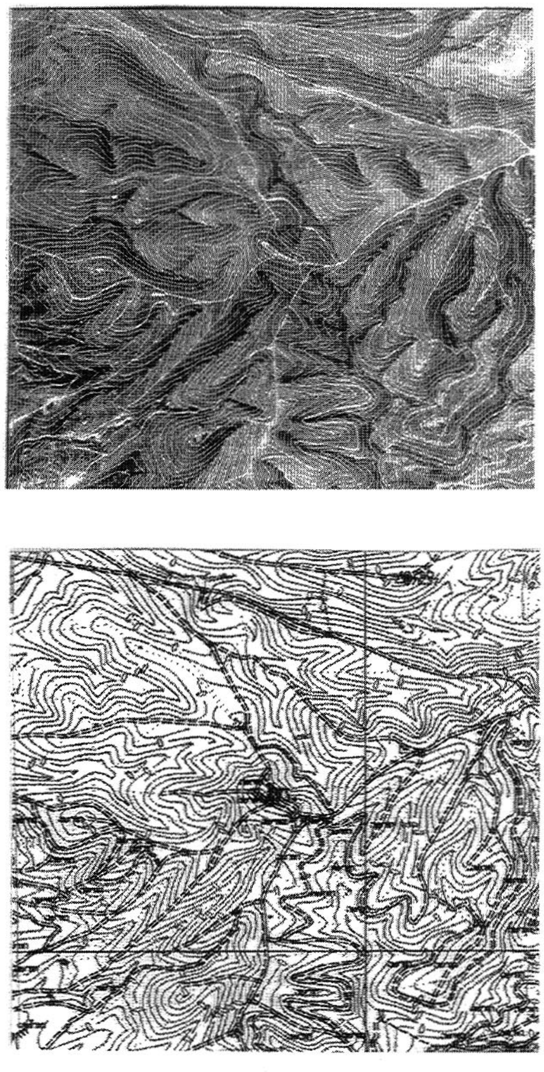
- A statement regarding the principle of mutual consultation in the spirit of mutual accommodation, as well as a clear statement that the delimitation will be a milestone in preserving friendly relations and cooperation between the parties.

- 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.

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



Let us first consider the perfect delimitation, based on the data and information collected before and during the negotiations, including good quality maps at 1:50,000 or 1:25,000 scales, aerial photographic coverage, a field reconnaissance during which prominent features were checked and named, a preliminary survey made, and even preliminary demarcation executed.

In such a case only replacement of temporary marks by permanent ones would be in order, followed by a final survey, with the results expressed in a well defined coordinate system.

There are, however, no perfect delimitations and the delimitation becomes a directive for demarcation of the boundary, except for those sections where the boundary follows a well defined natural feature. Thus the extent of work delegated to the Boundary Demarcation Commission is a function of the degree of quality of the delimitation and the geographical reliability of the definition. The appointment of a bilateral Boundary Demarcation Commission should be made within the framework of the agreement and its terms of reference stated.

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.

1.2.2 Delimitation by reference to a third party

A disagreement on questions regarding the meaning of terms, expressions or clauses in a treaty, or the incompatibility between the definition and the reality of the terrain are referred first for diplomatic settlement.

The diplomatic effort may result in negotiation, mediation and conciliation,[3] and the characteristic of the diplomatic settlement is that the parties retain control of the disagreement, and are not bound by it.

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), Merrills (1991) and others.

Many boundary disputes have been settled by an arbitration award or by judgement of the International Court of Justice. For details of some of the disputes settled by arbitration and judgements 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).

[3] 'Conciliation' - a kind of institutionalised negotiation or inquiry.

- *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 Judgement of the International Court of Justice are in the nature of 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 circumstances.

1.3 Demarcation

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

> *"La démarcation, si elle est utile, n'est pas, en droit, nécessaire."*
> (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 transformed to the terrain. 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."*

It should be mentioned that in some places demarcation is not feasible, for example in areas of swamps or flying sands.

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 however inappropriate and dangerous to dismiss the demarcation as a purely technical operation of minor importance.

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 eruption depending on the political climate.

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 and its composition should be bilateral and based on equality of representation of the parties on both sides of the boundary.

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. 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 of the line of the boundary following well defined and recognisable natural features such as rivers or canals, where only a definition of where, within the feature, the demarcation is necessary in order to symbolise and preserve the 'sanctity' of the boundary and to aid the maintenance of the boundary regime.

It would be appropriate 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).

Thus, in the problem of transforming a verbally and/or graphically delimited boundary to the terrain, we have to use points which eventually will form a line by joining them. We are faced with the problem of selecting points, which represent as truly as possible the delimitation. The selected points would 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, hinting that the monumented points should be prominent features. In addition, during the delimitation and demarcation stages, intervisibility between the monumented points is a most desirable property, even if it is not an absolute must. Intervisibility means the physical ability to observe point B from point A and vice versa.

The principle of intervisibility was essential during the long 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 intervisibility and does not require a direct measurement between points.

The concept of an ideal boundary emerges as a line following a well defined natural feature, or a series of straight lines between inter-visible points. The non-ideal reality provides us with boundaries, which 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 of boundary making, but one which reminds all boundary makers not to add to the already existing problems, through ignoring the geographical and geodetic aspects in delimitation and demarcation of boundaries.

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 both 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 of difficulties in interpreting the intent of the signatories. The great importance of demarcation as 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."*

Demarcation may not be strictly necessary in all cases, especially where the boundary line follows a major well defined feature of the terrain or where it is not possible to demarcate because of terrain inaccessibility. Many delimited boundaries were not demarcated for a variety of reasons such as: the expense and logistic effort involved, the emotions of local inhabitants involved in 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, every effort has to be made to demarcate the boundary wherever possible.

Now that the location of the boundary markers can be established by GPS (satellite) surveys which do not require optical or electronic intervisibility between boundary points, the question of density of markers can be considered independently.

Studying various writings on the subject of demarcation, one comes to the conclusion that the head of the commission is 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 bilateral parity should be stressed; persons of equal standing and similar qualifications, equal number of parties in the field, meeting places rotating between the parties - all these contribute to the quality of cooperation during and after the demarcation.

A general specification of demarcation can be found in 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), where one finds the specification of frontier demarcation documents to be drawn up 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 the frontier line;*
>
> *5. Protocols relating to placement of the frontier marks, together with sketches;*
>
> *6. Protocols relating to the placement of auxiliary frontier marks, together with photographs."*

Another useful monumentation principle is included in Article 6 of the above mentioned Treaty:

> *"(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 marks and each boundary treaty or agreement may choose its own form of monuments. Figures 3 and 4 provide examples of boundary pillars. The pillar marking the Egypt-Israel boundary (Figure 3) is in the form of a truncated pyramid.

Figure 3: ***A Photograph of a Boundary Pillar on the Israel-Egypt Boundary***

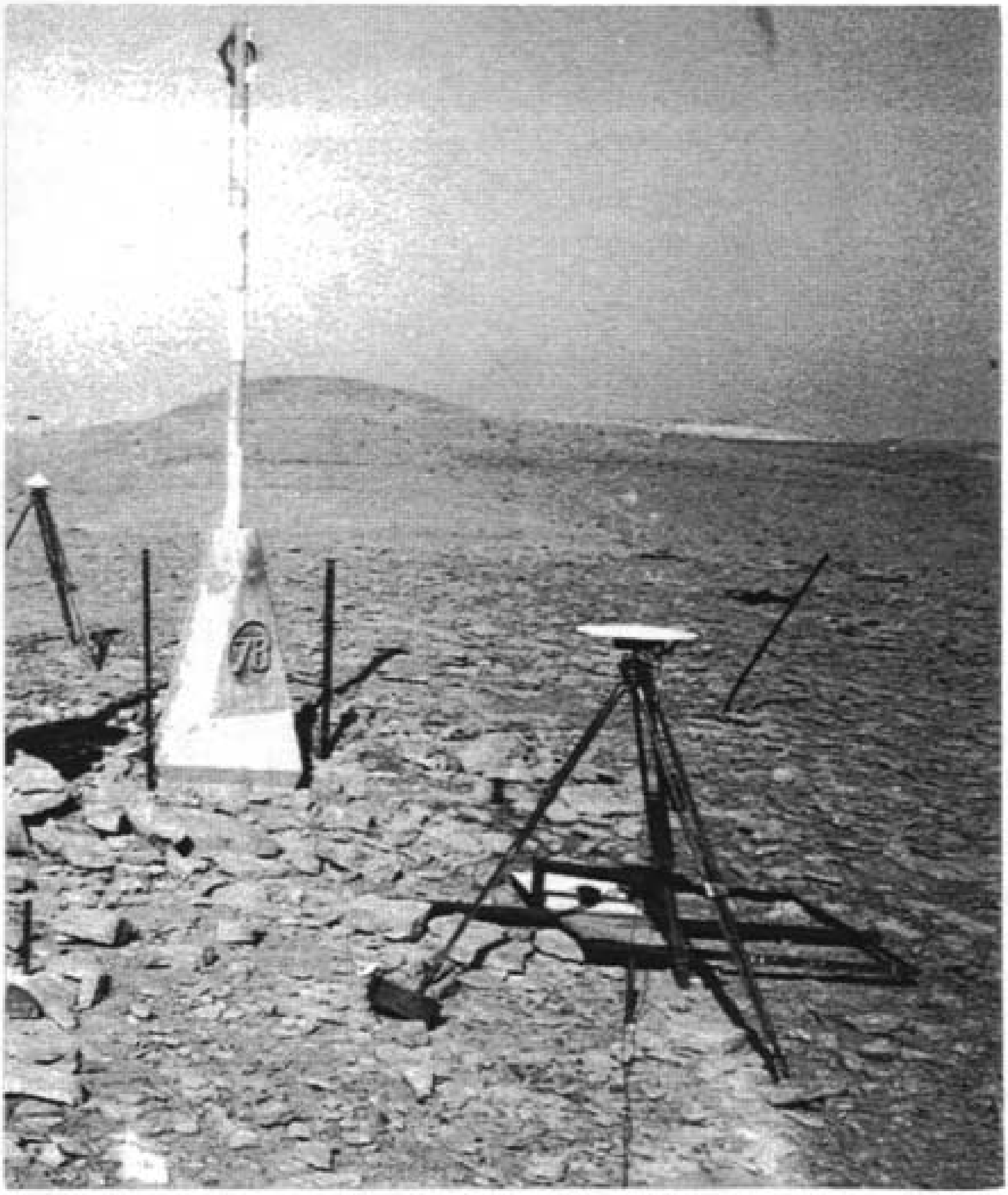


Figure 4: ***A Boundary Pillar between Canada and USA***
(By courtesy of the USA - Canada Boundary Commission)

Another example of a boundary marker specification can be found in the *Burma-China Protocol* (UN Treaty Series, 1976, Vol. 1011) (Figure 5).

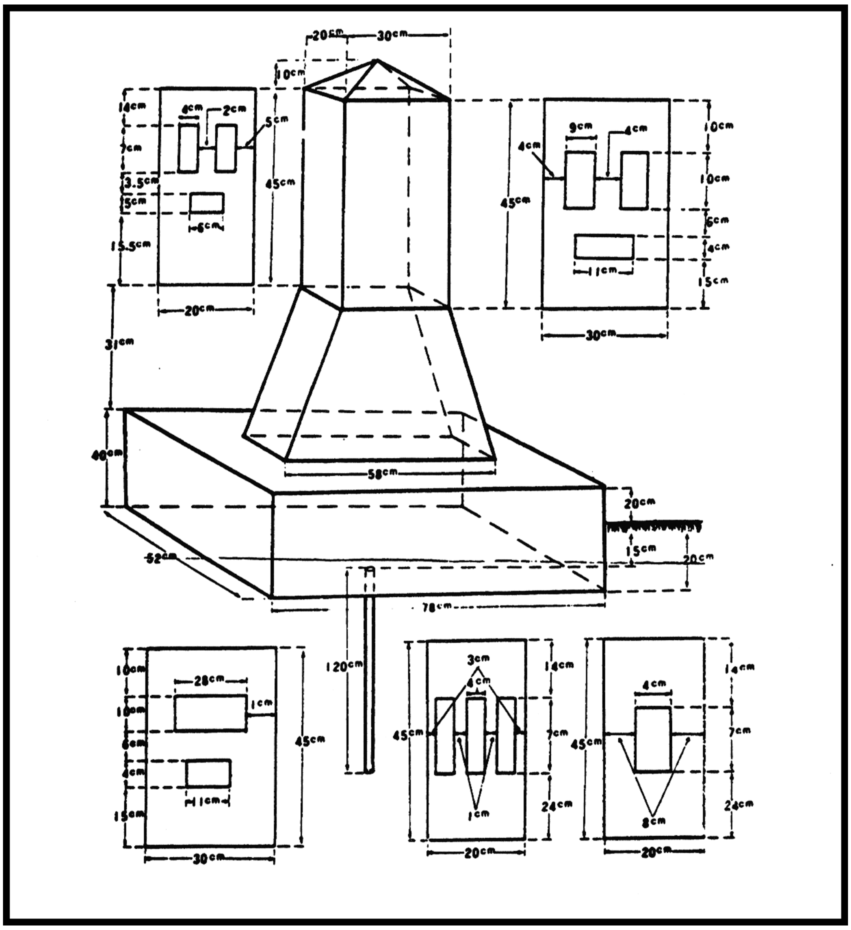
The demarcation records are usually voluminous. In the case of the 460km of the demarcated boundary between Poland and Germany, there are 646 pages of protocol in Polish and 584 pages in German, 34 maps, 143 pages of coordinate lists and 169 pages of frontier mark descriptions (UN Treaty Series, 1959,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

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.

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



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:

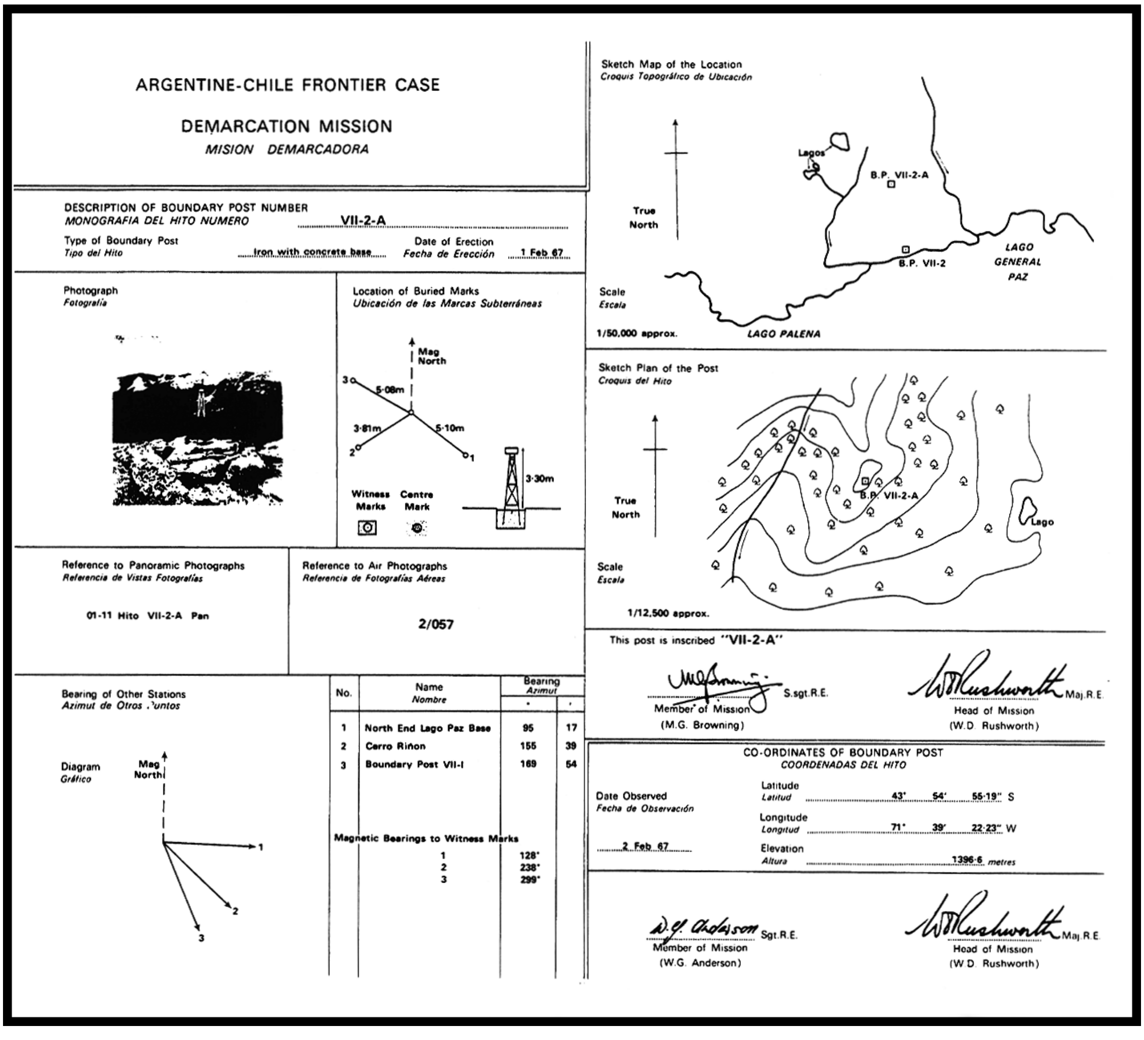
- Name and number of the boundary point.
- Description of the marker, including a photograph.
- Reference measurements to witness marks.
- Reference directions to prominent features in the vicinity.
- Sketch map of the vicinity (approach map).
- Detailed sketch of the immediate vicinity.

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.

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.

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

Sketch Map of the Location
Croquis Topográfico de Ubicación

Scale
Escala
1/50,000 approx.

Sketch Plan of the Post
Croquis del Hito

Scale
Escala
1/12,500 approx.

Reference to Panoramic Photographs
Referencia de Vistas Fotografías
01-11 Hito VII-2-A Pan

Reference to Air Photographs
Referencia de Fotografías Aéreas
2/057

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)

Bearing of Other Stations
Azimut de Otros Puntos

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°

Diagram
Gráfico

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

- Longitude and latitude of the datum point.

- 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.[4]

- 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.

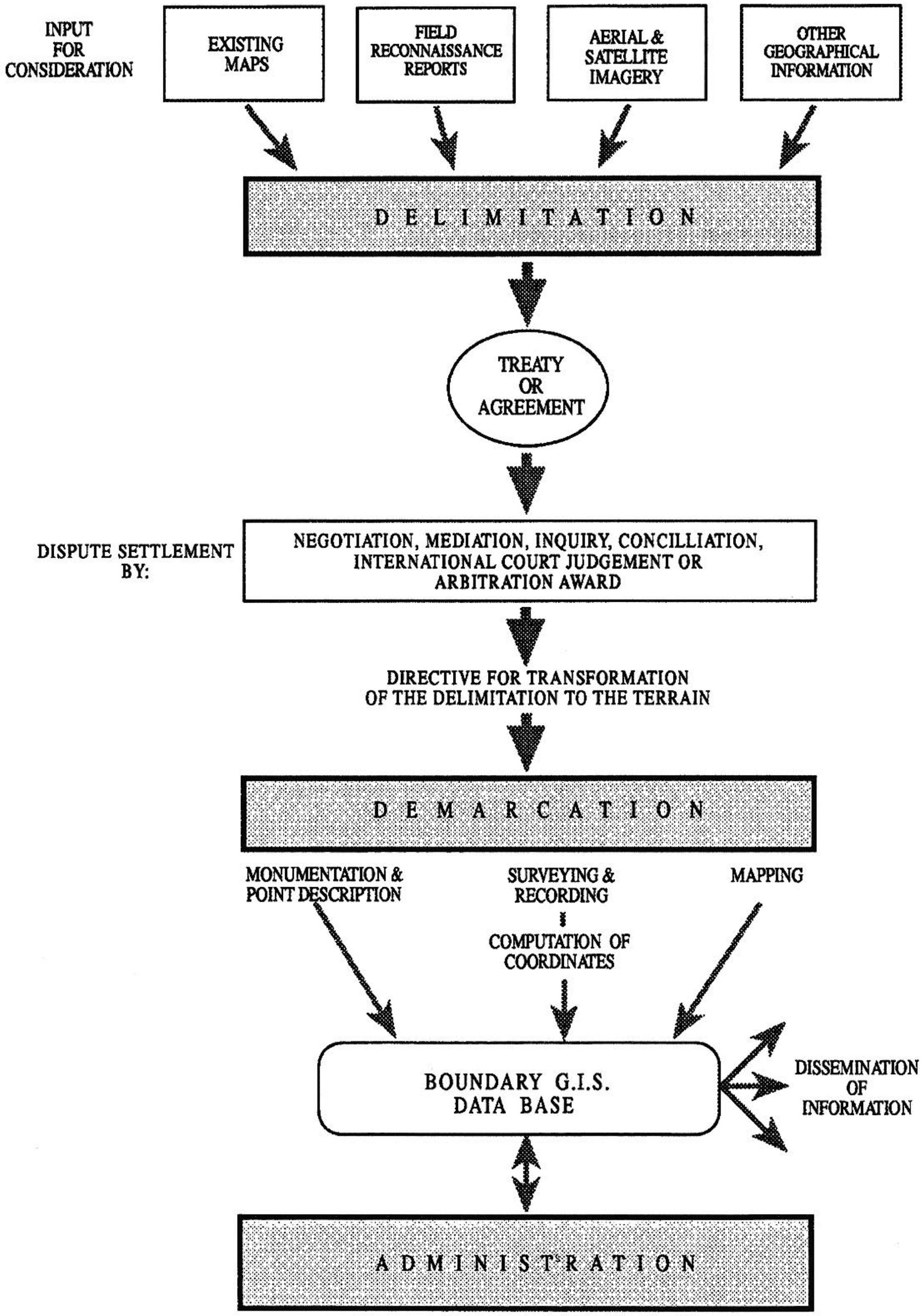
These rather complex problems are treated in Vanicek and Krakivsky (1982), Bomford (1980), Rapp (1989) and others and are outside the scope of this briefing.

The coordinate system defined for documenting the boundary avoids the necessity to use the control systems of the parties, which is often a sensitive matter with security conscious countries.

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

4 '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.

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



2. The Technologies of Boundary Engineering

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

2.1 Introduction

In the latter half of the twentieth century, a number of technologies were developed which considerably raised the level of technical services to international boundaries. The electronic computer greatly influenced almost all the technologies which today serve the international boundary applications. Artificial satellites are not only instrumental in the precise position determinations, but also serve as remote sensing platforms. The acquisition and processing of aerial photography, computation of positions, digital databases in information systems from which information products can be derived - all these were developed and brought to a high level of efficiency with the aid of the computer, its enhanced performance on the one hand and the miniaturisation of its components on the other.

2.2 Use and Abuse of Significant Figures - Accuracy Estimates of Digital Data

The international agreements and treaties, awards, judgements 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 the documents mentioned have to be aware of the importance of significant figures.[5] We 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 exist and therefore we use the term accuracy estimate, which is obtained from the precision of procedures employed to produce a value. Whenever accuracy is mentioned, an estimate of accuracy is meant.

Let us 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!

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5 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.

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 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.

Let us consider whether the various architects of treaties were aware of the implications of significant figures. One of the many cases of delimitation of boundaries 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) expresses 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 arrives 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. Let us now imagine that the delimitation were expressed as 1°00’00” S, the accuracy implied would have become ±15m.

In the work of Brownlie (1979) on African boundaries many cases of complete unawareness of significant numbers can be found. However, 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), we find the table of coordinates given in metres: Station 1, North 209,008.07 and East 81,418.18, stating also that these are coordinates in Texas State Lambert Projection, South Control Zone, implying an accuracy of ±0.005m in each coordinate. Further on we have 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 consequently decision on, the number of significant figures, have to be made by an expert in 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.

2.3 Maps

> *"...a map has a probative value proportionate to its technical qualities".*
>
> (Brownlie, 1979: 5).

2.3.1 Estimating accuracy of maps

Maps constitute an important part of infrastructure for boundary creation and map evidence is essential in answering queries pertaining to boundaries. 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.

A map is a scale model - a two dimensional (plane) representation of a 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).

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.

2.3.2 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.

(i) 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 the sea level, can be considered errorless for all practical purposes, because all surveying and mapping methods take care of it 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.

Let us imagine a distance of 55.5mm measured on a 1:50,000 map, which suffers from scale distortion due to map projection of + 0.15%. The distortion is the measured distance converted to metres multiplied by the scale denominator and multiplied by the distortion percentage, i.e., 0.0555m x 50,000 x +0.0015 = 4.16m, meaning that the distance measured on the map is 4m too large.

It should be remembered that all coordinates, expressed in a plane rectangular system of a map projection, are affected by distortion.

(ii) The source of data acquisition

Most topographical mapping produced in the second half of the twentieth century 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, which is treated further on, but here we are concerned with the source from the point of view of qualitative accuracy, which is a question of interpretation and classification, in mapping land use, in mapping of 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.

(iii) 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, relatively 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

(iv) 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, previously mentioned.

Now let us consider the *“not more than 10 percent of the points tested...”*. This 90 percent 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 percent probability level.

One can summarise this topic 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. This is stated:

> *“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 which combine to result in the total error of the map.

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 10 m 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 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:

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

at the map scale, which for a 1:50,000 map would be 35m on the ground. One may hear the argument that this is a very conservative estimate, which is probably true.

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.

The author's estimate is supported by Maling (1989), who estimated the total error to vary between 0.42mm and 0.73mm.

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 in consideration into evaluating the quality of delimitation and its limitations.

(v) 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, resulting in gradual deterioration of map quality, as 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.

(vi) 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 see a gradual transformation to the concept of a digital database for mapping, which means a digital storage of collected data, including updates. This approach will result in speaking of data accuracy in the data base, rather than 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.

Having discussed the quantitative error estimates and having recognised the fact that qualitative errors exist, one may 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 present author does not recommend a conclusion rejecting the cartographic evidence, he does however recommend that boundary architects, negotiators, judges and arbitrators should be aware of the map limitations regarding its quantitative and qualitative accuracy. 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 by incorporation of reliable maps in boundary treaties.

2.3.3 Maps as 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 court room.

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 details 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.

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).

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.

2.3.4 Maps incorporated into or annexed to delimitation documents

Maps are used as an integral part of the treaty, judgement 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 an information, the accuracy of which varies as 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).

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

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.

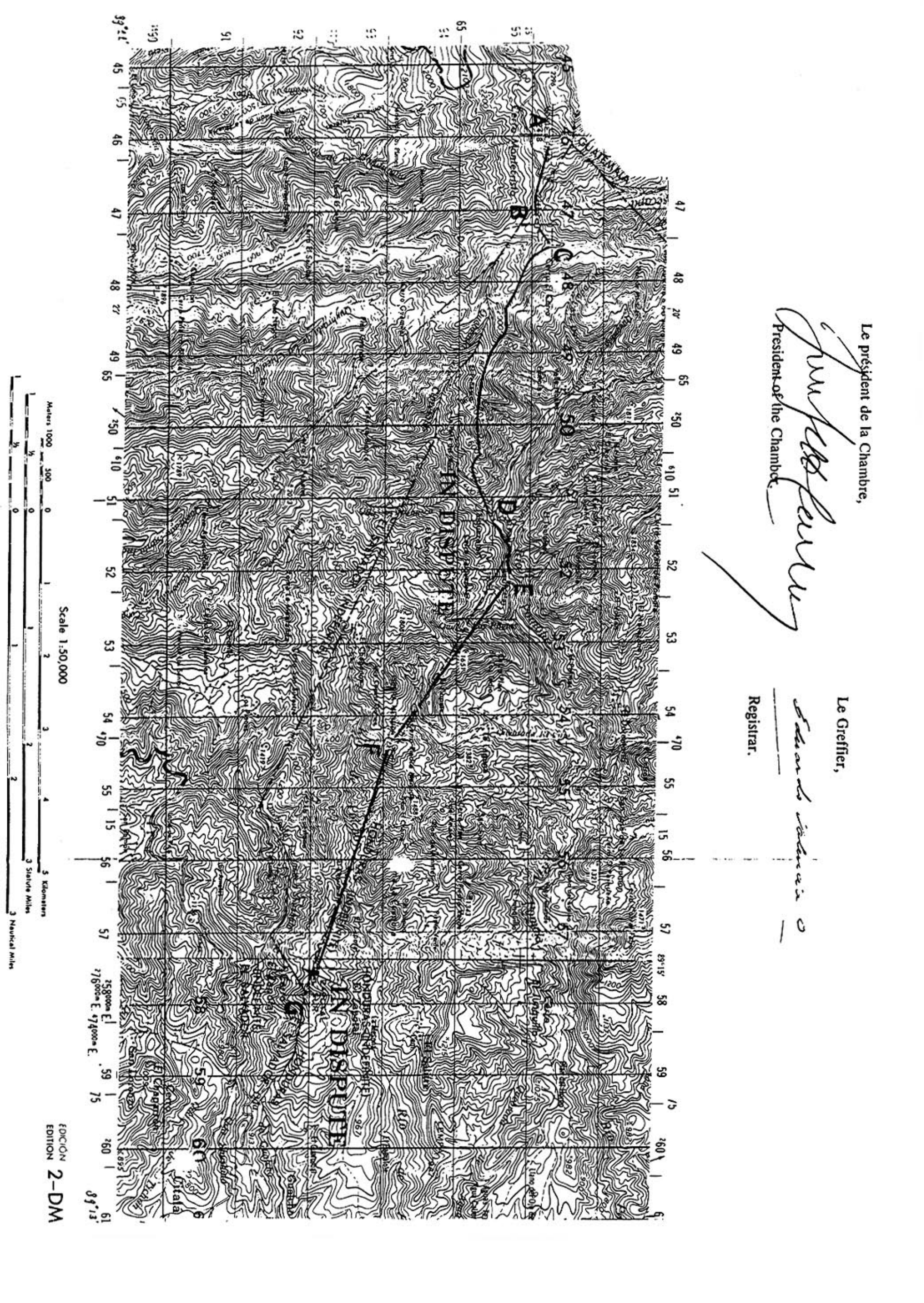
In a later case before the International Court of Justice, namely the case concerning the *Land, Island and Maritime Frontier Dispute, El Salvador v. Honduras: Nicaragua intervening*, the judgement of 11 September, 1992, recognises the fact that discrepancies of the order 9".2 (equivalent to approximately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

The judgement incorporates maps and marks made upon them in the delimitation of the boundary, but the coordinates given in the judgement 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 directive to demarcators who would have no problem in transferring the judgement 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 be the case of 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 during the course of demarcation.

Figure 9: ***Part of the Map Used to Express the Judgement of the ICJ of September, 1992***



2.3.5 Maps as background to demarcation

This is an application where maps serve as an aid in transferring the delimitation to the terrain. 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 in 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.

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.

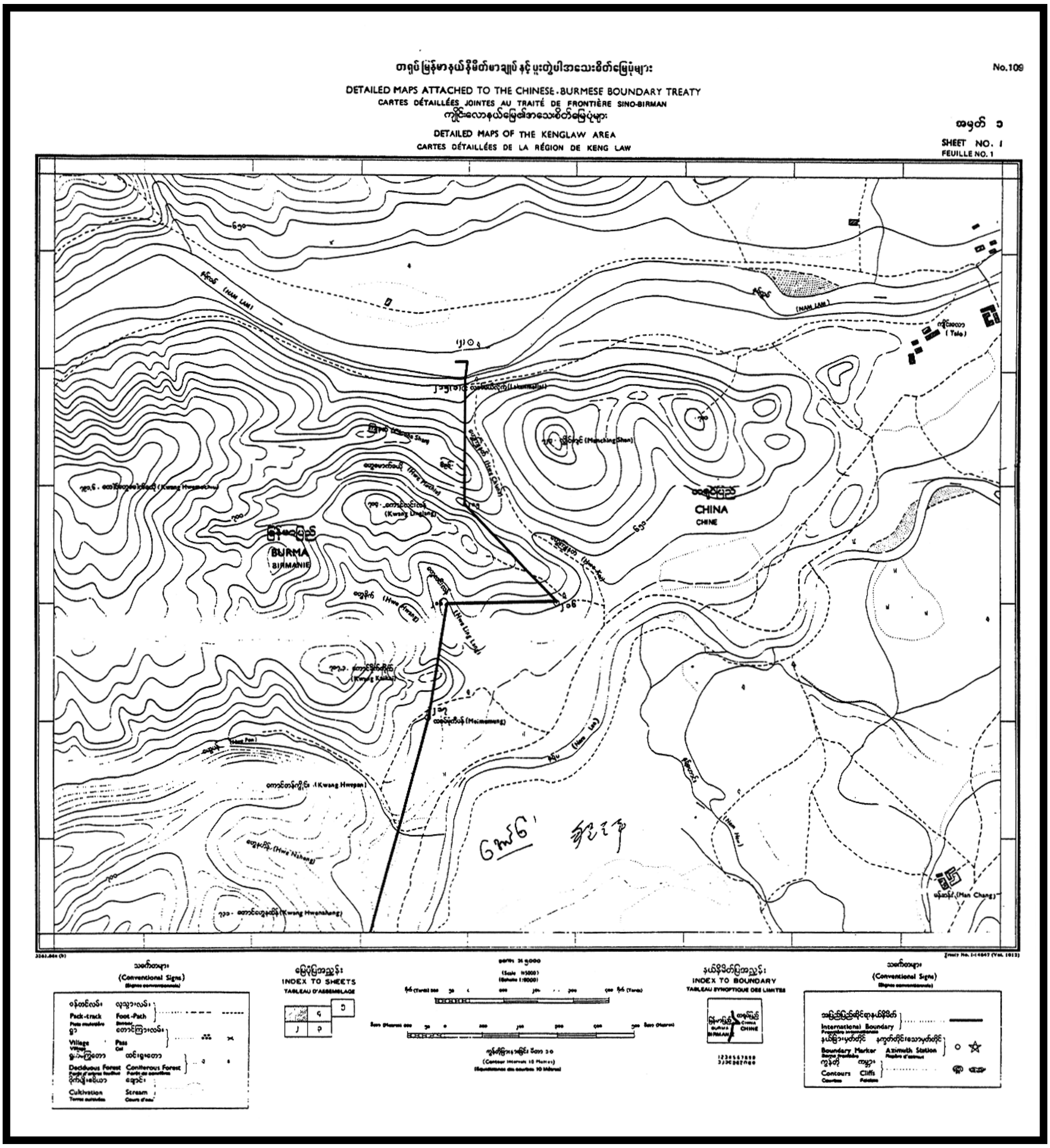
An example of a combined application of maps and aerial photographs is in the arbitration of the *Argentine - Chile Frontier Case*, known as the *Palena Case*. A specially ordered 1:50,000 map was produced as well as aerial photographs and a field visit was made by the arbitrators. Enlargements of aerial 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.

2.3.6 Maps showing the boundary 'as made'

This is an application following the actual boundary making process, an exposure of the boundary 'as made' to the general public and an aid to the boundary regime consisting of 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).

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



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 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.

2.4 Remote Sensing Applications

2.4.1 Introduction

> *"...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 in bringing the terrain to the negotiation table, as products which complement maps or serve as alternative to maps. Aerial photographs have been an acceptable product for the past 75 years approximately, whilst satellite imagery is a relatively new product, in use only 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[6] is capable of a resolution of 10m and expected to improve to 5m.

It is easier to control aerial photography parameters: the flying height and the focal length[7] of the camera. A satellite orbit is planned in advance of the launch and is almost impossible to change considerably.

We can conclude that the natural preference should 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

6 The reference here is made to earth observation satellites and not intelligence satellites.
7 'Focal length' is the distance between the cehtre of the lens and the film plane.

sharing the expenses and in overflying the territory of the neighbours. Satellite images are available commercially, without logistic and administrative difficulties, at a reasonable cost.

The following considerations should be made towards the decision whether to use aerial photography or satellite imagery:

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

2.4.2 Aerial photographs

One may assume that all modern aerial photography cameras have excellent lenses, an automatic film advance feature, 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:

- *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

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

In Figure 11 one can see 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 square kilometre). On the left is the same area covered by part of an air photo at a scale 1:30,000 approximately. 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.

Now let us imagine that for the purpose of preparing a proposal for delimitation, a number of elevations were measured to enhance the photograph and the values annotated as in Figure 11. 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, and the annotated photograph is almost as effective as a field visit.

This is not an appropriate framework for going in depth into photogrammetry,[8] 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).

2.4.3 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 being 5m favourably comparing 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 12 an enlargement of the photograph to 1:100,000 is presented.

8 'Photogrammetry' - the science of measuring photographs.

Figure 11: ***Aerial Photographs at 1:4,000 and 1:30,000 Illustrating Differences in Clarity***

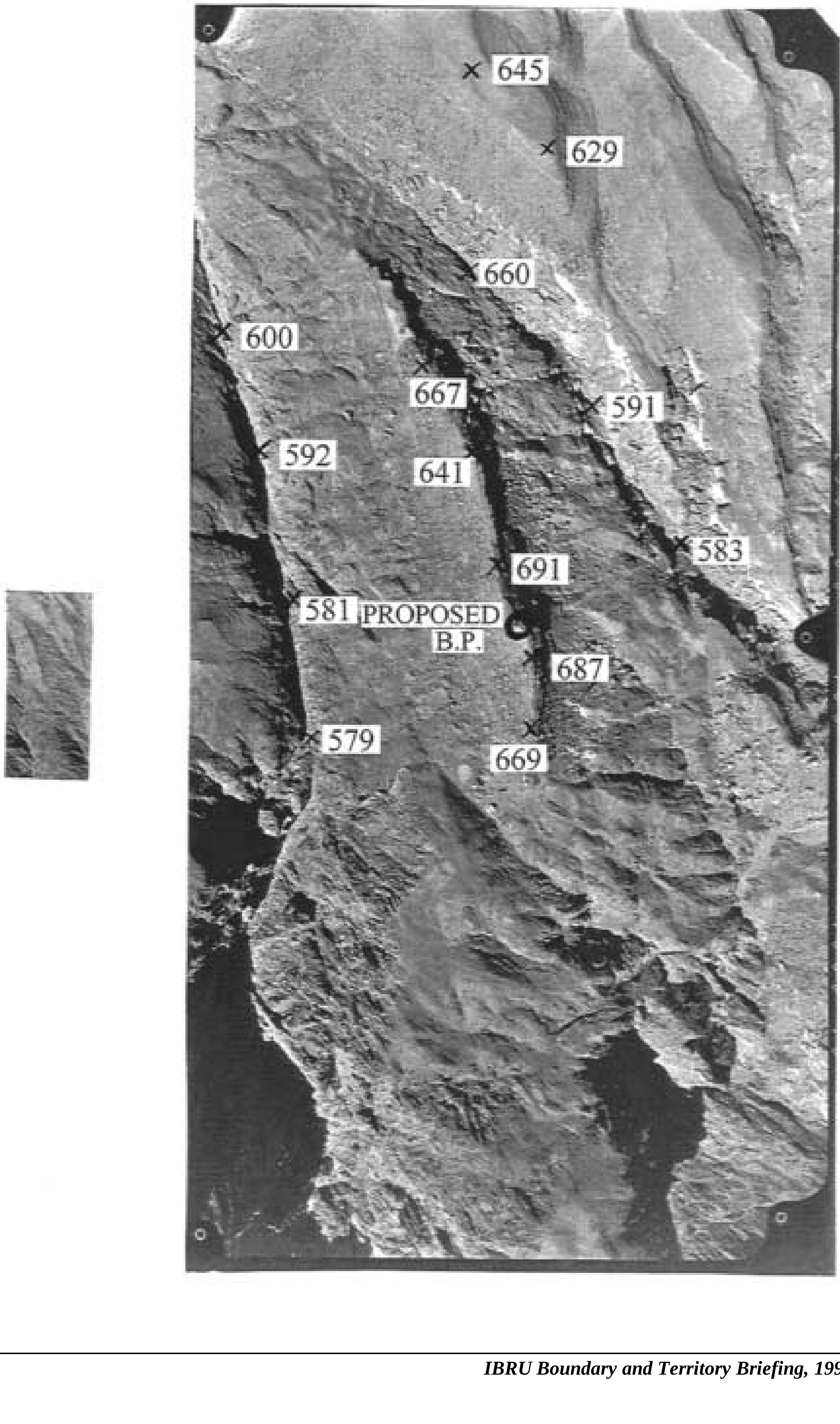
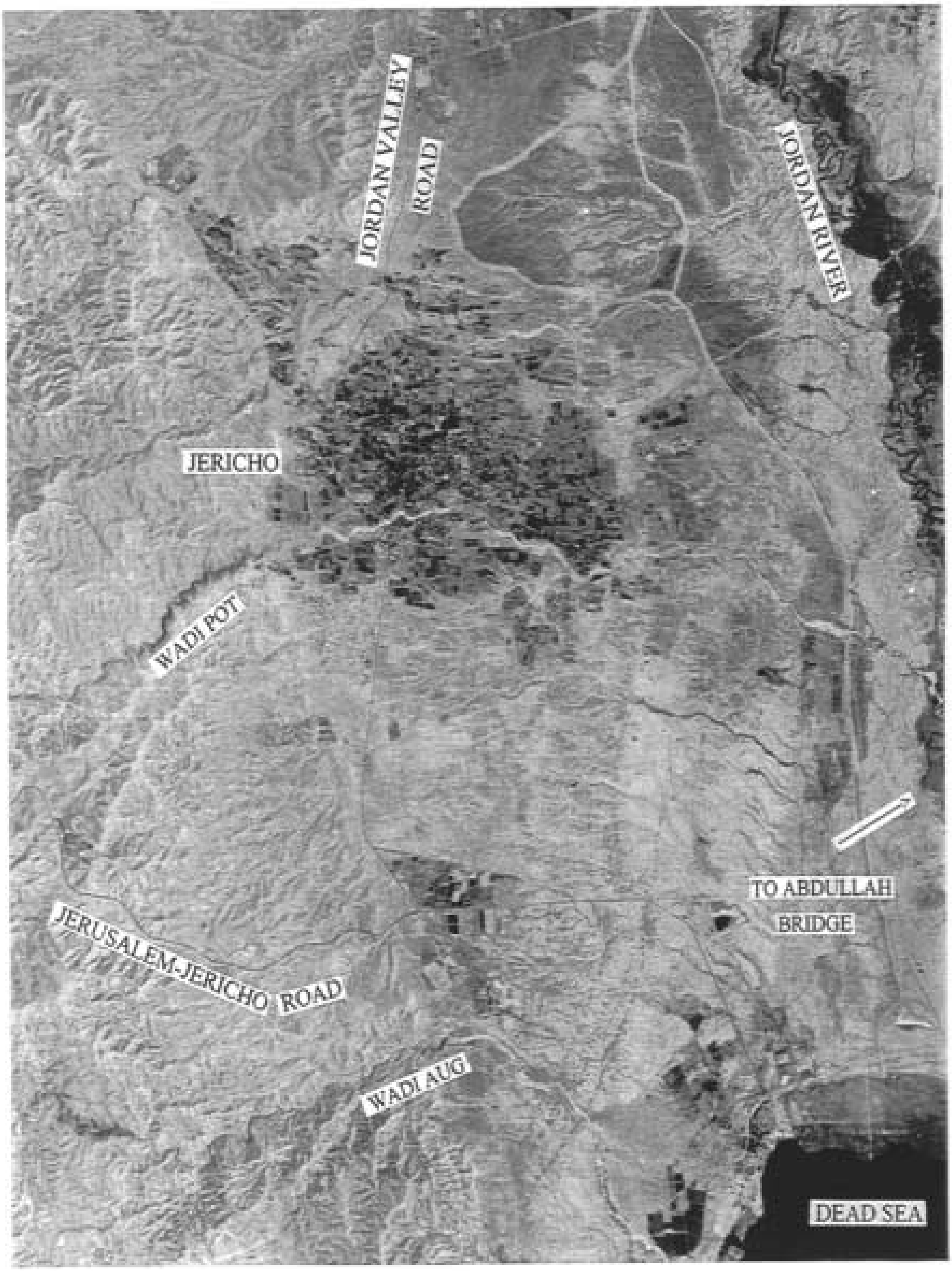


Figure 12: ***A Part of a KFA 1,000 Photograph Enlarged to Approximately 1:100,000***
(Some annotation is added to facilitate orientation. Courtesy of *Priroda*, Russian Scientific Research and Production Center).



2.4.4 Satellite images[9]

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 and two additional satellites were added in 1982 and 1984, which orbit the earth at an elevation of 705km.

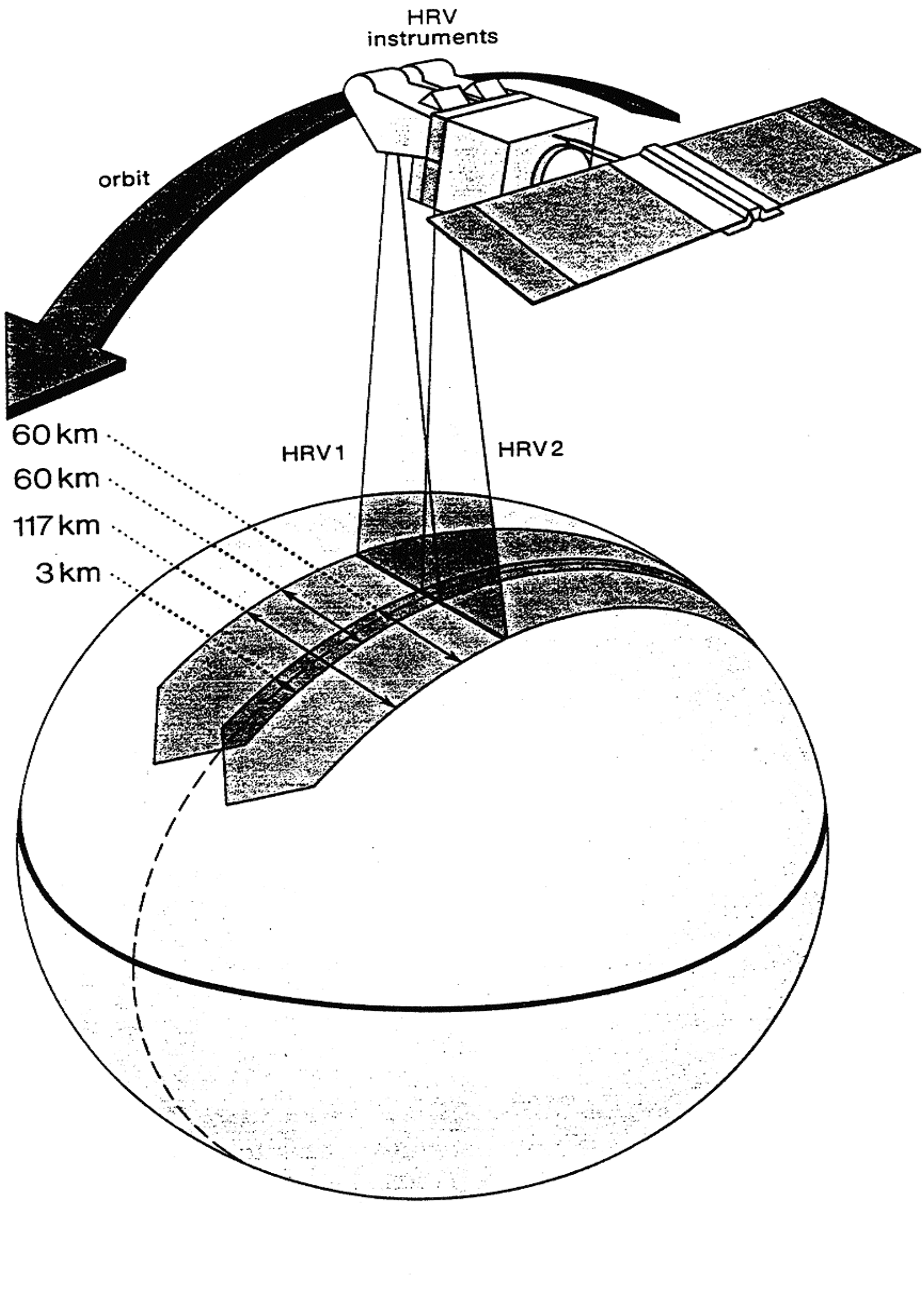
From the point of view of international boundaries applications, the most suitable images are those obtained by the French satellite SPOT. The first SPOT satellite was launched in 1986, the second one (still active) in 1990 and the third one in 1993. The height of the orbit is 822 kilometres. The image 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 10 metres on the ground, hence one observation device covers 60 kilometres on the ground.

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.

In Figure 13 one can see the principle of sensing through two sensing devices. Please 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.

9 A ‘satellite image’ is a picture of the earth’s surface obtained from a satellite through the use of sensors.

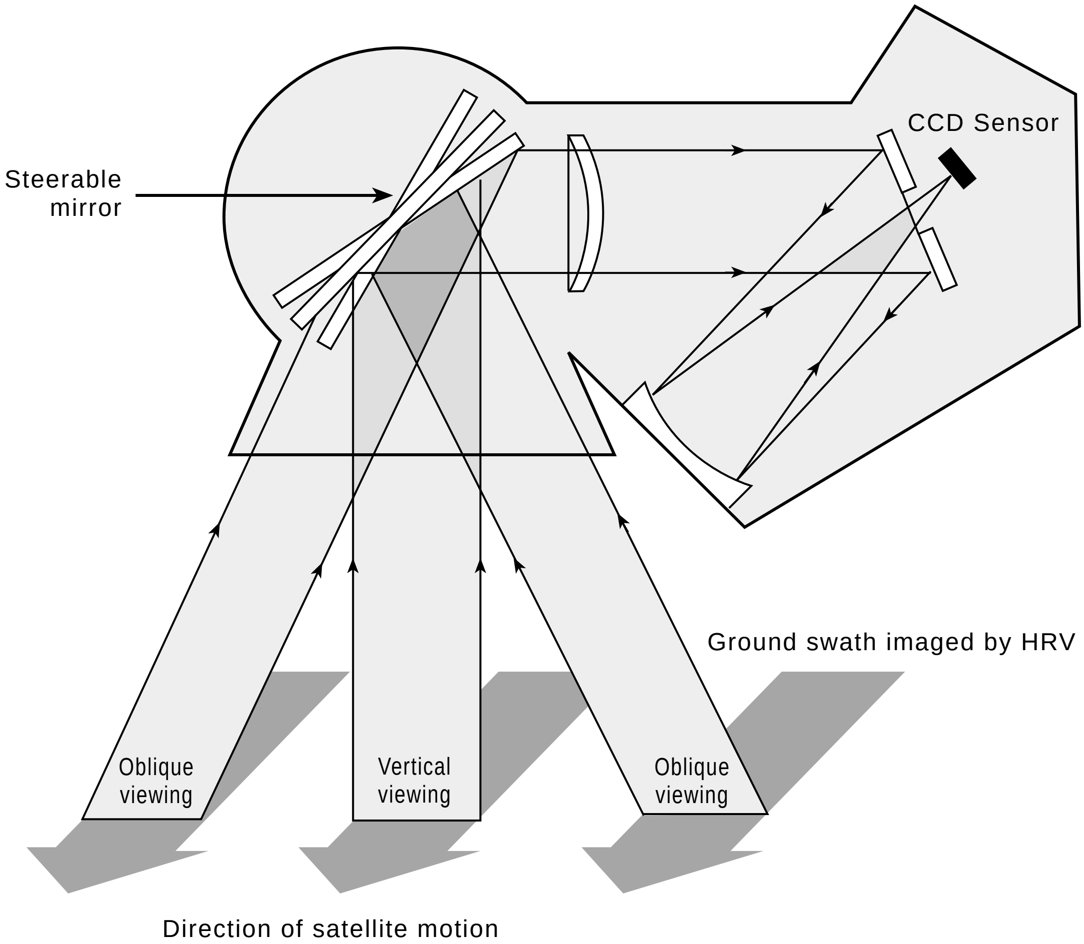
Figure 13: ***The Earth Coverage by Two HRV Devices***
(Courtesy of SPOT Image).



The HRV device can be tilted by 27° from the vertical. This capability facilitates a repeated coverage more often and also permits to view the area stereoscopically through overlapping coverage obtained from different angles (see Figure 14).

Figure 14: ***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 15.

To summarise, remote sensing applications to 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 15: ***A SPOT Satellite Image of the Area of Sant Feliu de Guixols, Enlarged to 1:50,000 from the Original 1:400,000***
(Courtesy of Institut Cartografic de Catalunya).

2.5 Global Positioning System (GPS)

2.5.1 Introduction

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

GPS was conceived as a worldwide positioning system and was developed by the United States Department of Defence, to serve navigational requirements of the armed forces on land, on sea and in the air.

The task of precise measurement and computation of the position of points on the earth's surface was since times 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, through a work intensive process, slow, 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.

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.

GPS 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 is based on a reference framework of 24 satellites; orbiting the earth in 6 orbits, 4 satellites per orbit, at the elevation of 20,000km (Figure 16). 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 4 different satellites.

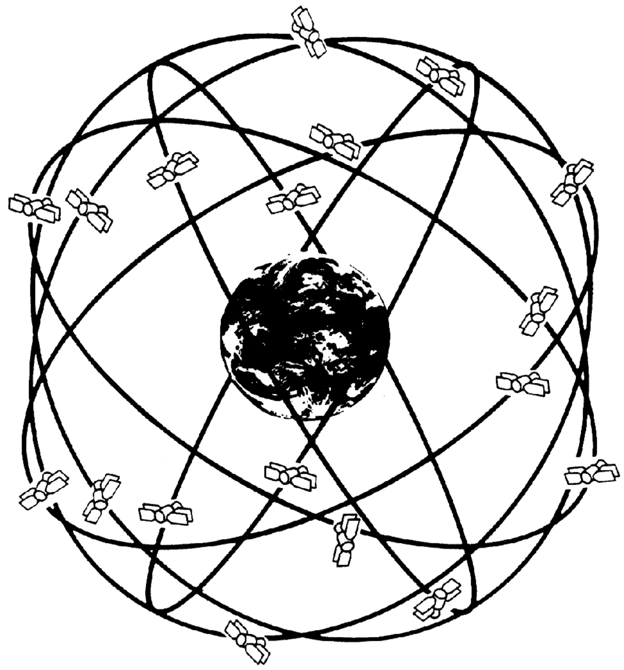
2.5.2 The measurement of distance from a satellite

Every satellite is equipped with an atomic clock. The satellite broadcasts signals at two frequencies[10] for positioning purposes namely L1 at 1,575.45 Megahertz[11] and L2 at 1,277.6 Megahertz. Radio waves travel in vacuum at the speed of light, which is known with great accuracy.

[10] 'Frequency' is the number of cycles of an electromagnetic wave per unit of time.

[11] '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.

Figure 16: ***A Reference Network of 24 GPS Satellites in 6 Orbits***



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 'Δt' is the delay of the signal broadcast by the satellite with reference to a replica of the signal broadcast at the receiver (Figure 17). The clocks at the sat ellite 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 we need 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.

Models of the atmosphere and of the ionosphere[12] enable us to compute 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).

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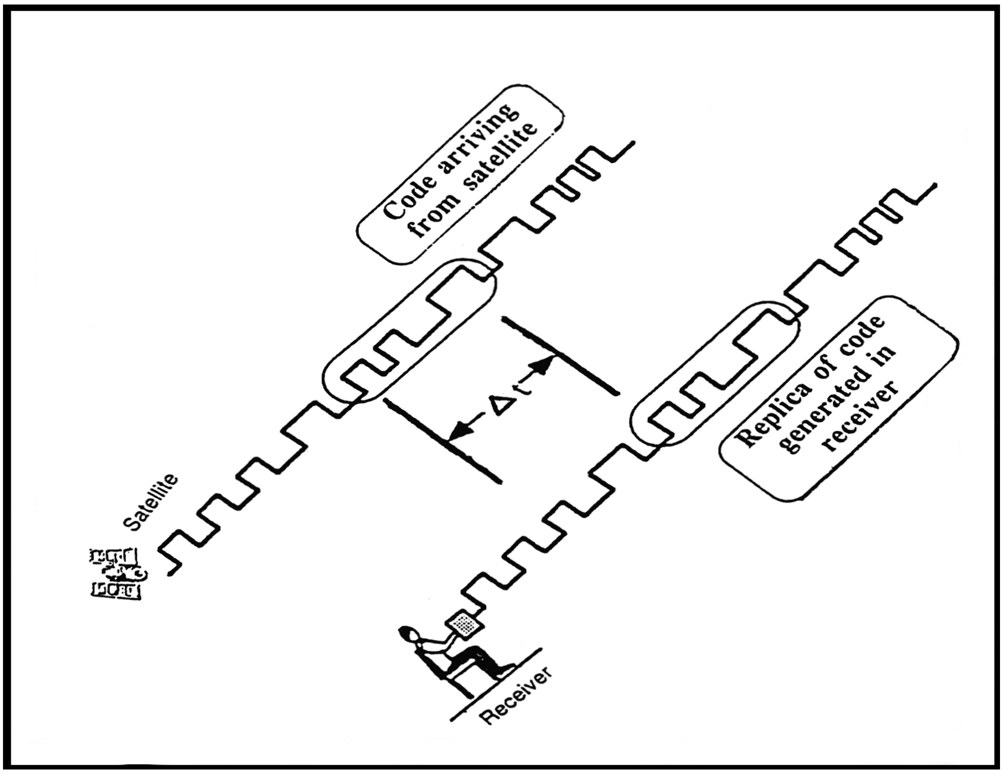
12 'Ionosphere' is a layer of electrically charged particles at the elevation of 130 to 190 kilometres above the earth's surface.

Figure 17: ***The Principle of Measuring the Distance Satellite-Point Being Fixed, with the Aid of Time Signals***



2.5.3 GPS receivers

Modern receivers, such as those manufactured by Trimble, Leica and Ashtech, 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 us to increase the estimated accuracy of positioning.

A typical GPS receiver weighs approximately three kilograms. Adding a back-pack and including nickel-cadmium batteries the weight approaches six kilograms. In addition we need an antenna and a controller, which is 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 be either set up on a tripod or mounted on a portable staff. Figure 18 shows a back-pack 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.

This is a truly wonderful capability for boundary positioning.

Figure 18: ***A Portable GPS Receiver with the Antenna and Controller***
(Courtesy of Trimble Navigation).

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 three observational techniques, suitable for different purposes. Following is a table which summarises the three techniques.

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

Type of Receiver	**Distances Between Points**	**Measurement Technique**		
		Static (several hours[13])	***Fast-Static (5-20 minutes)***	***Kinematic (several seconds)***
Double Frequency	Up to thousands of kilometres	5mm plus 1ppm[14] of distance	2cm plus 1ppm of distance	2cm plus 2ppm of distance
Single Frequency	Up to tens of kilometres	1cm plus 2ppm of distance	2cm plus 2ppm of distance	2cm plus 2ppm of distance

2.5.4 Applications of GPS technology to boundary making

The 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 a ccuracy of the order of several tens of centimetres or even single metres is sufficient and, therefore, no particular observational procedure is recommended.

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

[14] ‘1ppm’ = 1 part per million of the distance, which for 100m = 0.1mm, for 1km= 1mm, for 10km = 1cm and for 100km = 10cm.

Almost any method is acceptable on condition that the negotiating parties are aware of the coordinate system used and the accuracies involved. Figure 19 shows a static observation situation.

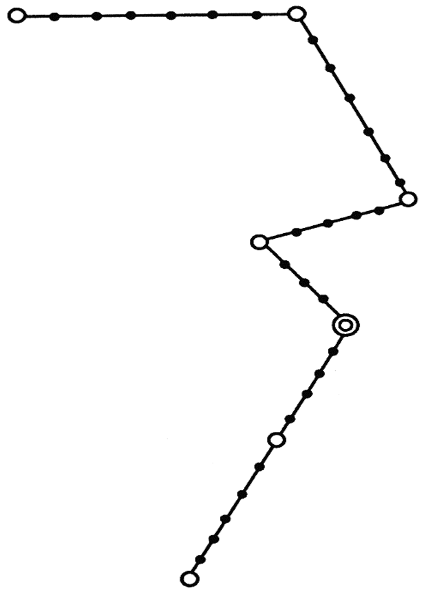
Figure 19: ***Static GPS Observation with the Antenna set up over a Boundary Pillar***
(Courtesy of Leica Corp).

This is not the case in the stage of demarcation and documentation. Here, the accuracy of single centimetres is essential and the scheme in Figure 20 is recommended as a general model.

It would be a good idea to work with two survey parties when observing according to a fast-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.

Figure 20: ***A Scheme of GPS Observations for Recording the Position of an International Boundary***



◎ Boundary Datum - static measurement.

○ Major Reference Points - density approx. 100km - static measurement.

• Reference Points - density 10 - 15km - fast static measurement.

× Boundary Markers between Reference Points - density 100m to 10km - kinematic measurement.

2.6 Computerised Boundary Information System

"...the emphasis is on query and response rather than display."
(Clarke, 1990: 11).

2.6.1 The importance of information on the boundary

The creation of a boundary achieves its objective with the transition from demarcation and final recording of the boundary position to the peaceful management and coexistence on both sides of the line.
This is the culmination of international political process and the beginning of cooperation in protection, maintenance and administration of the created boundary, with emphasis on its permanency and stability. It would therefore be most appropriate to establish a bilateral authority for the purpose of constant evaluation of all matters pertaining to the measures necessary to achieve a smooth administration of the frontier.

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 database is eminently applicable in this context. The following kinds of data should be included in the envisaged database.

- The text of the treaty, agreement, judgement, 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.

It would be most desirable if the kind of data to be included in the database were contained in a Treaty or Agreement concluded between the countries concerned, on the lines of agreements detailed in the UN Treaty Series (1972).

2.6.2 Boundary digital database

A boundary digital database is the heart of a computerised Boundary Information system, which can respond to queries and retrieve or disseminate information. There are actually two kinds of digital databases.

The first kind is a world wide International Boundary database such as the one developed by the International Boundaries Research Unit of the University of Durham and described by Blake (1994). The database is designed to include boundary profiles which supply information on general geographical facts, legal status, historic background, relevant treaties and bibliographic material. Parallel with the profile database, a current affairs database and a database of expertise are developed and maintained.

The second kind of International Boundary database is a database designed to handle detailed information on specific boundaries described below.

The establishment of a Boundary Information System is a task for experts, but this is a one-off project and existing software systems, commercially available, can be easily adapted to boundary applications. An example of a digital boundary database was simulated for the purpose of illustrating the suggested system (Figure 21). The simulated boundary is between two imaginary countries, Giramar and Morisca. Eighty-three boundary points define the boundary which consists of several sections representing different kinds of boundary line:

- 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.

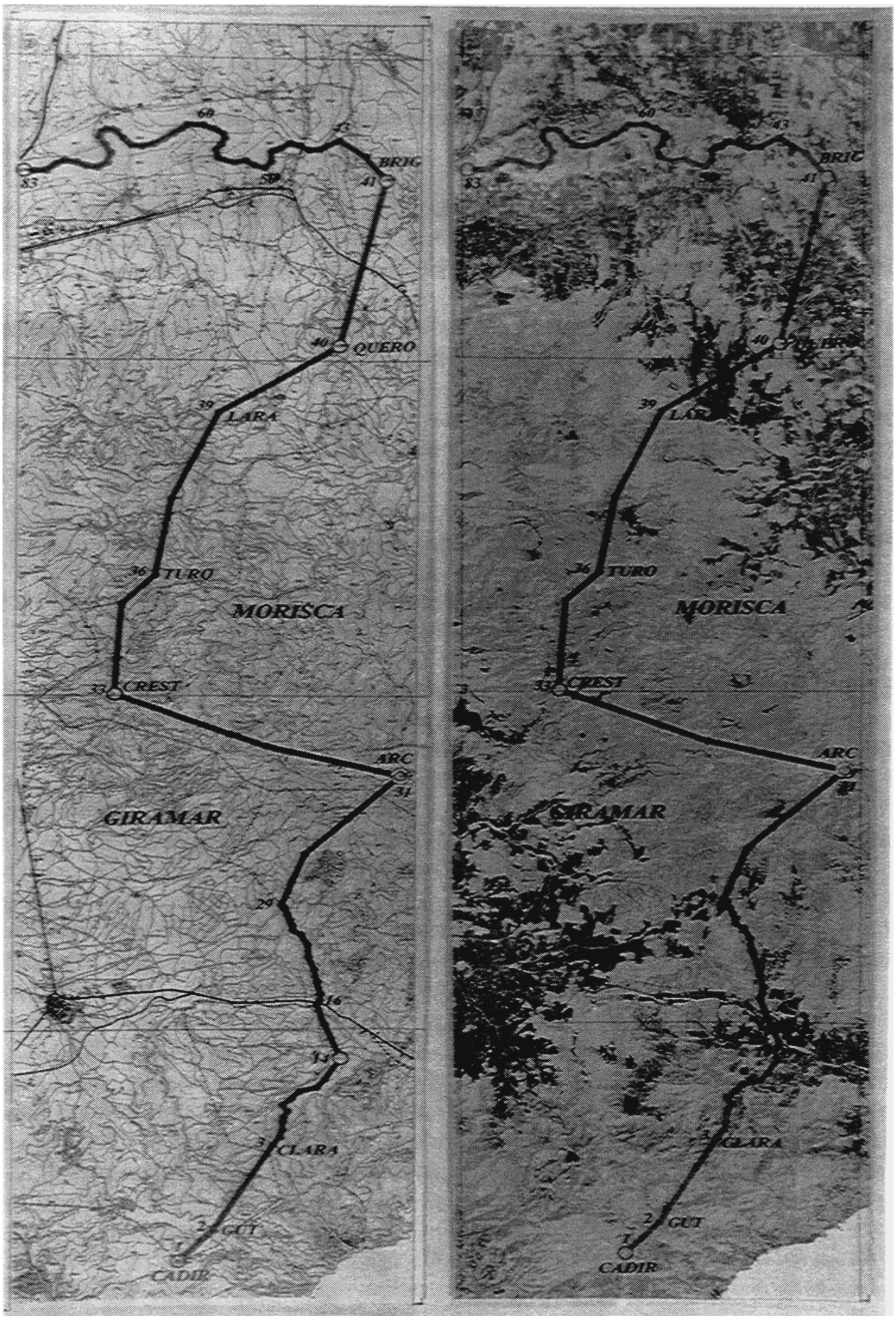
- A line along a stream, the coordinates recorded by digital photogrammetry without marking envisaged.

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

One of the demarcated points was chosen to serve as the boundary datum point at which static GPS observations were made. This point also became the central meridian of the plane rectangular projections system, Universal Transverse Mercator (UTM)-like, 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.

Figure 21: ***The Simulation Scheme on Map Background (left) and Satellite Background (right) (Scale 1:100,000)***

(Map and satellite background by courtesy of Institut Cartografic de Catalunya).



A typical survey description was included in the database, showing distant prominent orientation features recorded by magnetic bearings, a sketch of local witness marks and a separate sketch of lines to adjacent boundary monuments, with measured distances and the measured angle between the lines. All these measures would permit restoration of the point, if it were destroyed. The point description was scanned and entered into the data base in digital form.

A photograph(s) of each demarcated boundary point, taken on the ground and, if possible, from a helicopter, would further enhance the description. These photographs can be scanned and stored in digital form.

The above digital description of the boundary becomes the infrastructure of the boundary database, the heart of a boundary information system to which queries could be addressed and various required products derived.

In addition, a digital boundary diary could be created, recording various occurrences along the boundary, precisely located, updated at all times and available to both neighbouring countries.

The computerised diary could also be used for recording inspections and maintenance operations, including monument restoration or replacement.

2.6.3 Boundary simulation results

The objective of the simulation was to create a boundary digital database, containing all the relevant information which would be disseminated, as required, for administration purposes.

The simulated boundary[15] between two imaginary countries Giramar and Morisca, covered some 100km and was delimited by 83 points. Practically all types of boundary points were included, namely, six geodetic control quality points (one of which - point No. 31 Arc - was chosen as the boundary datum point), nine GPS fixed points, 12 points along a local watershed fixed by digital photogrammetry, 16 points along a stream defined by digital photogrammetry and 40 points along the middle of a river, digitised from a good quality map.

Thus all boundary points have coordinates X, Y in UTM projection system based on a boundary datum, with five different levels of estimated accuracy. 43 of the 83 points have an elevation, with three different levels of estimated accuracy. The six geodetic quality points and the nine GPS fixed points were monumented by pillars and pipes. It is assumed that each one of the 15 monumented points has a description containing details shown on the surveyors sketch and accompanied by a photograph.

All the above details were entered in digital form into a typical boundary database. In addition a typical point description and a typical photograph were scanned in a raster scanner and stored in the database in raster form, occupying approximately 1.25Mb of memory.

15 The basic data for the simulation in the form of a 1:50,000 topographicla map sheet Baix Emporda and the coordinates of geodetic control points were kindly provided by the Institut Cartografic de Catalunya in Barcelona.

Dissemination of information was programmed using ARCINFO modules, with the envisaged principal queries shown as selectable options.

- *Display all points*. All points within a specified window will be shown on the computer monitor screen. A list of attributes is displayed: Point ID (Number), name, height, survey method, marker or monument, situation (sketch, photograph).
- *Query-Display attributes*. Any point in the boundary database can be selected by number or name and its attributes will be displayed on the monitor shown in the hardcopy of the computer screen (Figure 22).
- *Query-Image View*. The surveyor's sketch and photograph for the point selected will be displayed on the monitor screen.
- *Query-Boundary Crossing*. This is a simulation of a boundary crossing occurrence. An approximate coordinate of the occurrence is entered (from GPS data or map reference) and the distances from the nearest defined boundary points will be displayed on the monitor screen (Figure 22).

The day-to-day operation of such a system does not require expertise in systems analysis or computer programming. A two or three day course would be sufficient to train an operator.

The simulation described proved conclusively that a boundary digital database is a powerful tool in efficient dissemination of information concerning the boundary.

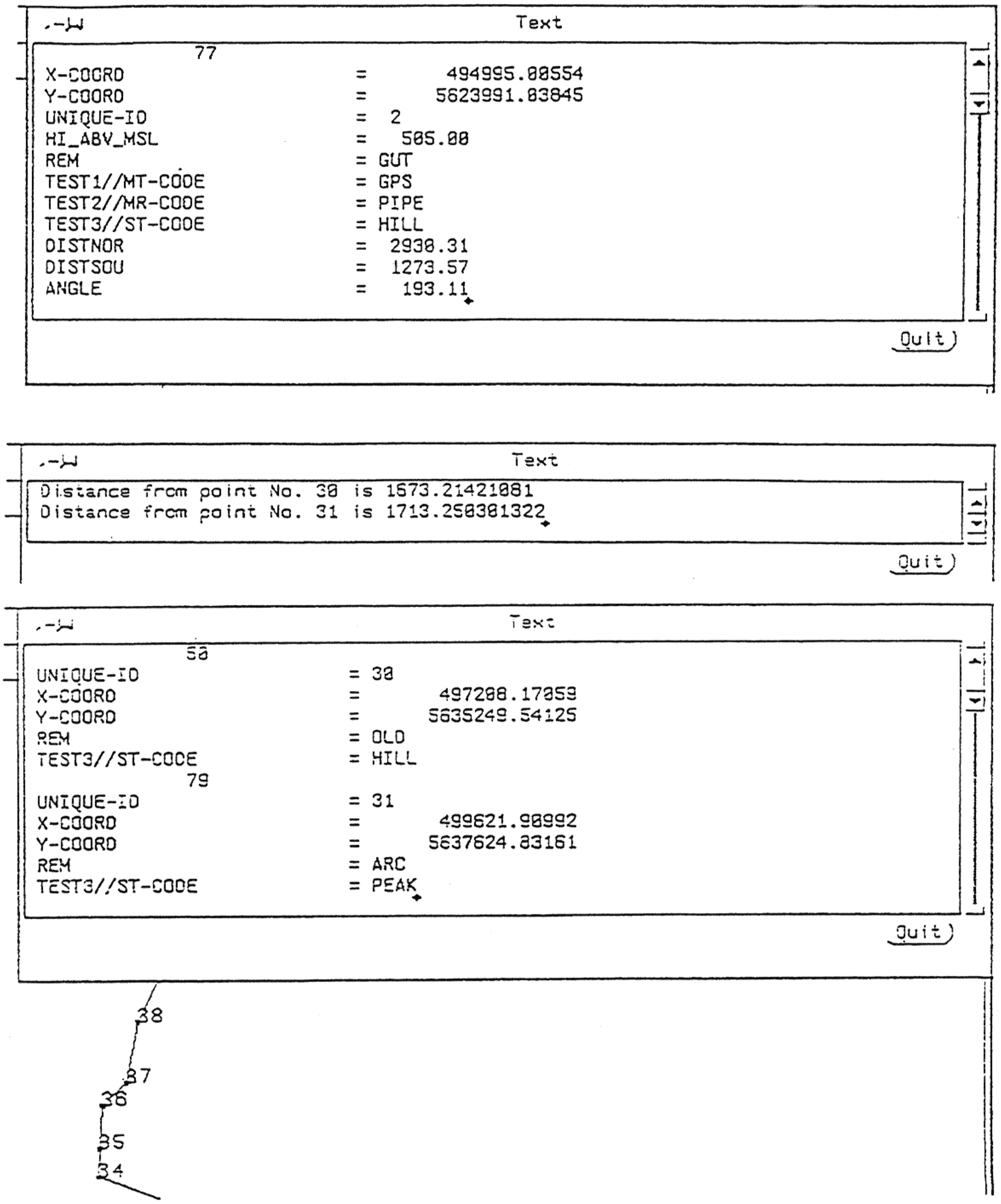
2.6.4 Boundary administration and management

The boundary line over land is immovable and runs in a straight line between the established markers of monuments, except where the line between markers follows a watershed. In section where the line follows a ditch, it is positioned in the middle of the ditch.

Unless explicitly stated otherwise, where the boundary follows a watercourse (non-navigable rivers, streams and canals), the line runs in a straight or curved path along the middle of the watercourse or the middle of the main branch. In navigable rivers, the line can either follow the middle of the watercourse, or it can follow the middle of the main navigation channel (thalweg). The term 'thalweg' is sometimes erroneously used for lines following nonnavigable rivers and for lines following dry land.

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.

Figure 22: ***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***



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.

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. 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. 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.

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's, 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.

It is appropriate to hold the meetings of the Boundary Commission 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).

3. Summary and Conclusions

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

It is however imperative to implement the boundary making technologies outlined in this paper in all cases of newly emerging boundaries or 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 outlined in this briefing should 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 world wide 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 to boundary creation and its administration will, through its implementation, become a contribution to preserving the international peace.

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Abbreviations

ICJ International Court of Justice
ILM International Legal Materials
ILR International Law Review

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