2 Cartography, remote sensing and GIS

"...The results of remote sensing processes are seen more and more as single steps in the greater context of GIS. The appropriate means of making the various streams of information provided by GIS visible, still remains cartography. But the cartographic representations of the various relationships need not be maps in the convential sense at all..."

H.J. Vogel (1991)

2.1 On defining cartography, remote sensing and GIS

2.1.1 Introduction

In order to understand the full extent of the process that transforms remotely sensed data into meaningful information, one has to define the meaning of remote sensing and its position amidst other but related disciplines. Remote sensing, GIS and cartography are interacting mapping fields in the sense that they - at least partly - exhibit mutual dependencies as far as sound information extraction is concerned. They tend to grow closer to one another under the influence of technology (see previous chapter). A remarkable number of papers dating from the late 1980s is exclusively dedicated to the distinctions and relations among these three areas of interest and their separate definitions (e.g. Blakemore, 1988; Cowen, 1988; Fisher & Lindenberg, 1989; Fussel *et al.*, 1986; Maguire, 1991).

From the positions taken in these publications, one could not escape the impression that some of them are dictated by a "survival instinct". Exemplary for this observation is the critical attitude of cartographers with respect to the restricted presentational tasks in a GIS environment assigned to them. The "de-skilling crisis" (Rhind, 1988) expressing the depreciation to which some exclusively cartographic knowledge is subjected in the GIS era is put into its perspective by Muehrcke (1990) who states that *"...currently, information systems supported by electronic technology are forcing a creative transformation of cartography as we know it...fortunately, this promises life, not death....".* This seems to link up very well with the idea of a "new cartography" as proposed by Taylor (1985) in response to technological and socio-economic changes caused by the information revolution. As an exponent of the latter, remote sensing techniques offer promising opportunities for a challenging cartography (Denègre, 1994; Monmonier, 1987).

The danger that is lurking in the above-mentioned discussions, however, is that of losing oneself in the goo concerning the dominance of one of the disciplines. Instead, a more practical approach is advocated, namely that of exploring the actual possibilities for interchanging concepts among the disciplines, for example in higher education (Dahlberg & Luman, 1991). It would be interesting to consider the core concepts in cartographic communication as discussed by Ormeling (1992) in view of developments in GIS and remote sensing. Therefore, as a brief introduction, attention is paid to the relevant relationships between remote sensing, GIS and cartography. But first, the three areas of interest will be subjected to a critical review that clearly demarcates their extent. Remote sensing will receive somewhat more attention in order to link up better with the contents of the chapters to follow.

2.1.2 Cartography

When reviewing the cartographic literature of the past 30 years, the predominant role of theories of cartographic communication in the 1960s and 1970s catches the eye. The communication models proposed by e.g. Koeman (1971), Kolacny (1969) and Ratajski (1973) are well known in the cartographic community but their initial illuminating views on the cartographic process are now considered too restricted to do justice to the subject. Among the objections raised against the communication paradigm are its failure to deal with *"the extraction of cartographic information (map reading) and the cognitive processes involved in interpreting the map image"* (Wood & Keller, 1996) and its intolerance to the art component in cartography (MacEachren, 1995). Due to the interest in computer assisted cartography in the 1980s, the communication theories have lost some of their influence as well.

In accordance with MacEachren (1995), cartography is defined here as a discipline dealing with "representation". Instead of considering maps merely graphic messages to convey relevant geographic information, based on information theory (Shannon, 1948) and semiotics (Bertin, 1983), maps are viewed as spatial representations, thereby stressing cartography's function as *"...creating interpretable graphic summaries of spatial information (i.e., representations)..."* (MacEachren, 1995). Such a representation is just one out of many possibilities to depict the complex environment, for example for decision-making purposes, without claiming to be an objective and all-embracing "messenger". Ormeling (1995) states that *"...no one map can be considered as the only true map based on specific data, as subjective decisions regarding data thresholds, classification systems, class boundaries, or numbers of classes have been made..."* (Monmonier (1991a) even dares to claim that providing a single view is unethical!). It is interesting to note that these opinions are deviating from the "traditional" communication paradigm in which, according to MacEachren & Ganter (1990) *"...there is an optimal map for each (known) message..."* In fact, this doesn't affect the definition proposed by Taylor (1991) that has been given at the beginning of section 1.2, at least if one keeps one's mind on this "flexible" map concept. As will be learnt from chapter 7, the *"multiple map view"* is referring to a field known as cartographic visualisation.

In order to create interpretable graphic summaries, metadata have to be provided, preferably graphically as well. This presupposes understanding of the data gathering and processing stages of the information process.

2.1.3 Geographical Information Systems (GIS)

Defining GIS is not an easy task to do as is apparent from the large number of divergent views spouted in literature. Chrisman (1984) refers to it as a complicated type of software covering the whole life cycle of geographical data, from data collection to interpretation and on. A better and more widely accepted definition of GIS is given by Burrough & McDonnell (1998) who consider GIS a complex of computer hardware and software embedded in a proper organisational context. The latter refers to such issues as training of staff and appropriate implementation of the system in the present workflow.

As far as the software is concerned, Burrough & McDonnell (1998) distinguish the following five technical tasks (see figure 2.1):

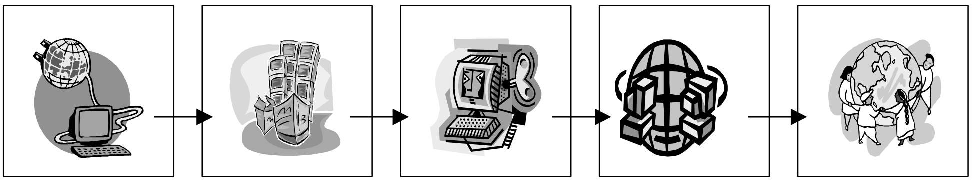

Figure 2.1: Five main tasks of GIS software, schematically represented

- Data input and data verification. The conversion of collected data into a suitable, digital format, for example by means of digitizers, scanners or keyboard. Moreover, it involves some kind of pre-processing, as data can be subjected to generalisation or simple classification procedures.
- Data storage and database management. Once passed the input stage, data are stored in a database according to a particular data structure and database structure.
- Data manipulation. This involves all transformations being applied to the data. Berry (1987) uses the term "operations" whereas Abel (1989) prefers "transactions". In general, a distinction can be made between analyses (spatial or not) and more trivial processing tasks like updating and simple error removal.
- Data output and presentation. The data, processed or not, can be presented in a graphic or alphanumeric way, as hardcopy (e.g. a paper map) or softcopy (e.g. so-called ephemeral output on a computer screen).
- Interaction with a user. A user is able to communicate with the information system ("query input") in order to extract information from the stored data.

Marble & Peuquet (1983) give a well-chosen description of the functionality of a GIS, that summarises the above-mentioned tasks: *"... a GIS is designed to accept large volumes of spatial data, derived from a variety of sources, including remote sensors, and to efficiently store, retrieve, manipulate, analyse and display these data according to user-defined specifications..."*

2.1.4 Remote sensing

In general, remote sensing is considered primarily a data acquisition technique that includes traditional aerial photography as well as more advanced air- and spaceborne sensor technology. Its extent is, however, dependent on the various disciplines that make use of the technology; here, remote sensing refers to the use of electromagnetic energy sensors that derive information about the features at the Earth's surface by measuring and analysing the type and amount of energy that they emit or reflect. The type of energy is referring to different parts of the electromagnetic spectrum ("wavelengths"), e.g. visible, near-infrared, thermal infrared or microwave bands (with increasing wavelengths). Figure 2.2 presents a schematic representation of the principle of electromagnetic remote sensing of the

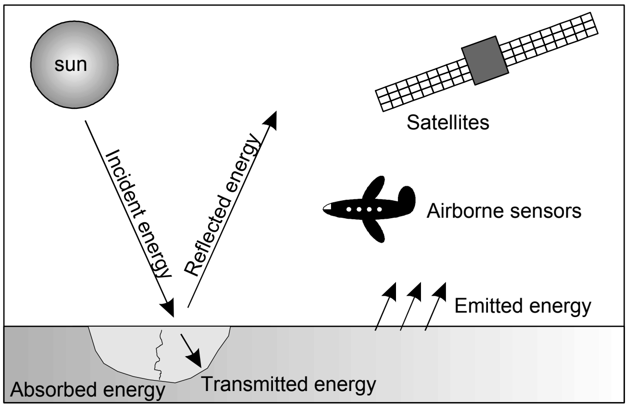

Figure 2.2: The principle of remote sensing (after Lillesand & Kiefer, 1994)

Earth (after Lillesand & Kiefer, 1994). Based on the observations made by Rees (1990), it encompasses the collection of information about a *scene object* (Abkar, 1999) located on or near the earth's surface without coming into physical contact with it, by using an airborne or spaceborne sensor that is more or less above and at a "substantial" distance from this object. Moreover, the information is carried by electromagnetic radiation, as stated before. Note that the above definition does exclude other remote sensing techniques such as sonar that uses acoustic waves and medical imaging that does indeed apply electromagnetic energy, yet not in the sense that is meant by environmental remote sensing with a sensor at a "substantial distance" from an earthbound object.

In order to understand the unique character of remotely sensed data, some attention will be paid to the principles of remote sensing. A more extended discussion on remote sensing techniques can be found in e.g. Richards (1999), Mather (1987) and Lillesand & Kiefer (1994). Gonzalez & Woods (1992) provide an introduction to the concepts and methodologies to process the image data that are acquired by remote sensing techniques.

The term remote sensing dates back to the early 1960s when new data acquisition techniques failed to conform to the narrow definition of aerial photography (Fussell *et al.*, 1986). Since then, satellite platforms have enabled observations from high altitude with sensors operating in the visible, infrared and thermal section of the electromagnetic spectrum as well as in the microwave region as exemplified by active radar systems. Fussell *et al.* (1986) state that there exists no single definition of the field because of the different viewpoints that could be taken by a differing audience and the lack of a widely accepted academic home base. The latter contention is easily tackled by the fact that the process does have a sound physical basis, e.g. quantum mechanics describes the behaviour of electromagnetic radiation in terms of waves as well as quanta (photons). Concentrating on *passive*, *imaging* remote sensing systems such as represented by the Landsat Thematic Mapper (TM) whose data are dealt with in this thesis, the following observations can be made. The TM sensor onboard the Landsat satellite behaves like a line scanner - a "whiskbroom" scanner (Rees, 1990) - carrying a number of detectors (100) that can be characterised as *photon counters* (figure 2.3). Physical models describe the interactions between objects and the atmosphere on the one hand, and electromagnetic energy - emitted or reflected - on the other. The amount of energy measured by the detectors provides some clues concerning the nature of the objects. The system that measures the so-called photon flux (amount of energy per second) can be described by physical models as well.

The data acquisition process can be roughly subdivided in the following stages (see also figure 2.2):

- The flow of incident solar energy and its interactions with the atmosphere such as scattering and absorption as well as the atmospheric interactions of the reflected and emitted portion of that energy.
- The interaction with earth-bound objects and the subsequent reflection, absorption and transmission of energy.
- The recording of energy values by scanner optics, over an area on the ground that is observed by the sensor at a certain point in time - the Instantaneous Field of View (IFOV).
- The transformation of the photon or radiant flux into an electrical current and the subsequent sampling during which analogue photon counts are converted into digital integer numbers or DN's (quantization).

Fact Sheet

Landsat-5 Thematic Mapper

Date of launch: March 1, 1984

Orbit: 705 km, near polar, sun synchronous

Orbit period: 98.9 minutes

Band:	micrometer:	resolution (m):
1	0.45 - 0.52	30
2	0.52 - 0.60	30
3	0.63 - 0.69	30
4	0.76 - 0.90	30
5	1.55 - 1.75	30
6	10.40 - 12.50	120
7	2.08 - 2.35	30

application (example):

band 1:	bathymetric mapping forest mapping
band 2:	green relectance from healthy vegetation
band 3:	chlorophyll absorption in vegetation
band 4:	near infrared reflectance peaks in healthy green vegetation
band 5/7:	vegetation and soil moisture studies geology
band 6:	thermal mapping soil moisture and vegetation studies

Figure 2.3: Characteristics of the Thematic Mapper onboard Landsat-5

Actually, the system records a value that corresponds with a weighted average of radiance values over a particular field of view. The *point spread function* of a sensor (the “weighting function”), determined by the characteristics of the optical system and the extent to which features are in contrast with their environment (as far as radiance values are concerned), can be held responsible for the fact that this recorded radiance is affected by the surroundings of the actual measurement area. In areas where the radiance values exhibit a high spatial variability, such as in urban areas, this phenomenon can cause serious problems with respect to classification (Curran, 1985). Estimation of the point spread function of the sensor could contribute to a reduction of this confusion as Abkar (1999, page 40 and on) demonstrates.

Pixels can be considered the representations of samples in the eventual image (“image samples”). They correspond e.g. with a *scene element* of 30 by 30 meters; talking about pixels of this size is utter nonsense (!), and it is depressing to observe that literature still fuels this confusion (e.g. Moss *et al.*, 1989).

2.2 A closer look at some relevant relationships

2.2.1 Introduction

As indicated in section 2.1, the interrelationships between the above-mentioned areas of interest have been the subject of a number of - only by spurts captivating - discussions since the late 1980s, attempting to model the mutual interactions. The simple "model of three-way interaction" presented by Fisher & Lindenberg (1989) offers the best way to depict the equivalent positions of cartography, remote sensing and GIS (see figure 2.4). From this, it becomes clear that - next to overlaps - each field exhibits its own scientific area of interest, remote sensing for example is strongly rooted in physics. This observation has consequences for the individual domain expert. A cartographer for example, is unable to gain a comprehensive view of all aspects of GIS (e.g. modelling) and remote sensing (e.g. non-imaging techniques) and his innovating role must be played in the overall overlap area (represented in black in figure 2.4). It is stated that remote sensing and GIS are primarily data acquisition and data processing techniques whereas cartography can only partly be regarded as such because it encompasses more than mere tools. The establishment of a *Spatial Information Science* as proposed by Goodchild (1990) could, however, offer a framework for a functional coexistence of science and technology with respect to the above-mentioned overlap.

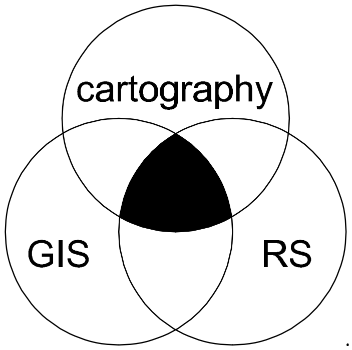

Figure 2.4: The positions of cartography, remote sensing and GIS *(after Fisher & Lindenberg, 1989)*

The elements of such a framework can be crystallised from the separate interactions among cartography, remote sensing and GIS. Here, the main issues will be touched upon before being discussed more thoroughly in one of the following chapters. It must be mentioned in advance, that a more or less isolated view on the mutual relationships is not always a realistic option. As an example consider the updating of topographic maps in a GIS environment, a cartographic application in which e.g. satellite imagery is subjected to a change detection process.

2.2.2 Remote sensing - GIS

As the relationship between remote sensing and GIS is brought up for discussion, the keyword is *integration*. Efforts are directed at the development of a workable synergy of both technologies on system as well as data level. Referring to the latter, Archibald (1987) makes a further distinction between display integration (visual overlay of digital images and maps in a GIS) and integrated data analysis that requires a higher level of data integration. Wilkinson (1996) summarises the relationships in terms of complementarity:

- Remote sensing can be considered a data acquisition and processing technology whose (digital) data sets serve as input to a GIS. As such, "raw" images as well as classified images can add a substantial information potential to the cartographic GIS data. Trotter (1991) attributes this extra value to possible reduced costs of data acquisition as compared to more traditional collection methods, while still meeting minimal requirements regarding such aspects as accuracy and topicality. Hellyer *et al.* (1990) present an interesting study demonstrating the value of land use/land cover information derived from Landsat Thematic Mapper data for further processing in a GIS during an environmental investigation of a wetland area.
- GIS data can be used as ancillary information to increase the quality of products derived from remotely sensed data. With reference to the classification process, these data can be applied during all stages of the information extraction: before, during as well as after classification. As an example of the first stage, the stratification of a remotely sensed image in preparation to classification comes into mind, while the second stage refers to the use of GIS data as *a priori* knowledge (Strahler, 1980). Janssen (1993) gives an example of using cartographic GIS data during a post-classification editing procedure in order to improve the accuracy of the classification. In his 2-stage object-based classification, a pixel-based classification is integrated with object boundaries (agricultural fields) that are contained in a GIS, and the objects are labelled in accordance with the membership of the majority class of the pixels within the object's boundaries.
- A third relationship concerns the use of both remotely sensed and GIS data in environmental modelling and analysis. Davis (1991) provides an overview of some of the research issues concerning the processing of remotely sensed and GIS data for environmental analyses. Probably, some of the more interesting research initiatives are to be expected in the area of scale (with respect to information contents) and time (in view of dynamic modelling).

The processing of digital imagery from satellites is still bound to specific image analysis systems and the discussions on integration are therefore not only concentrated on data exchange from one system (image processing) to another (GIS) and vice versa, but on actual system integration as well. Ehlers *et al.* (1989) argue that the integration of GIS with remotely sensed data and with image analysis *"...can be considered an evolutionary extension of the capabilities of existing geographic information* *systems technologies...”* They describe the developments in integration as “separate but equal” (based on data exchange formats), “seamless integration” (common user interface) and “total integration” (based on a complete, comprehensive model of the real world) respectively. The latter is still a blueprint for a total information system that can achieve maturity on the breeding ground of Goodchild’s (1990) Spatial Information Science.

These perspectives notwithstanding, data integration is seriously hampered by the different levels of generalisation of remotely sensed image data and GIS data. This issue touches upon the concepts of space on which both technologies are based, most obviously expressed in terms of object-based models versus models based on image elements (Ehlers *et al.*, 1991). This difference is primarily a conceptual discord as Goodchild & Wang (1989) argue, but it can be regarded as a technical problem if it is projected on the issue of data structure, so on the raster-vector dichotomy. Note that image elements are not necessarily represented by a raster data structure (e.g. a Digital Elevation Model composed of a *Triangulated Irregular Network* or TIN (Ehlers *et al.*, 1989)) whereas objects are not the exclusive domains of vector data structures. Ehlers *et al.* (1991) provide an extended discussion on the topic of data structures with respect to the integration of remote sensing and GIS. As far as the conversion of geographical data is concerned (raster-vector formats), Piwowar *et al.* (1990) present an interesting benchmark study in which they included not only the speed of the operation, but also the quality, accuracy and efficiency of the conversion methods.

Besides the conceptual and technical impediments to integration, Lauer *et al.* (1991) distinguish some more institutional issues relating to e.g. costs of data, availability of processing equipment, education and training, and organisational infrastructures. It is indeed of the utmost importance to prepare the user community for the integrated use of remote sensing and GIS as this may prove to be decisive for the acceptance and widespread application of remotely sensed data.

2.2.3 Cartography - Remote Sensing

Mason (1990) states that *“...the close relationship that presently exists between cartography and remote sensing is one which is founded upon the importance of remote sensing as a basic data source in map compilation...”* The data that are acquired by earth observation satellites can prove their value for cartographic applications in one of the following three ways (Albertz, 1991):

- to produce and subsequently update topographic maps;
- to derive satellite image maps;
- to generate thematic maps.

The creation of a *topographic map* solely on the basis of satellite imagery places stiff requirements on the data, especially with respect to the geometric accuracy. With the advent of the French SPOT series of satellites, started in 1986 and already spanning years to come with the expected launch of SPOT-5B in 2004 (Gomarasca, 1996), high spatial resolutions and stereoscopic capabilities have opened up new perspectives for cartography. The HRG instrument onboard SPOT-5 will allow for spatial resolutions of

5 and 10 meters in the panchromatic and multispectral range respectively! But the Russian Resours series, carrying photographic instruments (e.g. KFA-1000) already succeeds in providing images with a very high resolution (up to about 6 meters). In the near future, digital data exhibiting still higher spatial resolutions are to be expected from the United States with the launch of commercially exploited but military inspired satellites. The Ikonos series of satellites will provide incredible high spatial resolutions of 1 meter and 4 meters in panchromatic and multispectral mode respectively (after the unfortunate launch of Ikonos-1 at April 27, 1999 Ikonos-2 has been placed into orbit successfully at September 24, 1999). These performances notwithstanding, it is still too early to consider the production of topographic maps with large scales (larger than 1 : 25000) without the introduction of serious positional errors.

Image maps still exhibit the characteristics of a satellite image but they have been subjected to extensive radiometric as well as geometric corrections before being completed with cartographic signatures representing topographic information such as road hierarchies and rivers (Galtier & Baudoin, 1992; Ruas, 1992). As an example, the ortho-images of the cartographic institute of Catalunya can be put on the scene. This autonomous Spanish region is covered by colour composites derived from Landsat-5 Thematic Mapper images and eventually presented as a series of 8 map sheets at a scale of 1:100 000. They differ completely from the attractive, exciting and eye-catching images that spark off enthusiasm without conveying spatial information, such as in advertising (note the use of colour composites as background in telecommunication ads!).

The third application, the generation of *thematic maps*, is closely (but not exclusively) related to the classification process that transforms remotely sensed data into land cover / land use information classes. Denègre (1994) presents a number of studies that each demonstrate the exclusive, supplementary or substitute use (Ciolkosz & Kesik, 1994) of remotely sensed data for thematic mapping purposes.

Focussing on the visualisation tools that could improve the interpretation of remote sensing information further expands the relationship between cartography and remote sensing. The adequate representation of dynamic information can for example support the identification of relevant change patterns (Van der Wel, 1995) whereas terrain visualisations provide for a “fly-through” reconnaissance as a preparation to military operations, e.g. in the Kosovo region.

2.2.4 Cartography - GIS

The relationship between cartography and GIS is an interesting issue for discussion. Tomlin (1990) pays attention to the role of GIS for cartographic modelling, thereby emphasising the way in which cartographic data (map layers) are used during the derivation of information instead of focussing merely on the presentational tasks of cartography. The latter view is, however, prevalent in the GIS literature and a thorn in the flesh of the cartographer who is right to cast doubt on the *“…wonderful, almost* *magical powers...”* (Muehrcke, 1990) that GIS offers. Instead of considering GIS a threat to traditional cartographic skills, it seems more sensible to concentrate on the new role of the cartographer in the GIS era, e.g. as a “geographical data broker”, a visualisation expert or a contributor to knowledge based information systems. Or the cartographer can help to tag data sets with a quality statement as he is well versed in dealing with meta-information as a consequence of handling and combining divergent geographical data (Kraak & Ormeling, 1996).

This “quality task” is becoming increasingly relevant as GIS has evolved into a multidisciplinary technology lacking a clearly circumscribed conceptual basis (there has been a vivid discussion on the question “GIS: tool or science?” summarised by Wright *et al.*, 1997). In other words, who can be held responsible for the sound application of geographical data given the methodologies present in the GIS repository? Certainly, the user has to rely on his own knowledge in the first place, but is the level of userfriendliness offered by the current generation of information systems not providing opportunities to an inexperienced, unsuspecting and therefore vulnerable group? And given this observation, is it not sensible that the cartographer fills this knowledge gap? It is stated that the cartographer can indeed contribute to a better information extraction and decision-making process, not on his own, but as the integrator that brings together all relevant meta-information in such a format that a user will be inclined to really consider it during processing. In essence, this role doesn’t differ substantially from the traditional one as the cartographer has always taken care of an, as appropriate as possible, conveyance of geographical information, mostly by means of taking advantage of the distinguishing abilities of human visual perception.

Without joining in the discussion concerning the extent to which GIS has evolved from efforts in computer cartography or other disciplines (e.g. Coppock & Rhind, 1991), it is undoubtedly true that digital mapping and GIS have approached each other very closely as far as the production of map end-products is concerned. Mapping agencies have changed over to information system technology or are still working on it, although they won’t use all integrated analysis capabilities of such systems. Rhind (1988) considers this development an indication of the acceptance of GIS, as he brings forward the introduction of such technology at Bartholomew’s, an example of a solid, formerly traditionally operating cartographic firm in the United Kingdom.

2.3 Beyond parochialism: the multidisciplinary nature of geographical data management

The above discussion on three major fields of interest within the realm of geographical data management emphasises the obvious need for co-operation. While computer technology progresses with maturing internet technology, the way in which data are accessed and used will change substantially. Maps will be produced on demand on specially equipped map servers, in large numbers and according to an astonishing variety, and distributed along the internet without intervention of a cartographer. As this thesis is written from the viewpoint of a cartographer, his role is recognised. Instead of looking sadly on the ongoing developments, it is stated that cartographic knowledge must be made available to the field of geo-informatics by joining forces. The extraction of information from remotely sensed data crosses several interdisciplinary borders, and in the remainder of the thesis the contribution of cartography will be assigned some more attention. Managing huge amounts of geographical data doesn't necessarily require the physical presence of a cartographer, but it sure suffers from his intellectual absence!