THE SOTER MANUAL

PROCEDURES FOR SMALL SCALE DIGITAL MAP AND DATABASE COMPILATION OF SOIL AND TERRAIN CONDITIONS

(Draft)

Editors:
V.W.P. van Engelen
Wen Ting-tiang

5th Edition
November 1992

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PREFACE

At the initiative of the International Society of Soil Science (ISSS) a workshop of international experts on soils and related disciplines was convened in January 1986 in Wageningen, the Netherlands, to discuss the "Structure of a Digital International Soil Resources Map annex Data Base (ISSS, 1986a). Based on the findings and recommendations of this workshop a project proposal was written for SOTER, a World **SO**ils and **TER**rain Digital Data Base at a scale of 1:1 million (ISSS, 1986b).

A small international committee was appointed to propose criteria for a "universal" map legend suitable for compilation of small scale soil-terrain maps, and to include attributes required for a wide range of interpretations such as crop suitability, soil degradation, forest productivity, global soil change, irrigation suitability, agro-ecological zonation, and risk of droughtiness. The committee compiled an initial list of attributes. The SOTER approach received further endorsement at the 1986 ISSS Congress in Hamburg, FRG.

A second meeting, sponsored by the United Nations Environmental Programme (UNEP), was held in Nairobi, Kenya, in May 1987 to discuss the application of the SOTER database for preparing soil degradation assessment maps. Two working groups (legend development and soil degradation assessment) met concurrently during this meeting. The legend working group was charged with the task of developing Guidelines for a World Soils and Terrain Digital Database at a 1:1 million scale, to propose general legend concepts, to prepare an attribute file structure, and to draft a tentative outline for a Procedures Manual (ISSS, 1987).

As a follow-up to the Nairobi meeting, UNEP contracted ISRIC to compile a global map on the the status of human-induced soil degradation at a scale of 1:10 to 1:15 million, and to have this accompanied by a first pilot area at 1:1 million scale in South America where both status and risk of soil degradation would be assessed on the basis of a digital soil and terrain database as envisaged by the SOTER proposal. In this context ISRIC subcontracted the preparation for a first draft of a Procedures Manual for the 1:1 million pilot study area to the Land Resource Research Centre of Agriculture Canada.

The first draft of the Procedures Manual (Shields and Coote, 1988) was presented at the First Regional Workshop on a Global Soils and Terrain Digital Database and Global Assessment of Soil Degradation held in March 1988 in Montevideo, Uruguay (ISSS, 1988). The proposed methodology was then tested in a first pilot area, covering parts of Argentina, Brazil and Uruguay (LASOTER). Soil survey teams of the participating countries collected soils and terrain data to assess the workability of the procedures as proposed in the draft Manual. During two correlation meetings and field trips minor changes were suggested, while further modifications were recommended at a workshop that concluded the data collection stage. The comments from both workshops were incorporated in the January 1989 version of the Procedures Manual (Shields and Coote, 1989).

Application of the SOTER methodology in Central Brazil, and in an area along the border between the USA and Canada (NASOTER), revealed additional shortcomings in the second version of the Manual. Also, the first tentative interpretation of the LASOTER data as well as the integration of the attribute data into a Geographic Information System demonstrated the need for further modifications.

A third revised version of the Manual was compiled by the SOTER staff (ISRIC, 1990a) and circulated for comments amongst a broad spectrum of soil scientists and potential users of the database. A workshop on Procedures Manual Revision was convened at ISRIC, Wageningen, to discuss the revised legend concepts and definitions (ISRIC, 1990b).

Based on the recommendations of this workshop, the proposed modifications were further elaborated, resulting in a fourth draft version of the Procedures Manual. This Manual consisted of three parts, the first of which dealt with terrain and soil characteristics. The second part treated land use in a summary way in the expectation that a more comprehensive structure for a land use database would become available from other organizations. In the third part information on related files and climatic data needed for SOTER applications were described. In each section definitions and descriptions of the attributes to be coded were given, while in the first section an explanation of the mapping approach was provided.

Contrary to earlier versions of the Manual, this Manual did not elaborate on the soil degradation assessment as this is considered an interpretative part. Guidelines for this and other interpretations will be subject of a future publication. Technical specifications (e.g. table definitions, primary keys, table constraints etc.) and rules for the SOTER database management will also be published separately.

A second SOTER workshop organized by UNEP was convened in February 1992 in Nairobi, Kenya, at which the Land and Water Division of the Food and Agriculture Organization of the United Nations (FAO) participated. At this meeting FAO expressed its full support for the SOTER programme and indicated that it was prepared to use the SOTER methodology for storing and updating its own data on world soil and terrain resources. To facilitate the use of SOTER data by FAO it was decided to use the FAO-Unesco Soil Map of the World Legend as a basis for characterising the soils component of the SOTER database.

To take account of these decisions a fifth version of the Manual was prepared in 1992 with active participation by FAO. The main arrangement of this latest version of the Manual is similar to the fourth version, with the difference that the Manual now consists of two parts only, the first one dealing with soils and terrain, and the second one dealing with the accessory databases in which land use, vegetation and climatic data can be stored.

No further revisions of the Procedures Manual are planned until more experience has been gained in the application of the SOTER methodology according to these latest guidelines. Nevertheless, all comments are welcome, and should be sent to the Manager of the SOTER project[1].

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PART I SOILS AND TERRAIN

1 General introduction

The aim of the SOTER project is to utilize current and emerging information technology to establish a World Soils and Terrain Database, containing digitized map units and their attribute data (ISSS, 1986b). The main function of this database is to provide the necessary data for improved mapping and monitoring of changes of world soil and terrain resources. It will be based on a computerized information system composed of a database, a Geographical Information System, and a database management system, that will be capable of delivering accurate, useful and timely information to a wide range of scientists, planners, decision-makers and policy-makers.

In the initial phases of the SOTER project there are no concrete plans for the physical establishment of a centralized SOTER database. Rather, a separate database will be set up for each area for which a land resource inventory is being undertaken according to the SOTER methodology. The common SOTER approach does, however, guarantee the possibility of merging the individual databases into a global database if and when this becomes feasible. Through its basic activities SOTER also intends to contribute to the establishment of national and regional soil and terrain databases, founded upon the same commonly acceptable SOTER principles and procedures, so as to further facilitate the exchange of land resource information and ultimate incorporation into a global database.

The Database will have the following characteristics:

a) be structured to provide a comprehensive framework for the storage and retrieval of uniform soil and terrain data that can be used for a wide range of applications at different scales,
b) contain sufficient data to allow information extraction at a resolution of 1:1 million, both in the form of maps and tables,
c) be compatible with global databases of other environmental resources,
d) be amenable to periodic updating and purging of obsolete and/or irrelevant data, and
e) be accessible to a broad array of international, regional and national environmental specialists through the provision of standardized resource maps, interpretative maps and tabular information essential for the development, management and conservation of environmental resources.

The SOTER database is supported by a SOTER Procedures Manual which translates SOTER's overall objectives into a workable set of arrangements for the selection, standardization, coding and storing of soil and terrain data.

SOTER requires soils from all corners of the world to be characterised under a single set of rules. As the FAO Soil Map of the World was designed to do the same, SOTER has adopted the recently revised FAO legend as the main tool for differentiating and characterizing its soil components. There being no universally accepted system for world-wide classification of terrain and terrain elements, SOTER has designed its own system, which is presented in section 6.1 of this Manual, and which is based on earlier FAO work.

The input of soil and terrain data into the SOTER database is contingent upon the availability of sufficiently detailed information. Although some additional information gathering may be required when preparing existing data for acceptance by a SOTER database, the SOTER approach is not intended to replace traditional soil surveys. Hence this manual cannot be used as guidelines for soil survey procedures or any other methodology for the collection of field data. Nor does it present a methodology for the interpretation of remotely sensed data. Several handbooks on these techniques are available on the market and any novice of land resource survey methodology should refer to them.

2 The SOTER mapping approach and database construction

2.1 Introduction

Within the context of the general objectives of SOTER, as defined in chapter 1, the following subjects will be treated in more detail:

a) the procedure for delineating areas with a homogeneous set of soil and terrain characteristics,

b) the construction of an attribute database related to the mapping units and based on well-defined differentiating criteria,

c) the development of a methodology that should be transferable to and useable by developing countries for national database development at the same or at a larger scale (technology transfer).

2.2 The SOTER mapping approach

Basic in the SOTER methodology is the separation of areas of land with a distinctive, often repetitive, pattern of landform, lithology, surface form, slope, parent material, and soil. Tracts of land distinguished in this manner are named SOTER Units (SU). Each SU thus represents one unique combination of terrain and soil characteristics. To the extent that SOTER Units can be mapped out they are called SOTER Map Units (SMU). A SOTER Map Unit is only similar to a SOTER Unit if every constituent part of that SOTER Unit is mappable. If not all the components of a SOTER Unit can be depicted on a map then a SOTER Map Unit covers more than one SOTER Unit. Figure 1 shows the structure of a SOTER Unit in the database and gives an example of a SOTER map, with polygons that have been mapped at various levels of differentiation within a SOTER Unit.

The mapping of land characteristics as outlined in this manual has originated from the idea that land (in which terrain and soil occur) incorporates processes and systems of interrelationship between physical, biological and social phenomena evolving through time. This idea was initially developed in the USSR and Germany (landscape science) and was gradually accepted throughout the world. A similar integrated concept of land was used in the land systems approach developed in Australia (Christian and Stewart, 1953) and evolved further in time (McDonald et al., 1990, Gunn et al., 1990). SOTER has continued this development by viewing land as being made up of natural entities consisting of combinations of terrain and soil individuals.

The SOTER mapping approach in many respects resembles physio- graphic soil mapping. Its main difference lies in the stronger emphasis SOTER puts on the terrain-soil relationship as compared to what is commonly done in traditional soil mapping. This particularly will be true at smaller mapping scales. At the same time SOTER adheres to rigorous data entry formats necessary for the construction of an universal terrain and soil database. As a result of this approach the data accepted by the database will have a high degree of reliability and are fully standardized.

The methodology as presented in this manual has been developed for applications at a scale of 1:1 million. This approach has been tested successfully in pilot areas in North and South America. Nevertheless, the methodology is also intended for use at larger scales connected with the development of national soil and terrain databases. A first testing of such relatively detailed database was carried out in Sao Paulo State of Brazil at a scale of 1:100,000 (Oliviera and van de Berg, 1992). The SOTER methodology also lends itself well to the production of maps and associated tables at scales smaller than 1:1 million.

Terrain, soil and other units as used by SOTER are hierarchically structured to facilitate the use of SOTER procedures at scales other than the reference scale of 1:1 million.

2.3 SOTER source material

Basic data sources for the construction of SOTER units are topo- graphic, geomorphological, geological and soil maps at a scale of 1:1 million or larger (mostly exploratory and reconnaissance maps). In principle all soil maps that are accompanied by sufficient analytical data for soil characterization according to the revised FAO-Unesco Soil Map of the World Legend (FAO, 1988) can be used for mapping according to the SOTER approach. Seldom, however, will an existing map and accompanying report contain all the required soil and terrain data. Larger scale (semi-detailed and detailed) soil and terrain maps are only suitable if they cover sufficiently large areas. In practice such information will be mostly used to support source material at smaller scales.

As SOTER map sheets will in general cover large areas, they will often include more than one country, and correlation of soil and terrain units may be required. In case no maps of sufficient detail exist for a certain study area, or there are gaps in the available material, then it may still be possible to extract information from smaller scale maps (e.g. the FAO-Unesco Soil Map of the World at 1:5 million scale or similar national maps), provided that some additional fieldwork is carried out, where necessary in conjunction with the use of satellite imagery. Hence there will nearly always be a need for additional field checks, sometimes supported by satellite imagery interpretation and extra analytical work to complement the existing soil and terrain information. This should be carried out, however, within the context of complementing, updating or correlating existing surveys. It must be stressed that SOTER specifically excludes the undertaking of new land resource surveys within its programme.

In case there is a requirement to have an area included in the SOTER database on which there is insufficient readily available information, then it is recommended that a survey be carried out according to national soil survey standards, while at the same time ensuring that all additional parameters not already part of the data set being collected, but required by the SOTER database, be recorded as well. This will ease the subsequent conversion from the national data format into the SOTER data format.

SOTER makes use of the 1:1 million Operational Navigation Charts for its base maps and its digital version the Digital Chart of the World (DCW). Although it aims at world-wide coverage, the SOTER approach does not envisage a systematic mapping programme to cover (parts of) the world, and hence does not prescribe a standard block size for incorporation in the database. Nevertheless, SOTER does recommend that at its reference scale of 1:1 million a block should be at least 150,000 km^2 in size, and be bounded by full or half degree coordinates (this would typically cover 12 square degrees at the equator and approximately 18 square degrees at 50° latitude).

2.4 Associated and miscellaneous data

SOTER is a land resource database. For many of its applications SOTER data can only be used in conjunction with data on other land-related characteristics. SOTER does not aspire to be able to provide all these data. Nevertheless, in order to be able to obtain a broad characterisation of tracts of land in terms of these extraneous characteristics, the SOTER database does include files on climate, vegetation and land use. The former file is in the form of point data, that can be linked to SOTER units through GIS software. Vegetation and land use information is, on the other hand, provided at the level of SOTER units. It should be stressed, however, that for specific applications information on these characteristics should be obtained from specialized databases such as a climatic database. This also applies to natural resource data (e.g. groundwater hydrology) and socio-economic data (e.g. farming systems) which do not form part of the SOTER database.

Miscellaneous data refers to background information that is not directly associated with land resources. SOTER stores information on map source material, laboratory methods, and soil databases from which profile information has been extracted.

3 SOTER differentiating criteria

3.1 Introduction

The major differentiating criteria are applied in a step-by-step manner, each step leading to a further fragmentation of the land area under consideration. To a certain extent subdivision is possible within each step, as it will depend on the required resolution to what level of detail the disaggregation at each step should be pursued. The reference scale of SOTER being 1:1 million, this Manual provides the necessary detail to allow mapping at that scale.

3.2 Terrain

Physiography is the first differentiating criterion to be used in the definition of SOTER units. The form of the earth can be best described by denominating and quantifying as far as feasible the major landforms, based on the dominant gradient of their slopes and their relief intensity (see section 6.1). In combination with a hypsometric (absolute elevation above sea-level) grouping, and a factor characterizing the degree of dissection, a broad subdivision of an area can be made and delineated on the map (see fig. 2.1).

Areas corresponding to major or regional landforms can be broken down according to lithology or parent material (see section 6.1). This will lead to a further fragmentation of the physiographic units (illustrated in fig. 2.2). Terrain, in the SOTER context, is thus defined as an area characterized by a particular combination of landform and lithology. It also possesses one or more typical combinations of surface form, mesorelief, parent material aspect and soil. These form the rationale for a further subdivision of terrain into terrain components and soil components.

There is no limit as to the number of subdivisions that can be applied to terrain units and terrain components. It is, however, expected that in most cases a maximum of 3 or 4 terrain components and 3 soil components will be sufficient to adequately describe a terrain unit.

3.3 Terrain components

The second step is the identification of areas, within each terrain unit, with a particular (pattern of) surface form, slope, mesorelief and, in areas covered by unconsolidated material, texture of parent material. This will result in a further partitioning of terrain units into terrain components as is shown in figures 2.3 and 2.4. It should be noted that at this level of separation it is not always possible at a scale of 1:1 million for terrain components to be mapped individually, due to the complexity of their occurrence. In such cases the information related to non-mappable terrain components is stored in the attribute database only, and no entry is made into the geometric database.

3.4 Soil components

The final step in the differentiation of terrain units is the disaggregation of terrain components into soil components. As with terrain components, soil components can be mappable or non-mappable. In the case of mappable soil components, each soil component represents a single soil (see fig. 2.5) within a SOTER unit. However, at a scale of 1:1 million it often will be difficult to separate soils spatially, and a terrain component is likely to be made up of a number of non-mappable soil components. In traditional soil mapping such a cluster is known as a soil association or soil complex (two or more soils which, at the scale of mapping, cannot be separated). Non-mappable terrain components (of which there must be at least two in a terrain unit) are per definition associated with non-mappable soil components. Nevertheless, in the attribute database each non-mappable terrain component can be linked to one or more specific (but non-mappable) soil components. Similar to non-mappable terrain components, non-mappable soil components do not figure in the geometric database.

As following the SOTER methodology soil components are characterized according to the FAO-Unesco Soil Map of the World Legend, the criteria used for separating soil components within each terrain component are based on FAO diagnostic horizons and properties. At the SOTER reference scale of 1:1 million, soils must in general be characterized up to the 3rd (i.e. subunit) level following the guidelines provided for this in the latest draft annex to the revised FAO Soil Legend (FAO, 1988).

For soils classified according to the Soil Taxonomy (USDA, 1975), the FAO sub-unit level corresponds roughly to the subgroup level. As many of the diagnostic horizons and properties as used by Soil Taxonomy are more or less similar to those employed by FAO, there will in general not be many problems at this level of classification in translating Soil Taxonomy units into FAO units. A major difference between the two systems is the use by Soil Taxonomy of soil temperature and soil moisture regimes, particularly at suborder level. Since these characteristics do not feature in the FAO classification, and SOTER, as basically a land resource database, intends to keep climatic data (including those related to soil climate) separated from land and soil data, a more drastic conversion will be required of Soil Taxonomy units which include soil temperature and soil moisture characteristics. Nevertheless, experience has shown that even in these cases conversion from Soil Taxonomy great groups to FAO sub-units will in general not necessitate major adjustments with respect to the boundaries of soil mapping units.

In addition to diagnostic horizons and properties, soil components can also be separated according to other factors, closely linked to soils, that have a potentially restricting influence on land use or may affect land degradation. These criteria, several of which are listed by FAO as phases, can include both soil (sub-surface) and terrain (surface, e.g. micro-relief) factors. Like any other differentiating criteria, their area of occurrence must be at least the minimum mapping size of 0.25 cm^2.

For every soil component at least one, but preferably more, fully described and analyzed reference profiles should be available from the existing soil information source(s). Following judicious selection, one of these reference profiles will be designated as the representative profile for the soil component. The data from this representative profile must be entered into the SOTER database in accordance with the format as indicated in section 6.4 of this Manual. This format is largely based upon the FAO Guidelines for Soil Description (FAO, 1990), which means that profiles described according to FAO or to the Soil Survey Manual (USDA 1951), from which FAO has derived many of its criteria, can be entered with little or no reformatting being necessary. Compatibility between the FAO-ISRIC Soil Database (FAO, 1989) and the relevant parts of the SOTER database will also facilitate transfer of data already stored in databases set up according to FAO-ISRIC standards.

SOTER recommends that the number of horizons per profile be restricted to a maximum of five subjacent horizons, reaching a depth of at least 150 cm where possible. Apart from general information on the profile, including landscape position and drainage, each horizon has to be fully characterised in the database by two sets of attributes based on chemical and physical properties. The first set consists of single value data that belong to the representative profile. The second set, which is expressed in terms of attribute classes, indicates the modal value of all relevant parameters from the available reference profiles. In case there is only one reference profile for a soil component then it will obviously not be possible to calculate modal class values for the second set of data. Both sets consist of mandatory data and optional data. The SOTER database will not accept a profile if any of the mandatory data is missing. Optional data should only be entered if reliable information on them is available. For the representative profile these must be measured data, but for the set with modal class values these may be based on expert estimates.

As with terrain components, the percentage cover of the soil component within the terrain unit is indicated. The relative position and relationship of soil components vis-à-vis each other within a terrain component is recorded in the database as well.

3.5 SOTER Unit and SOTER Map Unit

At the reference scale of 1:1,000,000 a SOTER Unit (SU) is composed of an unique combination and pattern of terrain unit, terrain component and soil component. A SOTER Unit is labelled by a SOTER Unit identification code that allows retrieval from the database of all terrain unit, terrain component and soil component data, either in combination or separately. The inclusion of the three levels of differentiation in the attribute database does not imply that all components of a SOTER Unit can be represented on a map, as the size of individual components, or the intricacy of their occurrence may preclude cartographic presentation. The areas shown on a SOTER map, known as SOTER Map Units, can thus correspond to any of the three levels of differentiation of a SOTER Unit: terrain units, terrain components or soil components. The components not mapped out are known to exist, and their attributes are included in the database, although their exact location cannot be displayed on a 1:1 million map.

In an ideal situation, at least from the point of view of geo-referencing the data, a SOTER Map Unit would be similar to a SOTER unit, i.e. the soil component of the SOTER Unit could be delineated on a map. However, at the SOTER reference scale of 1:1 million it is unlikely that many SOTER units can be distinguished on the map at soil component level. This would only be possible if the landscape is relatively uncomplicated. A more common situation at this scale would be for a SOTER Map Unit to consist of either a terrain unit which covers a number of SOTER Units with non-mappable terrain components linked to an assemblage of non-mappable soil components (a terrain component association) or, alternatively, a SOTER Map Unit that is made up of a number of SOTER Units with mappable terrain components that contain several non-mappable soil components (a similar situation as with a soil association on a traditional soil map).

Thus, while in the attribute database a SOTER Unit will hold information on all levels of differentiation, a SOTER map will display SOTER Map Units whose content varies according to the mappability of the SOTER Unit components. The disadvantage of not being able to accurately locate terrain components and/or soil components is therefore only relevant when data of complex terrain units are being presented in map format. It does not affect the capability of the SOTER database to generate tabular information providing full data on terrain, terrain component and soil component attributes while at the same indicating the spatial relationship between and within these levels of differentiation. Figure 3 illustrates the relationship between SOTER units and SOTER Map Units on a 1:1 million SOTER map.

As for cartographic reasons a polygon can never be smaller than 0.25 cm^2 (see section 5.3), this is also the minimum size of a SOTER unit, or any of its components.

3.6 The SOTER approach at other scales

The methodology as presented in this manual has been developed for applications at a scale of 1:1 million, which is the smallest scale still suitable for land resource stock-taking and monitoring at national level. However, as potentially the most complete universal terrain and soil database, SOTER is also eminently suited to provide the necessary information for the compilation of smaller scale continental and global land resource maps and associated data tables. And as a systematic and highly organized way of mapping and recording terrain and soil data, the SOTER methodology can easily be extended to include reconnaissance level inventories, i.e. at a scale between 1:1 million and 1:100.000.

Flexibility to cater for a wide range of scales is partly achieved through adopting a hierarchical structure for various major attributes, in particular those that are being used as differentiating criteria (landform, geology, surface form etc.). Examples of such hierarchies are also given in this Manual for land use and vegetation (see Part 2). Different levels of these hierarchies can be related to particular scales. A hierarchy for the soil component can be derived from the FAO-Unesco Soil Map of the World Legend, with the level of soil groupings being related to extremely small scale maps, as exemplified by the FAO World Soil Resources report (FAO, 1991) at 1:25 million. Soil units (2nd level) can be used for 1:5 million world soil inventory maps, while the soil subunits are most suitable for 1:1 million mapping. The density per unit area of point observations will vary according to the scale employed, with larger scales requiring a more compact ground network of representative profiles, as soils are being characterised in more detail.

Adjustments in the content of the attribute data set are also necessary if SOTER maps at other scales than 1:1 million are being compiled. With an increase in resolution the highest level of the constituent parts of a SOTER Map Unit (the terrain unit) will gradually lose its importance, and may disappear altogether at a scale of 1:100,000. This is because in absolute terms the area being mapped is becoming smaller, and terrain units may not anymore be able to offer sufficient differentiating power. Conversely, the lower part of the SOTER unit will gain in importance with more detailed mapping. At larger scales SOTER units will thus become delineations of soil entities, with the information on terrain becoming incorporated in the soil attributes. Hence scale increases require more detailed information on soils for a number of applications. Additional attributes to be included could be soil micronutrient content, composition of organic fraction, detailed slope information etc. A simplification of the database can be applied at scales substantially smaller than the reference scale of 1:1 million. So will all but the most elementary soil physical and chemical data become meaningless if the scale is smaller than 1:10 million. It is thus necessary to realize that the SOTER database discussed in this Manual is meant for a scale of 1:1 million only, and that expansion or contraction of the data set will be necessary when changing the resolution of the SOTER database.

4 SOTER database structure

4.1 Introduction

In every discipline engaged in mapping of spatial phenomena, two types of data can be distinguished:

1) geometric data, i.e. the location and extent of an object represented by a point, line or surface, and topology (shapes, neighbours and hierarchy of delineations),
2) attribute data, i.e. characteristics of the object.

These two types of data are also present in the SOTER database. Soils and terrain information consist of a geometric component, which indicates the location and topology of SOTER Map Units, and of an attribute part that describes the non-spatial SOTER Unit characteristics. The geometry is stored in that part of the database that is handled by Geographic Information System (GIS) software, while the attribute data is stored in separate attribute files, manipulated by a Database Management System (DBMS). A unique label attached to both the geometric and attribute database connects these two types of information for each SOTER unit (see fig. 4, in which part of a map has been visualized in a block diagram).

The overall system (GIS plus DBMS) stores and handles both the geometric and attribute database. This manual limits itself to the attribute part of the database only, in particular through elaborating on its structure and by providing the definitions of the attributes (chapter 6). A separate manual for the geometric part of the database will in due course be published.

A relational database is one of the most effective and flexible tools for storing and managing non-spatial attributes in the SOTER database (Pulles, 1988). Under such a system the data is stored in tables, whose records are related to each other through the values of certain key fields (primary keys), such as the SOTER Unit identification code. These codes form the first field in each subsection of the database, e.g. in the terrain database, the terrain component and the soil component databases. Another characteristic of the relational database is that when two or more (terrain or soil) components are similar, their attribute data need only to be entered once. Fig. 5 gives a schematic representation of the structure of the attribute database. The blocks shown in it represent tables in the SOTER database, while the solid lines between the blocks stand for the identification codes that link the data records together.

4.2 Geometric database

The geometric database contains information on the delineations of the SOTER units, as far as they are mappable. It also holds the base map data (cultural features such as roads and towns, the hydrological network and administrative boundaries). In order to enhance the usefulness of the database, it will be possible to include additional overlays for boundaries outside the SOTER unit mosaic. Examples of such overlays could be socio-economic areas (population densities), hydrological units (watersheds) or other natural resource patterns (vegetation, agro-ecological zones).

4.3 Attribute database

Non-spatial attributes are stored in the attribute database. Depending on their importance and availability, two types of attributes can be distinguished: 1) mandatory attributes, and 2) optional attributes.

Each of these can be divided into descriptive (e.g. landform) and numerical (e.g. pH, slope gradient) data.

It is imperative that, in order not to compromise the integrity of the SOTER database, a complete list of mandatory attributes is entered for each soil component. Optional attributes are accepted by the database as and when available. The attribute lists provided in this manual show all the mandatory and optional terrain and soil parameters that are required.

Under the SOTER system of labelling (see section 5.2 for a detailed description of the labelling conventions) all SOTER Units are given an unique identification code, consisting of minimal 4 and maximal 6 digits. This identification code can be broken down into subcodes for terrain units, terrain components and soil components. All similar terrain units that are part of different SOTER Units have an identical subcode. This is not the case with terrain component and soil component subcodes, which are extensions of their respective terrain unit subcode and are therefore, although unique for each SOTER Unit, not identical for similar terrain and soil components occurring in different SOTER Units.

In order to minimize data storage requirements, the attribute data for similar terrain and soil components are only entered once. A data code is then used to link the members of each group of similar terrain and soil components. However, terrain and soil components do, even if they have identical attributes, vary with respect to their percentage occurrence and links with terrain unit and other component. Since this information is needed for every terrain and soil component, two tables are required to store all the data:

1) a *SOTER Unit terrain component subcode table* which indicates the terrain unit to which the terrain component belongs and the proportion that it occupies within that terrain unit, and also refers to the terrain component data set that contains the data of the terrain component, and

2) a *terrain component data set* storing the specific attribute values.

In the first table there is thus an entry for each individual terrain component, while in the second table only entries are made for terrain components with a different content.

Soil components are a part of a terrain component, but cannot be directly linked to the terrain component data file, as can be seen from figure 5. The attributes of a soil component are organized in three tables:

1) the *SOTER Unit soil component subcode table* which holds information to link the soil to the terrain component and to the profile table, as well as indicating the proportion it occupies within the SOTER Unit,

2) the *profile table* carries information on the profile and its horizons, while

3) the *horizon table* contains two sets of attribute values for each horizon, the first set being made up of single value data taken from the representative profile, and the second set being composed of modal values, expressed in discrete classes, and derived from all the reference profiles that are associated with the soil component to which the profile belongs.

The horizon tables must be completed with all mandatory data. In case there is no data for some of the quantifiable attributes, SOTER will allow expert estimates to be used as modal class values (second data set), but not for the representative profile attributes (first data set), which can only accept actual measurements. SOTER strongly recommends that in conjunction with the SOTER database a national soil profile database be established along the lines of the FAO-ISRIC Soil Database (FAO, 1989), in which, amongst others, all representative profiles would be accommodated.

Table 1 Non-spatial attributes of a SOTER unit

TERRAIN UNIT		
1 terrain unit subcode	6 relief intensity	11 dissection
2 date of data collection	7 major landform	12 general lithology
3 minimum elevation	8 second level major landform	13 permanent water surface
4 maximum elevation	9 regional slope	
5 slope gradient	10 hypsometry	
TERRAIN COMPONENT		
14 terrain component subcode	21 meso-relief, local surface form	28 depth of groundwater
15 terrain component mappability	22 meso-relief, average height	29 frequency of flooding
16 proportion of terrain unit	23 meso-relief, coverage	30 duration of flooding
17 terrain component data code	24 lithology	31 start of flooding
18 dominant slope gradient (%)	25 texture uncons. parent mat.	32 depth of flooding
19 estim. dominant length of slope	26 depth of bedrock	
20 form of the dominant slope	27 surface drainage	
SOIL COMPONENT		
33 soil component subcode	45 sensitivity to capping, cons.	57 classification
34 soil component mappability	46 surface cracks, depth	58 national profile code
35 proportion of terrain unit	47 surface cracks, width	59 national classification
36 soil component data code	48 surface cracks, distance	60 Soil Taxonomy
37 surface rockiness, percent.	49 rootable depth	61 phase
38 surface rockiness, distance	50 slope gradient	62 number of ref. profiles
39 surface stoniness, percentage	51 topographic position	63 latitude
40 surface stoniness, size class	52 rel. to other soil comp.	64 longitude
41 erosion, type	53 drainage	65 elevation repr. profile
42 erosion, area affected	54 permeability/hydr. conductivity	66 sampling date
43 erosion, degree	55 infiltration rate	67 laboratory ID code
44 sensitivity to capping, thickness	56 surface organic matter	
Horizon (* mandatory attributes)		
68 soil component subcode *	95 mineral fragments, abundance	129 exchangeable K^+
69 horizon number *	96 mineral fragments, nature *	130 exchangeable Al^{+++}
70 diagnost. horizon * & property *	97 mineral fragments, size	131 exchangeable acidity
71 horizon designation *	98 mineral fragments, hardness	132 CEC soil (pH7 in NH_4Ac) *
72 boundary, depth *	99-101 roots, abundance	133 soluble CO_3^{--}
73 boundary, distinctness *	102-104 roots, size	134 soluble HCO_3^-
74 boundary, topography	105 % very coarse sand	135 soluble Cl^-
75 colour, moist *	106 % coarse sand	136 soluble SO_4^{--}
76 colour, dry	107 % medium sand	137 total free carbonates
77 mottles, abundance *	108 % fine sand	138 total active carbonates
78 mottles, size	109 % very fine sand	139 total gypsum
79 mottles, contrast	110 % total sand *	140 total C (topsoil only *)
80 mottles, colour *	111 % silt *	141 total N
81 texture	112 % clay *	142 P_2O_5
82 structure grade	113 particle size class	143 P retention
83 structure size	114 % coarse fragments *	144 dithionite extractable Fe
84 structure type *	115 bulk density	145 pyrophosphate extractable Fe
85 consistence, dry	116-120 moisture contents	146 ditionite extractable Al
86 consistence, moist *	121 hydraulic conductivity	147 pyrophosphate extractable Al
87 stickiness	122 infiltration rate	148 clay mineralogy
88 plasticity	123 pH (H_2O) *	
89 cutanic features, nature	124 pH (KCl)	
90 cutanic features, abundance	125 EC_e soil (only if salt present *)	
91 cutanic features, contrast	126 exchangeable Ca^{++}	
93 cementation, nature *	127 exchangeable Mg^{++}	
94 cementation, degree	128 exchangeable Na^+	

All mandatory and optional soil component attributes are listed in table 1. This list is compatible, although smaller, with the data set that is stored in the FAO-ISRIC Soil Database.

Representative soil profiles constitute a network of point data. As such their attribute data is suited for statistical manipulation, but cannot be extrapolated to the soil component of the SOTER unit. On the other hand the modal class values of the attributes can, provided the sample size is reasonably large (this will depend on the area size and heterogeneity of the soil component), be taken as representing the whole area of the soil component.

The database will automatically calculate a number of derived parameters from the values entered for the mandatory and optional attributes. These include, amongst others, CEC per 100 g clay, base saturation and textural class. Some of the optional attributes could become temporarily mandatory, if they are required for certain applications.

5 Additional SOTER conventions

5.1 Introduction

The various conventions described in this chapter form an addition to those characterized in section 2. They concern mainly rules governing the minimum size of a SOTER unit, both in absolute and relative terms, as well as criteria determining the selection of representative profiles, relations with associated databases, type of data, missing data and the like.

SOTER database management procedures, such as date stamps and backup procedures, are not treated in this manual, but are to be described in a separate manual.

5.2 SOTER unit codes

Each SU is assigned an identifying code that is unique for the database in question. Tentatively, the SOTER coding will consist of a simple numbering system that begins with a terrain unit subcode. This code will normally range from 1 to 99, or 999 for large maps, although the SOTER database can handle numbers up to 9999. The terrain components within each terrain unit are given single digit extension numbers ranked according to the size of the component. A similar extension number is used to code the soil components. These extension numbers are separated from each other and the terrain unit subcode by a full stop. A SOTER identification code thus consists of a number that can range from 1.1.1 to 9999.9.9. Numbering is not strictly sequential, as the total number of terrain components per terrain unit and soil components per terrain component is limited (see 5.4), and identification codes like 1.1.7 or 25.5.3 are unlikely to occur.

When individual databases are merged into regional and global databases, then the SOTER identification codes will be preceded by the code for the ONC mapsheet that covers most of the mapped area, to which is attached a single digit number that allows more than one area to fall within the same ONC sheet. For instance, the LASOTER map SOTER units are globally identified by the code R241 (R24 being the ONC map, and 1 standing for the first map that falls largely within R24) followed by a numbering that ranges from 1 to 2083, as has been used in the LASOTER database. When adjoining sheets are entered into a database, then cross-boundary SOTER units will have different codes on each sheet. If a GIS is used the SOTER units on one sheet can automatically be given the code of their counterpart on the other sheet (assuming that proper correlation has been carried out), otherwise this has to be done manually.

Since the database can only handle numerical codes, the capital in the ONC map code has to be converted into an integer. Tentatively it is proposed to do this through the following two steps. The east-west running bands of ONC sheets indicated by a letter are, starting from the equator, given a sequential number to replace the letter. The J band which straddles the equator becomes band 1 of the northern hemisphere, while the K band below the J band becomes band 1 of the southern hemisphere. The most southern band (the U band) will be band 0. To prevent confusion between the northern and southern bands, which both run from 1 to 9, a figure of 50 will be added to the northern ONC sheet number. Thus F11 (northern hemisphere) will become 461, and N20 (southern hemisphere) will be converted into 420. An example of a globally unique SOTER Unit identification code would be 7241.0088*.2.3. This is soil component 3 of terrain component 2 within terrain unit 88 (the latter also being the SOTER Map Unit), which can be found on the first SOTER map that falls largely within ONC sheet R24.

At national level this coding convention is only applicable to 1:1 million maps. For larger scale maps and databases there is no need to follow a unified system.

5.3 Minimum size of the SOTER unit

As a general rule of thumb the minimum size of a single SOTER unit is 0.25 cm^2 on the map which, at a scale of 1:1 million, equals 25 km^2 in the field. This is the smallest area that can still be cartographically represented. Mostly such tiny units will correspond to narrow elongated features (floodplains, ridges, valleys) or strongly contrasting terrain and soil features. In general, SOTER units will be much larger.

If there are gradual changes in landscape features, new SOTER units can be delineated when any one terrain component of a SOTER unit changes in area by more than 50%.

5.4 Number of soil and terrain components

Within a SOTER unit terrain components and soil components can occupy any percentage of the terrain and terrain component respectively, provided the total area of each component is not less than what is indicated under section 5.3. In theory this would allow for an unlimited number of terrain components within each terrain unit, or soil components within each terrain component. In practice this is unlikely to occur, as many terrain components and soil components cover sizeable areas. SOTER recommends that a minimum of 15% is taken into account when defining terrain and soil components, unless the SOTER unit in question is very large, or it involves strongly contrasting terrain or soil components, when the percentage coverage can be less.

Most commonly it is expected that a terrain unit would be broken down into up to 3 or 4 terrain components, each with not more than 3 soil components, resulting in a maximum of 12 SOTER units, provided all soil and terrain units are mappable. In practice there would be less, as most soil components at the scale of 1:1 million are non-mappable. Obviously, the sum of soil components within each terrain component, and terrain components within each terrain unit, will always be 100 %.

It is advisable that map compilers exercise restraint in subdividing a terrain unit into terrain and soil components. Only those criteria for breaking up a landscape should be selected that can be considered important in subsequent interpretations. Significant changes in attributes such as parent material, surface form and slope gradient, which at the same time should cover substantial areas, qualify as criteria for defining new SOTER units. Terrain components should be split into soil components only if there are clear changes in diagnostic criteria which will reflect in land use or land degradation aspects. Minor changes in any of these criteria should be considered as part of the natural variability that at a scale of 1:1 million can be expected to occur within each SOTER unit. Discretion in defining terrain and soil components in order not to generate more components than is absolutely necessary will save much time in coding, entering and processing of data.

5.5 Representative soil profiles

The representative profile used to typify a specific soil component is chosen from amongst a number of reference profiles with similar characteristics. Where possible SOTER will rely on the selection of reference profiles as made by the original surveyors. It is envisaged that all reference profiles taken into consideration be stored in a national soil profile database, preferably based on the FAO-ISRIC Soil Database format. The SOTER database includes a key to national databases.

The SOTER database also includes a code that shows how many reference profiles were consulted for the selection of the representative profile, and were used to determine the modal values for the attribute classes as well.

5.6 Updating procedures

SOTER units and their attributes are unique in both space and time, and although soil and in particular terrain characteristics are thought to have a high degree of temporal stability, it might become necessary to update certain attributes from time to time. At present, there is no procedure for updates of the geographic data, such as the boundaries of the SOTER units. However, replacing (parts of) map sheets by more recent maps will involve changes in attribute data as well, for which the guidelines below can be used.

Updating the attribute database could become necessary because of *missing data, incorrect data* or *obsolete data* in the database. If there are some data gaps, the voids can be filled when additional data becomes available. Incorrect data, which include data that is being replaced by (a set of) more reliable data (e.g. a representative profile is being substituted by another, more representative profile) can be replaced by new data, although a note has to be made of this in the database. In contrast, obsolete data is not simply replaced by more up-to-date information. Instead, old data is downloaded into a special database containing obsolete data, after which the latest data is entered into the regular database. In this way the database with obsolete data can be used for the monitoring of changes over time. When certain parameters are measured at regular intervals, then periodic updating will become necessary.

The SOTER Unit Identification code does indicate to which level of differentiation the SOTER Unit can be mapped, while the map code for each SOTER Map Unit (SMU) is identical to the SOTER Unit subcode of the lowest level component that is still mappable. There is thus a direct and unique link between the data in the database and the polygons on the map. The database is capable of generating a number of relational data that are pertinent to each SOTER Unit, and between the SOTER Units (e.g. percentage of each soil component within terrain component or SOTER Map Unit, total area of all terrain components with identical terrain component data code, etc.).

6 Attribute coding

Note that the names of the attributes given in table 1 or in the following paragraphs need not to be similar to the identifier or codes used in the SOTER database. The numbers preceding the attributes in table 1 are identical to the numbers of the attributes in this chapter, and the numbers on the SOTER data input sheet.

The SOTER Unit identification code is composed of three elements, separated by full stops. The first element represents the terrain unit subcode, while element one and two together constitute the terrain component subcode. All three elements combined form the subcode for the soil component which, with a slight difference, is also the SOTER Unit identification code. Eventually, these identification codes will be the unique identifier for SOTER Units on a world-wide scale (see also section 5.2).

However, for compilers of SOTER data on a national or regional scale it is sufficient to attach locally unique identification codes to each SOTER unit, taking into account the coding conventions explained in section 5.2. These identification codes will be converted into a global unique identifiers before entry into a continental or world-wide SOTER database.

6.1 Terrain unit

1 *SOTER Unit identification code, terrain unit subcode*

For each SOTER map, a unique 4 digit code is assigned to every terrain unit that has been distinguished (on most SOTER maps 2 or 3 digits will suffice). The terrain unit subcode will be identical for all SOTER units that have been separated within a certain terrain unit. Where an association of SOTER Units have been mapped at the terrain unit level, the SOTER Map Unit code is identical to the terrain unit subcode.

2 *Date of data collection*

The year in which the original terrain data were collected will serve as the time stamp for each SOTER unit. In case the SOTER unit has been composed on the basis of several sources of information, it is advisable to use the major source for dating the SOTER unit. In this manner a link between the SOTER unit and the major source of information, which should be listed under the references, can easily be made. The year of compiling the data according to the SOTER procedures is thus not recorded, unless the compilation itself has resulted in some major reinterpretation based on additional sources of information, like fresh satellite imagery. In general the year of compilation can be deducted from the year in which the data was entered into the database, as both years are likely to be the same or very close to each other. It is assumed that the year in which the terrain date were collected also applies to the terrain component data, and no separate date entry is required for this.

3 *Minimum elevation*

Absolute minimum elevation of the SOTER unit, in metres above sealevel. Both the minimum and maximum elevation can be easily read from a contoured topographic map.

4 *Maximum elevation*

Absolute maximum elevation of the SOTER unit, in metres above sealevel.

5 *Slope gradient*

The dominant slope angle, expressed in percentage, prevailing in the terrain unit.

6 *Relief intensity*

The relief intensity is the median difference between the highest and lowest point within the terrain per specified distance. This specified distance can be variable, but is expressed in m/km in the database.

7 *Major landform*

Landforms are described foremost by their morphology and not by their genetic origin, or processes responsible for their shape. The dominant slope is the most important differentiating criterion, followed by the relief intensity. At the highest level of landform separation, suitable for scales equal to or smaller than 1:10 million, four groups are being distinguished (adapted from Remmelzwaal, 1991):

L	Level lands	Lands with characteristic slopes of 0-8 %, and a relief intensity of less than 100 m per km.
S	Sloping lands	Lands with characteristic slopes of 8-30 % and a relief intensity of more than 50 m per slope unit. Areas with a limited relief intensity (< 50 m per slope unit) but slopes in excess of 8% are included, as are isolated mountains (relief intensity > 600 m) with slopes of 8-30 %.
T	Steep lands	Lands with characteristic slopes of over 30 % and a relief intensity of mostly more than 600 m per 2 km.
C	Lands with composite landforms	Lands made up of steep elements together with sloping or level lands, or sloping lands with level lands, in which at least 20 % of the area consists of land with the lesser slope.

Figure 6 illustrates the relationship between dominant slope and relief intensity, and delineates the various major landforms.

8 *second level major landform*

An initial breakdown of major landforms is possible according to table 2.

Table 2 Second level major landforms

1st level major landform	2nd level major landform	gradient	relief intensity
level land	plain	0-8%	< 100 m/km
	plateau	0-8%	< 100 m/km
	depression	0-8%	< 100 m/km
sloping land	eroded plain	> 8%	< 50 m/s.u.
	hills	8-30%	> 50 m/s.u.
	major ridge	8-30%	> 600 m
	isolated mountain	8-30%	
steep land	badlands	> 30%	< 600 m/2 km
	mountains	> 30%	> 600 m/2 km
	major escarpment	> 30%	> 600 m/2 km
	minor escarpment	> 30%	< 600 m/2 km
lands with composite landforms	major valley	> 8%	> 50 m/s.u.
	major depression	> 8%	> 50 m/s.u.

s.u. = slope unit. Where not clear from the gradient or relief intensity, the distinction between the various 2nd level major landforms follows from the description

9-11 *REGIONAL LANDFORMS*

Regional landforms can be distinguished at the 1:1 million scale. Within the framework of the major landforms, they are being separated according to three criteria. These are:

1. regional slope 2. hypsometry 3. dissection

The differentiating power of these criteria is highest with respect to level lands, although they can be used for sloping lands with a relief intensity of less than 600 m as well. For steep lands with a high relief intensity they have little utility, with the exception of the hypsometric level.

9 *Regional slope*

At the 1:1 million scale a refining of slope classes compared to those used for major landforms is possible. The dominant slopes can be broken down into the following classes:

A. Simple landforms

1	0- 2 % flat, wet*	**5**	8-15 %	rolling
2	0- 2 % flat	**6**	15-30 %	mod. steep
3	2- 5 % gently undulating	**7**	30-60 %	steep
4	5- 8 % undulating	**8**	> 60 %	very steep

B. Complex landforms**

11 Cuestaformed
12 Dome-shaped
13 Ridged
14 Terraced
15 Inselberg covered (occupying at least 5% of level land)
16 Dune-shaped
17 With intermontane plains (occupying at least 15%)

* wet is defined as < 90% permanent water surface > 50% (see also item 13)

** in the case of complex landforms, the protruding landform should be at least 25 m high (if not it is to be considered mesorelief) except for terraced land, where the main terraces should have elevation differences of at least 10 m.

These subdivisions are mainly applicable to level landforms, and to some extent to sloping landforms. They are not to be used for steep lands, except in the case of mountains with intermontane plains, but may be used for lands with complex landforms, where the subdivision can be related to the constituent landform with the lesser slope.

10 *Hypsometry*

The hypsometric level is, for level and slightly sloping land (relief intensity of less than 50 m) an indication of the height above sealevel of the local base level. For lands with a relief intensity of more than 50 m the hypsometric is used to indicate the height above the local base (i.e. local relief).

A Level lands and sloping lands (relief intensity < 50 m/SOTER unit)

1	< 300 m	very low level (plain etc.)
2	300- 600 m	low level
3	600-1500 m	medium level
4	1500-3000 m	high level
5	> 3000 m	very high level

B Sloping lands (relief intensity > 50 m/SOTER unit)

6	< 200 m	low (hills etc.)
7	200-400 m	medium
8	> 400 m	high

C Steep and sloping lands (relief intensity > 600 m/2 km)

9	600-1500 m	low (mountains etc.)
10	1500-3000 m	medium
11	3000-5000 m	high
12	> 5000 m	very high

11 *Dissection*

The degree of dissection is difficult to quantify in a practical manner. Factors like coverage, slope and depth of dissected features all contribute to the intensity of landscape dissection. SOTER uses the *drainage density* as a qualitative measure of the degree of dissection. The higher the drainage density, the more dissected a tract of land will be, and in general also the steeper the slopes of the dissected parts will be. The depth of dissection can be assumed to increase with an increased density of the drainage network and steeper landscape slopes. Conversely, a high drainage density on very flat land (dominant slopes < 2%) is not necessarily related to the dissection of the terrain, but could be an indication of the wetness of the land.

The most accurate way to measure the drainage density (defined as the average length of drainage channels per unit area of land, expressed as $km \times km^{-2}$) is to actually measure the length of all well-defined, permanent and seasonal, streams and rivers within a representative block. This should be done on good quality 1:50,000 or larger maps. Techniques exist to speed up this measurement through intersection point counting (Verhasselt, 1961). In practice the necessary material to carry out this measurement is often not available, and only quantitative estimates can be made. This should be done with aid of the most detailed material available (maps, aerial photos or satellite images). Only three classes are being distinguished:

1	< 10	slightly dissected
2	10-25	dissected
3	> 25	strongly dissected

Figure 7 provides an illustration, at a scale of 1:50,000, of these three classes. The degree of dissection is not applicable to land with a relief intensity of more than 600 m.

12 *General lithology*

For each SOTER unit a generalized description of the consolidated or unconsolidated surficial material, underlying the larger part of the terrain, is given. Major differentiating criteria are genesis and mineralogical composition. For a detailed description of the hierarchy of terms, as shown in table 3 (Holmes, 1968), reference should be made to Appendix 1. At the 1:1 million scale the lithology should at least be specified down to group level.

Table 3 Hierarchy of lithology.

major class		group		type	
I	igneous rock	**IA**	acid igneous	**IA1**	granite
				IA2	grano-diorite
				IA3	quartz-diorite
				IA4	rhyolite
..		**II**	intermediate igneous	**II1**	andesite, trachyte, phonolite
				II2	diorite-syenite
..		**IB**	basic igneous	**IB1**	gabbro
				IB2	basalt
				IB3	dolerite
..		**IU**	ultrabasic igneous	**IU1**	peridotite
				IU2	pyroxenite
				IU3	ilmenite, magnetite, ironstone, serpentine
M	metamorphic rock	**MA**	acid metamorphic	**MA1**	quartzite
				MA2	gneiss, migmatite
..		**MB**	basic metamorphic	**MB1**	slate, phyllite (pelitic rocks)
				MB2	schist
				MB3	gneiss rich in ferro-magnesian minerals
				MB4	metamorphic limestone (marble)
S	sedimentary rock	**SC**	clastic sediments	**SC1**	conglomerate, breccia
				SC2	sandstone, greywacke, arkose
				SC3	siltstone, mudstone, claystone
				SC4	shale
..		**SO**	organic	**SO1**	limestone, other carbonate rocks
				SO2	marl and other mixtures
				SO3	coals, bitumen & related rocks
..		**SE**	evaporites	**SE1**	anhydrite, gypsum
				SE2	halite
U	unconsolidated	**UF**	fluvial		
		UL	lacustrine		
		UM	marine		
		UC	colluvial		
		UE	eolian		
		UG	glacial		
		UP	pyroclastic		
		UO	organic		

13 *Permanent water surface*

Indicate the percentage of the SOTER unit that is largely (i.e. > 90%, thus excluding small islands etc.) permanently (i.e. more than 10 month/year) covered by water. Bodies of water large enough to be delineated on the map are not considered part of a SOTER Unit.

6.2 Terrain component

14 *SOTER Unit identification code, terrain component subcode*

The terrain component subcode is made up of the terrain unit subcode (four digits) to which is added a single digit extension number according to the ranking of the terrain component within the terrain unit (the largest terrain component is given extension number 1, the second largest extension number 2, etc.). Where an association of SOTER Units has been mapped at terrain component level, the SOTER Map Unit code is identical to the terrain component subcode.

15 *Terrain component mappability*

Enter one of the following two options:

Y terrain component is mappable
N terrain component is not mappable.

16 *Proportion of terrain unit*

The proportion that the terrain component occupies within the terrain unit. As stated in section 5.4, a terrain component normally covers not less than 15% of a terrain unit. The sum of all terrain components should be 100% for each terrain unit.

17 *Terrain component data code*

If two (or more) terrain components are completely similar, then their data will only be entered once in the database. The data code (which has the same format as a terrain component sub-code) of the first terrain component with a particular attribute content will also be used for subsequent identical terrain components. In case a terrain component has not been described before in the database, then its sub-code will also be used as its data code (four plus one digits). Some examples are given in table 4.

Table 4 Examples of SOTER Unit composition, and relation to data codes and SOTER Map Units

example A

two mappable terrain components, not earlier described in the attribute database, and two non-mappable soil components, of which the 2nd one has already been described before.

SU_id = 134.1*.3		SU_id = 134.2*.2	
SOTER Map Unit code	= 134.1	SOTER Map Unit code	= 134.2 1/
terrain unit subcode	= 134	terrain unit subcode	= 134
terrain comp. subcode	= 134.1	terrain comp. subcode	= 134.2
proportion within TU	= 70%	proportion within TU	= 30%
terrain comp. data_id	= 134.1	terrain comp. data_id	= 134.2
soil comp. subcode	= 134.1.3	soil comp. subcode	= 134.2.2
soil comp. data_id	= 134.1.3	soil comp. data_id	= 134.1.3
prop. of SC within TC*	= 25%	prop. of SC within TC*	= 35%
prop. of SC within TU	= 17.5%	prop. of SC within TU	= 10.5%

example B

two terrain components, not mappable, of which the latter has been described earlier, and two non-mappable soil components, of which the first has already been described in the database

SU_id = 289*.1.4		SU-id = 289*.2.1	
SOTER Map Unit code	= 289	SOTER Map Unit code	= 289
terrain unit subcode	= 289	terrain unit subcode	= 289
terrain comp. subcode	= 289.1	terrain comp. subcode	= 289.2
prop. of TC within TU*	= 55%	prop. of TC within TU*	= 45%
terrain comp. data_id	= 289.1	terrain comp. data_id	= 134.1
soil comp. subcode	= 289.1.4	soil comp. subcode	= 289.2.1
soil comp. data_id	= 134.1.3	soil comp. data_id	= 289.2.1
prop. of SC within TC	= 15%	prop. of SC within TC	= 40%
prop. of SC within TU*	= 8.3%	prop. of TC within TU*	= 18%

* SOTER Map Unit

18-20 *SLOPE CHARACTERISTICS*

The following three slope characteristics are recorded for each terrain component:

18 *dominant slope gradient (%)*

19 *estimated dominant length of slope (m)*

20 *form of the dominant slope*

this is only entered if the dominant slope gradient > 2%

U uniform
C concave
V convex

21-23 *MESO-RELIEF*

21 *Local surface form*

A number of characteristic meso-relief or local surface forms can be recognised at the 1:1 million scale (Day, 1983; FAO, 1977; Soil Survey Staff, 1951), in addition to the slope form, as listed below (this list is not exhaustive).

H hummocky	very complex pattern of slopes extending from somewhat rounded depressions or kettles of various sizes to irregular conical knolls or knobs. There is a general lack of concordance between knolls or depressions. Slopes are generally between 4 % and 70 %.
M mounded	coverage (at least 5 %) by isolated mounds at least 2.50 m high
K towered	coverage (at least 5 %) by isolated steep sided karst towers at least 2.50 m high
R ridged	coverage (at least 5 %) by parallel, sub-parallel or intersecting usually sharpcresed ridges (elongated narrow elevations) not less than 2.50 m high
T terraced	level areas (less than 2 % slope) bounded on one side by an at least 2.50 m high scarp with another flat surface above it
G gullied	coverage (at least 5 %) by steep-sided gullies not less than 2.50 m deep
S strongly dissected	areas with a drainage density of more than 25 km km^{-2}, the depth of the drainage lines being at least 2.50 m
D dissected	areas with a drainage density of more than 10 km km^{-2}, the depth of the drainage lines being at least 2.50 m

For each terrain component only the dominant meso-relief form is entered. The following two quantifiers are given for each meso-relief element:

22 *average height*

give the average height (or depth where applicable) in metres, depth being indicated by a minus sign

23 *coverage*

indicate the estimated percentage coverage of the meso-relief elements within the terrain component

24 *Lithology*

Generalized description of the consolidated or unconsolidated surficial materials which underlie most of the terrain component. These include the types of rockmass from which parent material is derived, and other unconsolidated mineral or organic deposits. The same breakdown of parent materials is used as was given for the terrain unit lithology (see table 3 and appendix 1). It the type level of parent material has already been indicated at terrain level, then no further entry has to be made here.

25 *Texture of non-consolidated parent material*

The texture group of particles <2 mm of the non-consolidated parent material, or the parent material at 2 m if the soil is deeply developed, is given. Figure ... shows the different groups in a texture triangle.

Y	very clayey	more than 60 % clay
C	clayey	sandy clay, silty clay and clay texture classes
L	loamy	loam, sandy clay loam, clay loam, silt, silt loam and silty clay loam texture classes
S	sandy	loamy sand and sandy loam texture classes
X	extremely sandy	sand texture classes

26 *Depth to bedrock*

The average depth to consolidated bedrock in metres. For depths more than 10 m the depth can be given to the nearest 5 metres.

27 *Surface drainage*

Surface drainage of the terrain component

E	extremely slow	water ponds at the surface, and large parts of the terrain are waterlogged for continuous periods of more than 30 days
S	slow	water drains slowly, but most of the terrain does not remain waterlogged for more than 30 days continuously
W	well	water drains well but not excessively, the terrain does nowhere remain waterlogged for a continuous period of more than 48 hours
R	rapid	excess water drains rapidly, even during periods of prolonged rainfall
V	very rapid	excess water drains very rapid, the terrain does not support growth of short rooted plants even if there is sufficient rainfall

28 *Depth of groundwater*

The depth in metres of the mean groundwater level over a number of years as experienced in the terrain component .

29-32 *FLOODING*

Flooding is characterised by the following 4 parameters (see also section 1.7.4 of the Guidelines for Soil Description (FAO, 1990):

29 *frequency*		30 *duration*	
N	none	1	less than 1 day
D	daily	2	1- 15 days
W	weekly	3	15- 30 days
M	monthly	4	30- 90 days
A	annually	5	90-180 days
B	biennially	6	180-360 days
F	once every 2-5 years	7	continuous
T	once every 5-10 years		
R	rare (less than once in every 10 years)		
U	unknown		

31 *start of flooding*

Give the month (indicated by a figure) during which flooding of the terrain component normally starts.

32 *depth*

1	very shallow	0- 25 cm
2	shallow	25- 50 cm
3	moderately deep	50-100 cm
4	deep	100-150 cm
5	very deep	> 150 cm

6.3 Soil component

This section includes all the surface attributes of the soil component (items 37 to 56), as well as general attributes linked to the representative soil profile (items 57 to 67). Horizon attributes are dealt with in the next section (6.4).

33 *SOTER Unit identification code, soil component subcode*

The SOTER Unit identification code is made up of the terrain component subcode (5 digits) to which is added a single digit extension number according to the ranking of the soil component within the terrain component (the largest soil component is given number 1, the second largest number 2, etc.). Soil components being the lowest level differentiating unit of SOTER Units, the soil component subcode is identical to the SOTER Unit code, except that it does not indicate to what level of differentiation the SOTER Unit can be mapped. Where a soil component is large enough to be mapped, the soil component subcode is similar to the SOTER Map Unit code.

34 *Soil component mappability*

Enter one of the following two options:

Y soil component is mappable
N soil component is not mappable.

35 *Proportion of terrain unit*

The proportion that the soil component occupies within the terrain unit. As stated in section 5.4, a soil component normally occupies not less than 15% of a terrain unit. sum of all soil components should be 100% for each terrain unit.

36 *Soil component data code*

If two (or more) soil components are completely similar, then their data will only be entered once in the database. The soil component data code (which has the same format as a soil component subcode) of the first soil component with a particular attribute content will also be used for subsequent identical soil components. In case a soil component has not been described before in the database, then its sub-code will also become its data code.

37-38 *ROCKINESS OF THE SOIL COMPONENT*

Outcrops of rocks, characterised by percentage surface cover and average distance (see also section 1.6.1 of the Guidelines for Soil Description (FAO, 1990).

37 *percentage surface cover*

N	none	0 %
V	very few	0- 2 %
F	few	2- 5 %
C	common	5-15 %
M	many	15-40 %
A	abundant	40-80 %
D	dominant	> 80 %

38 *average distance*

1	> 50 m
2	20-50 m
3	5-20 m
4	2- 5 m
5	< 2 m

39-40 *STONINESS OF THE SOIL COMPONENT*

Coarse fragments (> 0.2 cm), wholly or partly at the surface, is described in terms of surface coverage and size of the greatest dimensions (see also section 1.6.2 of the Guidelines for Soil Description (FAO, 1990).

39 *percentage surface cover*

N	none	0 %
V	very few	0- 2 %
F	few	2- 5 %
C	common	5-15 %
M	many	15-40 %
A	abundant	40-80 %
D	dominant	> 80 %

40 *size class (cm)*

F	fine gravel	0.2- 0.6
M	medium gravel	0.6- 2.0
C	coarse gravel	2 - 6
S	stones	6 - 20
B	boulders	20 - 60
L	large boulders	60 -200

41-43 *OBSERVABLE EROSION*

Any visible signs of (accelerated) erosion are to be indicated according to type, area affected and degree (see also section 1.6.3 of the Guidelines for Soil Description (FAO, 1990). If more than two types of erosion are active at the same time, then the type that overall results in the severest land degradation is indicated.

41 *types of erosion*

N no visible evidence of erosion
S sheet erosion
R rill erosion
G gully erosion
T tunnel erosion
P deposition by water
W water and wind erosion
L wind deposition
A wind erosion and deposition
D shifting sand
Z salt deposition
U type of erosion unknown

42 *area affected*

1 0- 5 %
2 5-10 %
3 10-25 %
4 25-50 %
5 > 50 %

43 *degree of erosion*

S	slight	Some evidence of damage to surface horizons. Original biofunctions largely intact.
M	moderate	Clear evidence of removal or coverage of surface horizons. Original biofunctions partly destroyed.
V	severe	Surface horizons completely removed (with subsurface horizons exposed) or covered up. Original biofunctions largely destroyed.
E	extreme	substantial removal of deeper subsurface horizons (badlands). Complete destruction of original biofunctions.

44-45 *SENSITIVITY TO CAPPING*

The degree in which the soil surface has a tendency to capping and sealing is characterised by the thickness and consistency (dry) of the surface crusts (see also section 1.6.4 of the Guidelines for Soil Description (FAO, 1990).

44 *thickness*

N none
T thin < 2 mm
M medium 2- 5 mm
C thick 5-20 mm
V very thick > 20 mm

45 *consistency*

S slightly hard
H hard
V very hard
E extremely hard

46-48 *SURFACE CRACKS*

The occurrence of surface cracks is indicated by the width, distance and depth of cracks (see also section 1.6.5 of the Guidelines for Soil Description (FAO, 1990).

46 *depth*

S	shallow	< 25 cm
M	mod. deep	25-50 cm
D	deep	> 50 cm

47 *width*

F	fine	< 1 cm
M	medium	1- 2 cm
W	wide	2- 5 cm
V	very wide	5-10 cm
E	extr. wide	> 10 cm

48 *distance between cracks*

C	very closely spaced	< 0.2 m
D	closely spaced	0.2-0.5 m
M	moderately widely spaced	0.5-2.0 m
W	widely spaced	2 -5 m
V	very widely spaced	> 5 m

49 *Rootable depth*

Estimated depth in cm to which root growth is not restricted by any physical or chemical impediment, such as an impenetrable or toxic layer. Strongly fractured rocks, such as shales, may be considered as rootable. (see also section 1.5.2 of the Guidelines for Soil Description (FAO, 1990).

1	very shallow	< 30 cm
2	shallow	30- 50 cm
3	moderately deep	50-100 cm
4	deep	100-150 cm
5	very deep	> 150 cm

50 *Slope gradient*

The dominant slope gradient of the soil component in percentage. If this gradient is similar to that of the terrain component (see 6.2) then no entry has to be made.

51 *Topographic position*

The relative position of the soil component within the terrain component is characterised by one of the following descriptions:

H	high	interfluve, crest or higher part of the terrain component
M	middle	upper and middle slope or any other medium position within the terrain component
L	low	lower slope or lower part of the terrain component
D	lowest	depression, valley bottom or any other lowest part of the terrain component
A	all	all positions within the terrain component

52 *Relation to other soil components*

A free-format space of 264 characters is available to succinctly indicate the relationship between this soil component and adjoining soil components. E.g. "Soil component A has formed in colluviated material derived from soil component B".

53 *Drainage*

The present drainage of the soil component is described according to one of the classes mentioned below (see also section 1.7.1 of the Guidelines for Soil Description (FAO, 1990).

E	excessively drained	Water is removed from the soil very rapidly.
S	somewhat excessively drained	Water is removed from the soil rapidly.
W	well drained	Water is removed from the soil readily but not rapidly.
M	moderately well drained	Water is removed from the soil somewhat slowly during some periods of the year. The soils are wet for short periods within rooting depth.
I	imperfectly drained	Water is removed slowly so that the soils are wet at shallow depth for a considerable period.
P	poorly drained	Water is removed so slowly that the soils are commonly wet for considerable periods. The soils commonly have a shallow water table.
V	very poorly drained	Water is removed so slowly that the soils are wet at shallow depth for long periods. The soils have a very shallow water table.

54 *Permeability or hydraulic conductivity*

The following 7 classes are used to express the measured hydraulic conductivity (in cm/h) (see also section 1.7.2 of the Guidelines for Soil Description (FAO, 1990).

E	extremely slow	< 0.06 cm/h
V	very slow	0.06- 0.2 cm/h
S	slow	0.2 - 0.6 cm/h
M	moderately slow	0.6 - 2.0 cm/h
D	moderately rapid	2 - 6 cm/h
R	rapid	6 -20 cm/h
Y	very rapid	> 20 cm/h

55 *Infiltration rate*

The basic infiltration rate, in cm/h, is indicated according to the following 7 categories (BAI, 1979).

V	very slow	< 0.1 cm/h
S	slow	0.1- 0.5 cm/h
M	mod. slow	0.5- 2.0 cm/h
M	moderate	2.0- 6.0 cm/h
R	rapid	6.0-12.5 cm/h
Y	very rapid	12.5-25.0 cm/h
E	extremely rapid	> 25 cm/h

56 *Surface organic matter*

Any litter or other organic matter on the surface will be described according to thickness (in cm) and degree of decomposition (Soil Survey Staff, 1975):

F	fibric	weakly decomposed organic soil material (fiber content >2/3 of volume)
H	hemic	degree of decomposition intermediate between fibric and sapric (fiber content between 1/6 and 2/3 of volume)
S	sapric	highly decomposed organic soil material (fiber content <1/6 of volume)

57 *Classification*

Characterisation of soil component according to the revised FAO Soil Map of the World Legend (FAO, 1990). The codes as given in this publication will be entered (see also FAO, 1989). Where possible the characterisation should be up to subunit level. The year of publication of the version of the Legend used for the characterisation must be given as well.

58 *National profile code*

The original code for the representative profile under which it stored in the national database. Any national code is permitted provided it is unique.

59 *National classification*

The original national classification of the representative profile.

60 *Soil Taxonomy*

Only the Soil Taxonomy classification (for codes see FAO, 1989) for representative profiles as is indicated in the national database or relevant report, is given. No entry will be made for soil profiles that were not originally classified according to Soil Taxonomy.

61 *Phase*

Any potentially limiting factor related to surface or subsurface features of the terrain, and not already specifically described in the soil profile, can be made a phase (see FAO, 1989). The coding for phases currently used by FAO is given in the FAO-ISRIC Soil Database (FAO, 1990). A note should be made on the code for new phases recognised.

62 *Number of reference profiles*

The number of reference profiles that were considered for the selection of the representative profile is indicated. These profiles have also contributed to the determination of modal class values for a number of chemical and physical parameters of the representative profile.

63-64 *LOCATION OF THE REPRESENTATIVE PROFILE*

The latitude and longitude, as accurate as possible, and expressed in decimal degrees. A profile of which the approximate location (i.e. accurate to the nearest full minute) is not known cannot be accepted in the SOTER database.

63 *Latitude*

The latitude is stored in decimal degrees north; latitudes in the southern hemisphere are negative.

64 *Longitude*

The longitude is stored in decimal degrees east; longitudes in the western hemisphere are negative.

65 *Elevation of the representative profile*

The elevation in metres above sea-level, and at least indicated to the nearest 50 m contour (if this is not possible, no entry should be made).

66 *Sampling date*

The date at which the profile was described and sampled. In case these two activities were carried out on different dates, the date of sampling should be taken.

67 *Laboratory ID code*

The ISRIC ID code for soil laboratories

6.4 Horizon data

This section provides the attributes for the various horizons that have been distinguished in the representative soil profile. In general, no more than 5 horizons should be described. Mandatory attributes must always be completed. Measured data are entered both as an actual value for the representative profile, and as a class value based on the modal value as derived from all the reference profiles.

68 *Soil component subcode*

The soil component code as given in section 6.3 (code 33) is repeated here.

69 *Horizon number*

A consecutive number, starting with the surface horizon, is allocated to each horizon.

70 *Diagnostic horizon and property*

The diagnostic horizon, or any diagnostic property, that is associated with the horizon, is entered. Section 2.1.3 of the Guidelines for Soil Description (FAO, 1990) lists all the diagnostic horizons and properties. This entry is mandatory.

71 *Horizon designation*

Master horizon with subordinate characteristics according to the rules given below (for more details see section 2.1 of the Guidelines for Soil Description (FAO, 1990). The horizon designation is mandatory.

Master horizons

H horizon or layer Layer dominated by organic material, formed from accumulations of (partially) undecomposed organic material at the soil surface, which may be underwater. All H horizons are saturated with water for prolonged periods, or were once saturated but are now artificially drained. An H horizon may be on top of mineral soils or at any depth beneath the surface if it is buried.

O horizon or layer Layer dominated by organic material, consisting of (partially) undecomposed litter, such as leaves, twigs, moss etc., which has accumulated on the surface. They may be on top of either mineral or organic soils. An O horizon are not saturated with water for prolonged periods. The mineral fraction of such material is only a small percentage of the volume of the material and generally is much less than half the weight. An O horizon may be at the surface of a mineral soil or at any depth beneath the surface if it is buried.

A horizon Mineral horizon which formed at the surface or below an O horizon, and in which all or much of the original rock structure has been obliterated. The A horizon is characterised by one or more of the following:

- an accumulation of humified organic matter intimately mixed with the mineral fractions and not displaying properties characteristic of an E horizon (see below);
- properties resulting from cultivation, pasturing, or similar kinds of disturbance; or
- a morphology which is different from the underlying B or C horizon, resulting from processes related to the surface (e.g. vertisols).

E horizon Mineral horizon, in which the main feature is a loss of silicate clay, iron, aluminum, or some combination of these, leaving a concentration of sand and silt particles, and in which all or much of the original rock structure has been obliterated.

An E horizon is most commonly differentiated from an underlying B horizon by colour of higher value or lower chroma, or both; by coarser texture; or by a combination of these. Although an E horizon is usually near the surface, below an O or A horizon, and above a B horizon, the symbol E may be used without regard to position in the profile for any horizon that meets the requirements, and that has resulted from soil genesis.

B horizon A B horizon has formed below an A, E, O or H horizon, and has as dominant feature the obliteration of all or much of the original rock structure, together with one or a combination of the following:

- illuvial concentration, alone or in combination, of silicate clay, iron, aluminum, humus, carbonates, gypsum or silica;
- evidence of removal of carbonates;
- residual concentration of sesquioxides;
- coating of sesquioxides that make the horizon conspicuously lower in value, higher in chroma, or redder in hue than overlying and underlying horizons without apparent illuviation of iron;
- alteration that forms silicate clay or liberates oxides or both and that forms a granular, blocky or prismatic structure if volume changes accompany the changes in moisture content, or
- brittleness

Layers with gleying but no other pedogenetic change are not considered a B horizon.

C horizon or layer A horizon or layer, excluding hard bedrock, that is little affected by pedogenetic processes and lacks properties of H, O, A, E or B horizons. Most are mineral layers, but some siliceous or calcareous layers (e.g. shells, coral and diatomaceous earth) are included. Sediments, saprolite and unconsolidated bedrock and other geological materials that commonly slake within 24 hours are included as C layers. Some soils form in highly weathered material that is considered a C horizon if it does not meet the requirements of an A, E or B horizon.

R layer Hard rock underlying the soil. Air dry chunks of an R layer will not shake within 24 hours if placed into water.

Transitional horizons

In the case of horizons dominated by the properties of one master horizon but having subordinate properties of another, two capital letter symbols are used, such as AB, EB, BE and BC. The master horizon symbol that is given first designates the horizon whose properties dominate the transitional horizon. Horizons in which distinct parts have recognizable properties of two kinds of master horizons, are indicated by two-letter symbols as well, but the two symbols are separated by a slash, as E/B, B/E, B/C or C/R. Commonly most of the individual parts of one of the components are surrounded by the other.

Subordinate properties

Designations of subordinate distinctions and features within master horizons and layers are based on profile characteristics observable in the field and are applied during the description of the soil at the site. Lower case letters are used as suffixes to designate specific kinds of master horizons and layers, as well as other features. The following lists indicates the subordinate properties that may be used (see section 2.1.1 (iii) of the Guidelines for Soil Description (FAO, 1990) for more details).

b buried genetic horizon
c concretions or nodules
f frozen soil
g strong gleying
h accumulation of organic matter
j jarosite mottling
k accumulation of carbonates
m cementation or induration
n accumulation of sodium
o residual accumulation of sesquioxides

p ploughing or other disturbance
q accumulation of silica
r strong reduction
s illuvial accumulation of sesquioxides
t accumulation of silicate clay
v occurrence of plinthite
w development of colour or structure
x fragipan character
y accumulation of gypsum
z accumulation of salts more soluble than gypsum

In brief, the following conventions apply with respect to the use of suffixes, vertical subdivision of the profile, and discontinuities in the profile development (the full set of rules is given in the Guidelines for Soil Description (FAO, 1990).

- letter suffixes should immediately follow the capital letter that indicates the master horizon or layer;
- generally, no more than 3 suffixes should be used;
- the following letters, if used in combination with other letters, are written first: **r,s,t** and **w**;
- the following letters, if used in combination with other letters, are written last: **b, c, f, g, m, u, v** and **x**.

Some examples are: **Btc, Bkm** and **Bsv**.

- the **t** has precedence over the **w, s** and **h** in **B** horizons that display significant accumulations of clay together with accumulation of organic manner and development of structure and colour;
- suffixes **h, s** and **x** are normally not used together with suffixes **g, k, n, o, q, y** or **z**;
- if none of the above rules apply, then suffixes are listed alphabetically.

Horizons or layers designated by a single combination of letter symbols can be subdivided using arabic numbers which must follow the letter combination. Every unique combination of letter symbols has its own numbering sequence, e.g. **Bt1-Bt2-Btg1-Btg2**. Significant discontinuities are indicated by a consecutive arabic number that precedes the letter combination, with the exception of the first layer which is not numbered as such. Discontinuities do not affect the sequential numbering of subordinate properties, as in the following example: **Ap-Bw1-2Bw2-2Bwk-2C**.

72-74 *HORIZON BOUNDARY*

The boundary of horizons is characterised by depth, distinctness and topography (see also section 2.1.2 of the Guidelines for Soil Description (FAO, 1990). Depth and distinctness are mandatory entries.

72 *depth*

The average depth of the lower boundary in cm (the upper boundary in the case of a **O** horizon)

73 *distinctness*

A	abrupt	0- 2 cm
C	clear	2- 5 cm
G	gradual	5-15 cm
D	diffuse	> 15 cm

74 *topography*

S	smooth	nearly plane surface
W	wavy	pockets less deep than wide
I	irregular	pockets more deep than wide
B	broken	discontinuous

75-76 *SOIL COLOUR*

The Munsell colours, moist and dry, for each horizon should be given (moist colours are mandatory). Only integer values and chromas are accepted.

75 *soil colour (moist)*

76 *soil colour (dry)*

77-80 *MOTTLING*

The colour (moist, and only described in general terms), abundance, size and contrast of the mottles are described (see section 2.2.2 of the Guidelines for Soil Description (FAO, 1990). Up to two type of mottles may be entered. The colour and abundance of the mottles is mandatory. Rusty colours along root channels are not considered as mottles.

77 *abundance*

N	none	0 %
V	very few	0- 2 %
F	few	2- 5 %
C	common	5-15 %
M	many	15-40 %
A	abundant	> 40 %

78 *size*

V	very fine	< 2 mm
F	fine	2- 6 mm
M	medium	6-20 mm
C	coarse	> 20 mm

79 *contrast*

F	faint	the mottles are evident only on close examination
D	distinct	the mottles are readily seen, although they are not striking
P	prominent	the mottles are conspicuous and mottling is one of the outstanding features of the horizon

80 *colour*

				11	green(ish)
1	white	**6**	brownish	**12**	grey
2	red	**7**	reddish brown	**13**	greyish
3	reddish	**8**	yellowish brown	**14**	blue
4	yellowish red	**9**	yellow	**15**	bluish black
5	brown	**10**	reddish yellow	**16**	black

81 *Texture*

The texture of the horizon is estimated in the field with the aid of the texture triangle as depicted in fig. 8 (see also section 2.3.1 of the Guidelines for Soil Description (FAO, 1990).

1	sand	7	silt loam
2	loamy sand	8	loam
3	sandy loam	9	silty clay loam
4	sandy clay loam	10	sandy clay
5	clay loam	11	silty clay
6	silt	12	clay

82-84 *STRUCTURE*

The grade, size and type of structure, defined according to the Guidelines for Soil Description (FAO, 1990), is described. Type of structure is a mandatory attribute.

82 *grade*

N structureless no observable aggregation or no orderly arrangement of natural planes of weakness (massive or single grain)

W weak soil with poorly formed indistinct peds, that are barely observable in place even in dry soil, breaks up into very few intact peds, many broken peds and much apedal material

M moderate soil with well-formed distinct peds, durable and evident in disturbed soil which produces many entire peds, some broken peds and little apedal material

S strong soil with durable peds that are clearly evident in undisturbed (dry) soil, which breaks up mainly into entire peds

83 *table 5 Size classes (in mm) for structure elements*

Table 5 Size classes for structure elements of various types. In mm's. (Soil Survey Staff, 1951; FAO, 1990).

Size classes	Ranges of size of structure elements (mm)				
	platy	prismatic/columnar	(sub)ang.blocky	granul.	crumb
V very fine	< 1	< 10	< 5	< 1	<1
F fine	1- 2	10 - 20	5 - 10	1- 2	1-2
M medium	2- 5	20 - 50	10 - 20	2- 5	2-5
C coarse	5-10	50 -100	20 - 50	5-10	
X very coarse	>10	>100	> 50	>10	

84 *type of structure*

P	platy	particles arranged around a generally horizontal plane
R	prismatic	prisms without rounded upper end
C	columnar	prisms with rounded caps
A	angular blocky	bounded by plains intersecting at largely sharp angles.
S	subangular blocky	mixed rounded and plane faces with vertices mostly rounded
G	granular	spheroidical or polyhedral, relatively non-porous
B	crumb	spheroidical or polyhedral, porous
M	massive	no structure
N	single grain	no structure, individual grains
W	wedge shaped	structure in horizons with slickensides

85-88 *CONSISTENCE*

The consistence dry, moist and wet is entered in accordance with the definitions as given in section 2.4.2 of the Guidelines for Soil Description (FAO, 1990). The consistence moist is a mandatory attribute.

85 *consistence dry*

L	loose	non-coherent
S	soft	weakly coherent
L	slightly hard	weakly resistant to pressure
H	hard	moderately resistant to pressure
V	very hard	very resistant to pressure
E	extremely hard	extremely resistant to pressure

86 *consistence moist*

L	loose	non-coherent
V	very friable	crushes under very gentle pressure
F	friable	crushes easily under gentle pressure
I	firm	crushes under moderate pressure
Y	very firm	crushes under strong pressure
E	extremely firm	crushes only under very strong pressure

87 *stickiness*

N	non-sticky	does not stick
S	slightly sticky	sticks slightly and stretches somewhat
T	sticky	sticks well and stretches clearly
V	very sticky	sticks very much and stretches strongly

88 *plasticity*

N	non-plastic	does not resist deformation
S	slightly plastic	easily deformed
P	plastic	not easily deformed
V	very plastic	very difficult to deform

89-91 *CUTANIC FEATURES*

The nature, contrast and abundance of cutanic features (see also section 2.6.1 of the Guidelines for Soil Description (FAO, 1990).

89 *nature*

C clay
Q clay and sesquioxides
O clay and organic matter
P pressure faces
S slickensides, non-intersecting
A slickensides, partly intersecting
I slickensides, predominantly intersecting
H shiny faces

90 *abundance*

N	none	0 %
V	very few	0- 2 %
F	few	2- 5 %
C	common	5-15 %
M	many	15-40 %
A	abundant	40-80 %
D	dominant	> 80 %

91 *contrast*

F	faint
D	distinct
P	prominent

93-94 *CEMENTATION*

Only the degree and nature of cementation are recorded (see also Guidelines for Soil Description (FAO, 1990). The nature of cementation is a mandatory entry.

93 *nature*

K	carbonates	**G**	gypsum
S	silicates	**C**	clay
Q	sesquioxides	**U**	unknown

94 *degree*

N	non-cemented	slakes in water
W	weakly cemented	can be broken in hands
M	moderately cemented	cannot be broken in hands but is discontinuous
C	cemented	cannot be broken in hands and is continuous

95-98 *MINERAL FRAGMENTS*

The presence of any rock or mineral fragments in the horizon, as described in section 2.6.3 and 2.3.2 of the Guidelines for Soil Description (FAO, 1990). The nature of mineral fragments is a mandatory attribute.

95 *abundance*

N	none	0 %
V	very few	0- 2 %
F	few	2- 5 %
C	common	5-15 %
M	many	15-40 %
A	abundant	40-80 %
D	dominant	> 80 %

96 *nature*

K	carbonates
C	clay
G	gypsum
S	salt
Z	sulphur
L	silica
F	iron
M	manganese
Q	sesquioxides (Fe and Mn)

97 *size* **98** *hardness*

V	very fine	< 2 mm	**S**	soft
M	fine	2- 6 mm	**H**	hard
M	medium	6-20 mm	**B**	both hard and soft
C	coarse	> 20 mm		

99-104 *ROOTS*

Three sizes of roots may be entered for each horizon, with for each size the abundance indicated (see also section 2.7.1 of the Guidelines for Soil Description (FAO, 1990).

99-101 *abundance (per dm^2)* **102-104** *size (diameter)*

N	no roots	0	**V**	very fine	< 0.5 mm
V	very few	1- 20	**F**	fine	0.5-2 mm
F	few	20- 50	**M**	medium	2-5 mm
C	common	50-200	**C**	coarse	> 5 mm
M	many	> 200			

105 *very coarse sand*

weight % of particles 2.0-1.25 mm in fine earth fraction

106 *coarse sand*

weight % of particles 1.25-0.63 mm in fine earth fraction

107 *medium sand*

weight % of particles 0.63-0.2 mm in fine earth fraction

108 *fine sand*

weight % of particles 0.2-0.125 mm in fine earth fraction

109 *very fine sand*

weight % of particles 0.125-0.063 mm in fine earth fraction

110 *total sand*

weight % of particles 2.0-0.063 mm in fine earth fraction. The total sand fraction, either as an absolute value, or as the sum of the sub-fractions, is a mandatory attribute.

111 *silt*

weight % of particles 0.063-0.002 mm in fine earth fraction (mandatory)

112 *clay*

weight % of particles < 0.002 mm in fine earth fraction (mandatory)

113 *particle size class*

the particle size class as derived, with the aid of figure 9, from the particle size analysis results.

1	sand, unsorted	**13**	coarse sand
2	loamy sand	**14**	medium sand
3	sandy loam	**15**	fine sand
4	sandy clay loam	**16**	very fine sand
5	clay loam	**17**	loamy coarse sand
6	silt	**18**	loamy medium sand
7	silt loam	**19**	loamy fine sand
8	loam	**20**	loamy very fine sand
9	silty clay loam	**21**	coarse sandy loam
10	sandy clay	**22**	medium sandy loam
11	silty clay	**23**	fine sandy loam
12	clay		

The sandy sub-classes are determined as follows (see also section 2.3.1 in the Guidelines for Soil Description (FAO, 1990):

very fine sand	50% or more very fine sand (and < 25% coarse and very coarse sand)
fine sand	50% or more fine and very fine sand (and < 25% coarse and very coarse sand)
coarse sand	25% or more very coarse and coarse sand, and < 50% medium sand (also <50% fine and very fine sand)
medium sand	either 50% or more medium sand, or 25% or more medium sand with <25% coarse and very coarse sand and <50% fine and very fine sand
unsorted sand	all other proportions

114 *coarse fragments*

volume % of particles > 2 mm in soil, a mandatory entry

115 *bulk density*

bulk density in kg dm^{-3}

116-120 *MOISTURE CONTENT AT VARIOUS TENSIONS*

The database accepts the soil moisture content (%) at 5 different tensions, of which one should be the moisture content at field capacity (-33 KPa) and one the moisture content at wilting point (-1500 KPa), e.g.

KPa	-33	-98	-300	-510	-1500
soil moisture (%)	0.41	0.22	0.17	0.12	0.09

121 *hydraulic conductivity*

the saturated hydraulic conductivity in cm h^{-1}

122 *infiltration rate*

the basic infiltration rate in cm h^{-1}

123 *pH (H_2O)*

pH is determined in the supernatant suspension of a 1:2.5 soil-water mixture (mandatory)

124 *pH (KCl)*

pH is determined in the supernatant suspension of a 1:2.5 soil-1 M KCl mixture

125 *electrical conductivity (EC_e)*

electrical conductivity of saturation extract, mS/m, only if the soil contains salts (mandatory)

126 *exchangeable Ca^{++}*

the exchangeable Ca in cmol(+) kg^{-1}

127 *exchangeable Mg^{++}*

the exchangeable Mg in cmol(+) kg^{-1}

128 *exchangeable Na^{+}*

the exchangeable Na in cmol(+) kg^{-1}

129 *exchangeable K^{+}*

the exchangeable K in cmol(+) kg^{-1}

130 *exchangeable Al^{+++}*

the exchangeable Al in cmol(+) kg^{-1}

131 *exchangeable acidity*

the exchangeable acidity, as determined in 1N KCl, in cmol (+) kg^{-1}

132 *CEC soil*

the cation exchange capacity of the soil at pH 7.0 in cmol(+) kg^{-1} (mandatory)

133 *soluble $CO_3^{=}$*

the $CO_3^{=}$ content in cmol (-) L^{-1}

134 *soluble HCO_3^{-}*

the HCO_3^{-} content in cmol (-) L^{-1}

135 *soluble Cl^{-}*

the soluble Cl^{-} content in cmol (-) L^{-1}

136 *soluble $SO_4^{=}$*

the soluble $SO_4^{=}$ content in cmol (-) L^{-1}

137 *total carbonate equivalent*

content of carbonates in g kg^{-1}

138 *active carbonate equivalent*

content of active carbonates in g kg^{-1}

139 *gypsum*

gypsum content in g kg^{-1}

140 *total carbon*

content of total organic carbon in g kg^{-1}, a mandatory attribute for the topsoil (first 25 cm, or A horizon, whichever is deeper)

141 *total nitrogen*

content of total N in g kg^{-1}

142 *P_2O_5*

the P_2O_5 content in 1% citric acid in mg kg^{-1}

143 *phosphate retention*

the phosphate retention in %

144 *Fe, dithionite extractable*

the Fe fraction, in weight %, extractable in dithionite

145 *Fe, pyrophosphate extractable*

the Fe fraction, in weight %, extractable in pyrophosphate at pH 10

146 *Al, dithionite extractable*

the Al fraction, in weight %, extractable in dithionite

147 *Al, pyrophosphate extractable*

the Al fraction, in weight %, extractable in pyrophosphate at pH 10

148 *clay mineralogy*

the dominant type of mineral in the clay fraction

A	allophane	**K**	kaolinitic
C	chloritic	**M**	montmorillonitic
I	illitic	**S**	sesquioxidic
X	interstratified or mixed	**V**	vermiculitic

Computer conventions

The SU_id in the computer consists of a 8 digit number: 4 digits for the terrain unit (in most cases 2 or 3 will be enough), one digit for the terrain component to which a "0" or "1" will be added for "non mappable" or "mappable", and a one digit number for the soil component, again followed by a "0" or "1". The computer can then decide to what level the SU is mappable. If both terrain and soil component numbers are followed by a "0" the terrain unit will be the SMU, if both terrain and soil component numbers will be followed by a "1" an error message will be given, and otherwise the component whose number is followed by a "1" will be the SMU. The SU_id will be printed out as a number consisting of a minimum of 3 digit and a maximum of 6 digits, in which the one but last (terrain component extension number) and last (soil component extension number) digits are separated from each other and from the first part of the number by full stops. Moreover, an asterisk is used to indicate the SOTER Mapping Unit, as in the following example 23.1*.3 (terrain unit 23, mappable soil component 1 within terrain unit 23, and non-mappable soil component 3 within terrain component 1 of terrain unit 23). This code is stored in the database as 00231130.

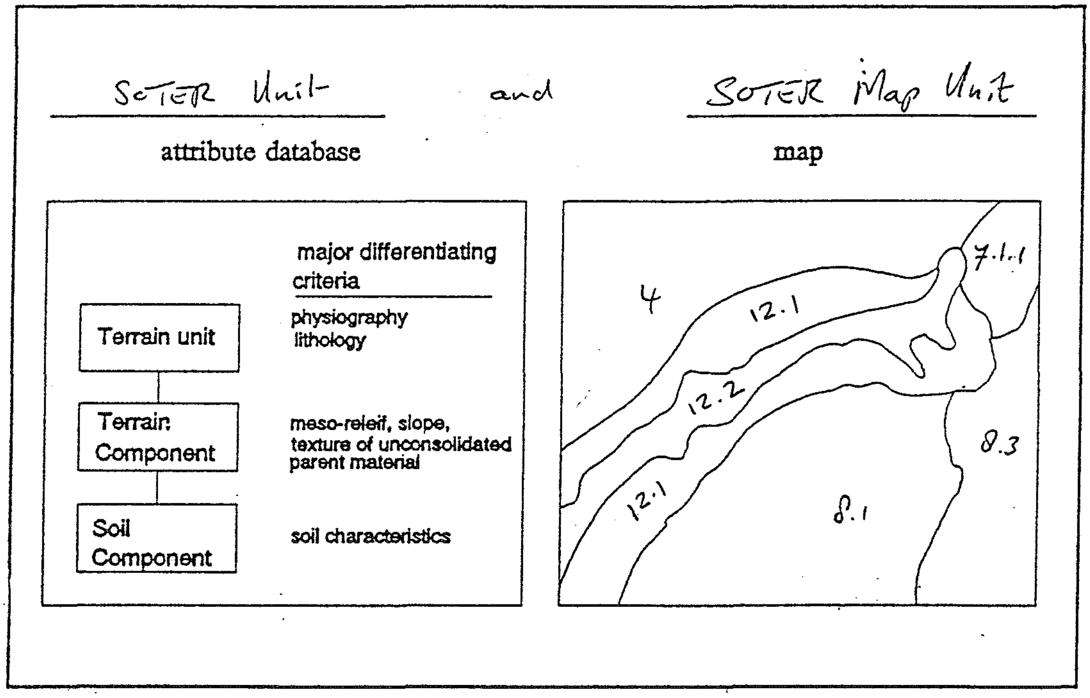


Fig. 1 SOTER Unit structure and SOTER map with SOTER Map Units. Only SOTER Map Units with a 3 component code (e.g. 7.1.1) correspond to a soil component within the SOTER unit. The others are indicating a terrain component (e.g. 12.1) or a terrain unit (e.g. 4).

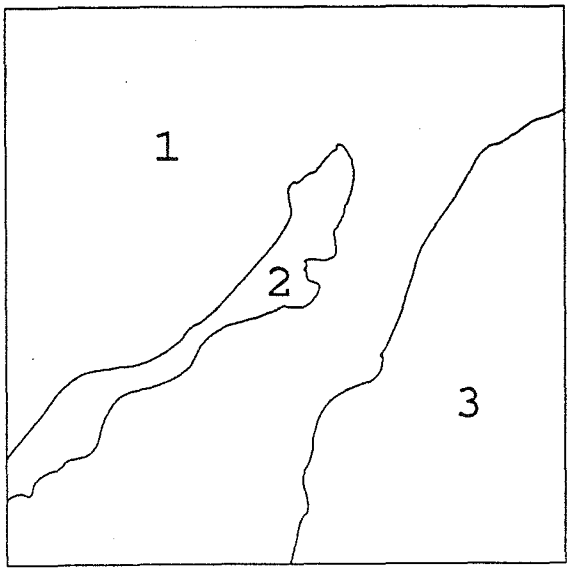


Fig. 2.1 Terrain subdivided according to major landforms

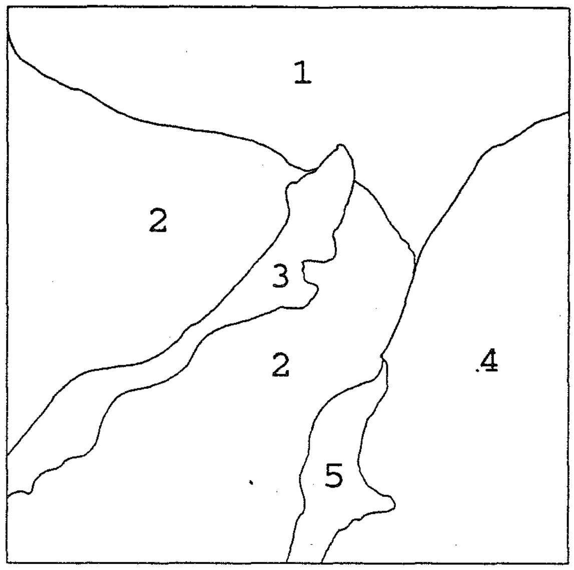


Fig. 2.2 Five terrain units differentiated according to major landform and lithology

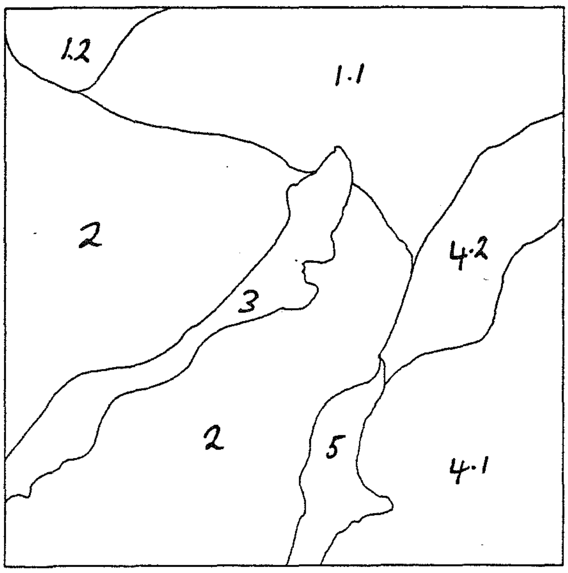


Fig. 2.3 Terrain units land further subdivided according to surface form

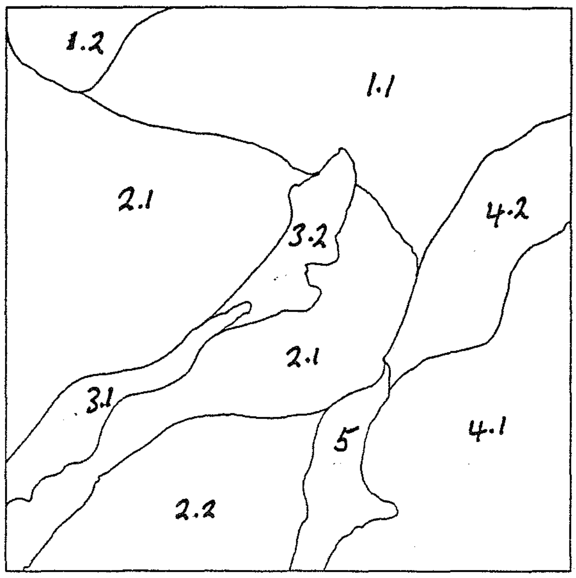


Fig. 2.4 Terrain components resulting form differentiation according to surface form and slope gradient

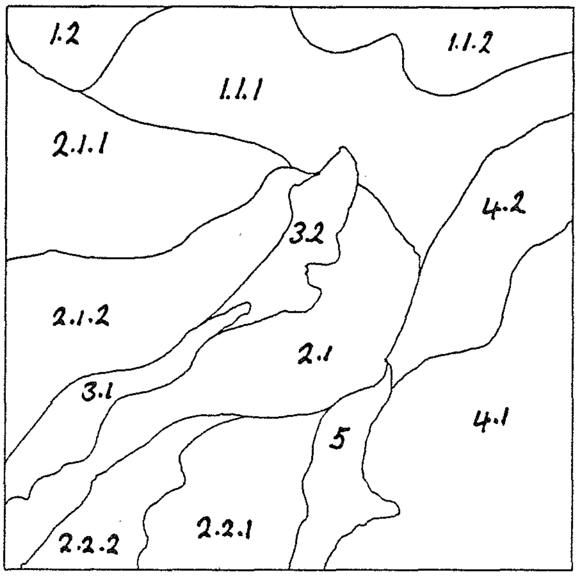


Fig. 2.5 SOTER Map Units based on a terrain unit (polygon 5), terrain components (polygons 1.2, 2.1, 3.1 and 4.1) and soil components (the others)

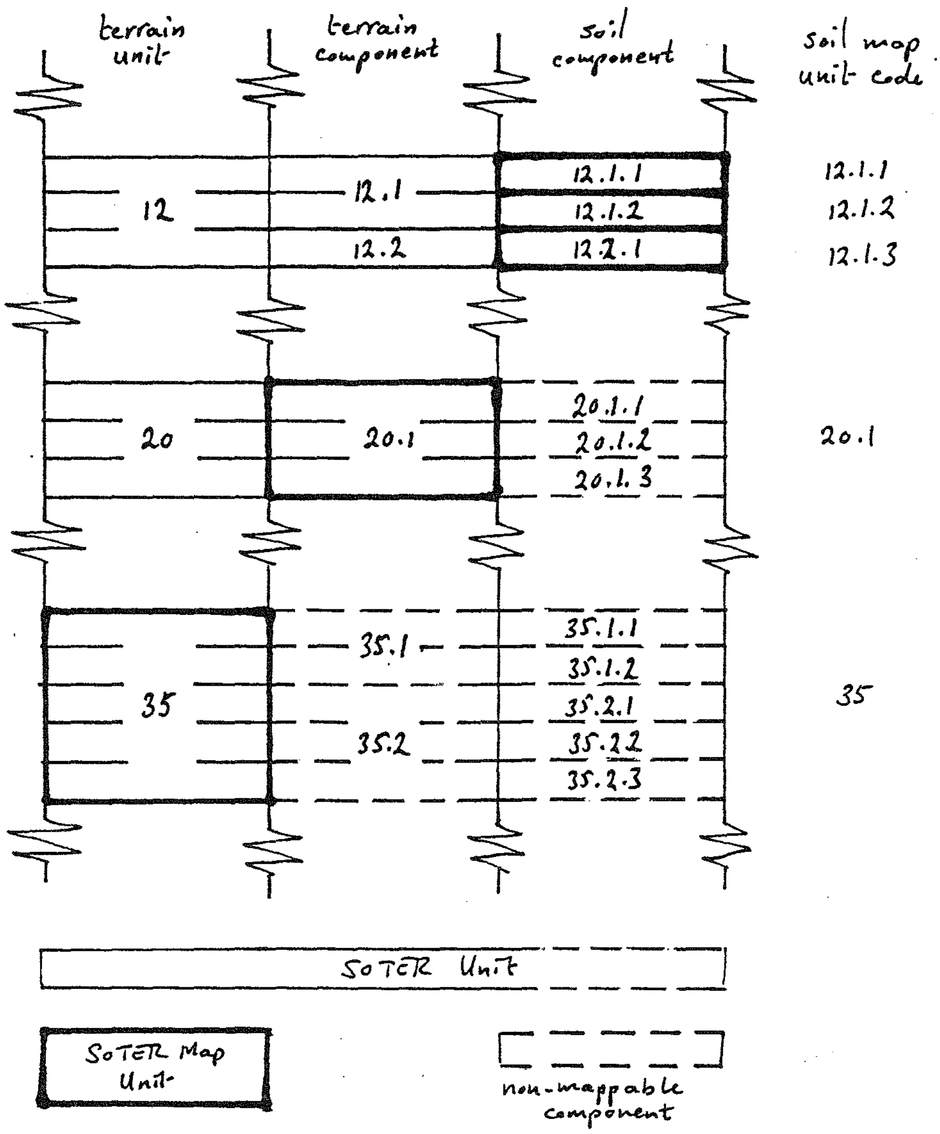


Fig. 3 Schematic representation of relationship between SOTER Unit and SOTER Map Unit

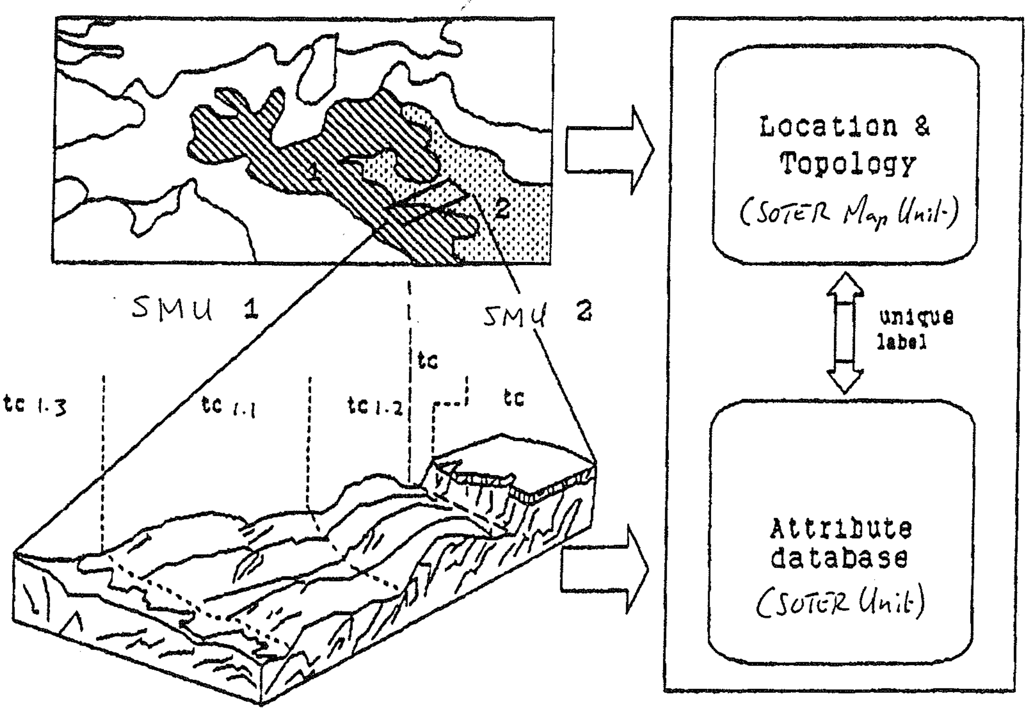


Fig. 4 SOTER Map Units, their (non-mappable) terrain components (tc), attribute data and location

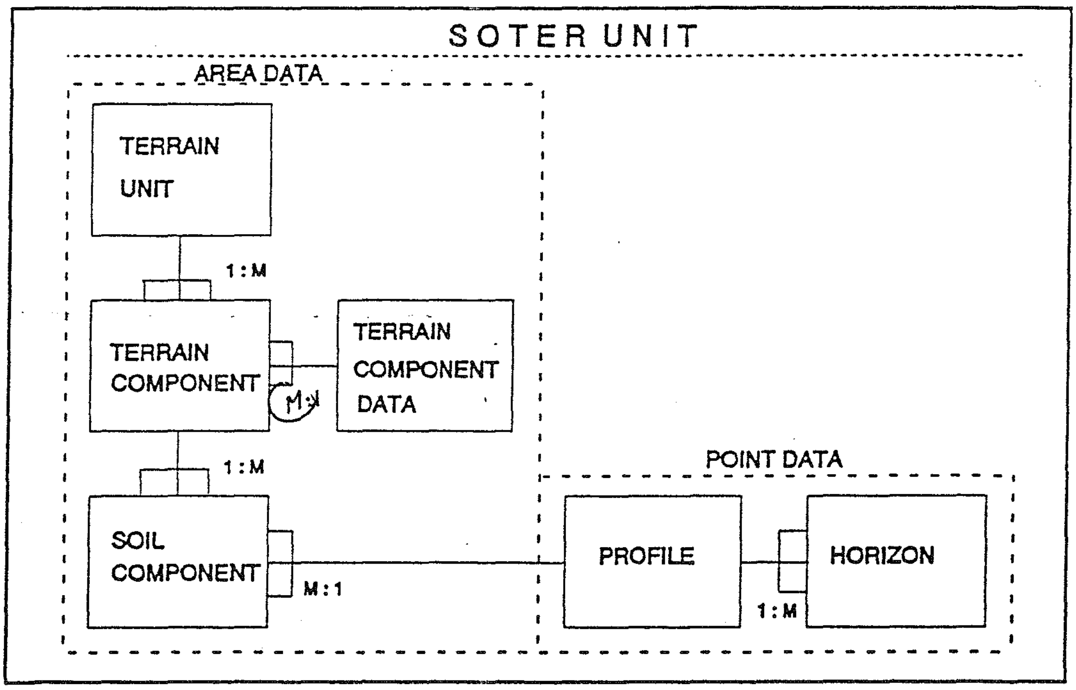


Figure 5. Schematic representation of a SOTER unit, and structure of the attribute database with its area data and point data (1:M stands for one to many relations, and M:1 for many to one relation:

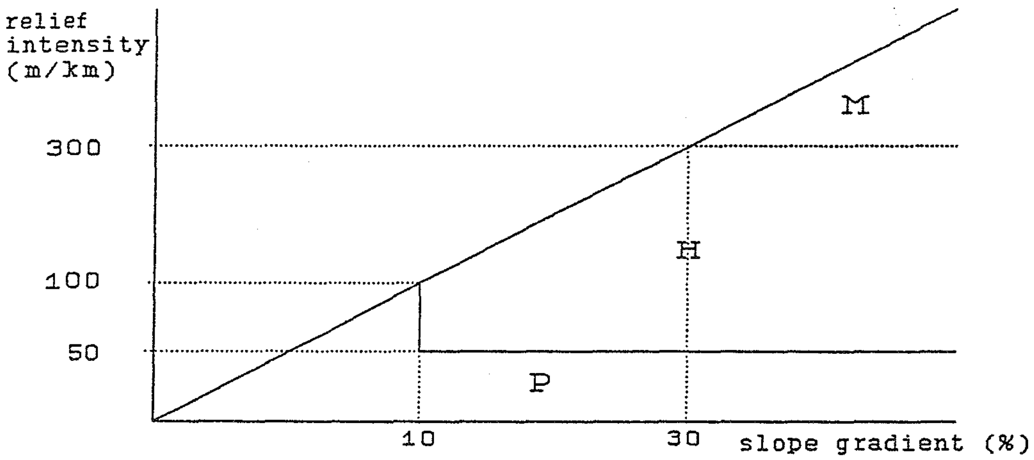
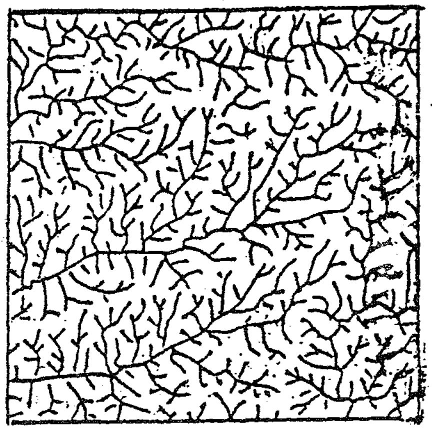
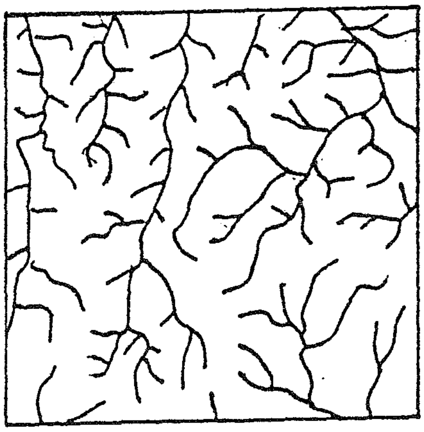


Fig. 6 Major regional landforms as determined by relief intensity and slope gradient



(b)



(a)

Fig. 7 Slightly dissected (a) and dissected (b) landscapes as indicated by the density of the drainage pattern on 1:50.000 maps

APPENDIX 1 Class values for attributes accepted by the modal value table of the soil component horizon database

115 bulk density (kg dm^{-3})

1	< 0.70
2	0.70-0.94
3	0.95-1.19
4	1.20-1.49
5	1.50-1.80
6	> 1.80

121 hydraulic conductivity (cm h^{-1})

1	< 0.5
2	0.5- 1.9
3	2.0- 5.9
4	6.0-12.4
5	12.5-25.0
6	> 25.0

122 pH (H_2O)

1	< 3.5
2	3.6-4.4
3	4.4-5.4
4	5.5-6.4
5	6.5-7.3
6	7.4-7.8
7	7.9-8.5
8	> 8.5

123 pH (KCl)

1	< 3.5
2	3.5-3.9
3	4.0-4.4
4	4.5-4.9
5	5.0-5.5
6	> 5.5

124 ECe (dS m^{-1})

0	nil
1	< 2.0
2	2.0- 3.9
3	4.0- 7.9
4	8.0-15.9
5	16.0-30.0
6	> 30.0

125-126 exch. Ca^{++} and Mg^{++} (cmol(+) kg^{-1})

0	nil
1	< 1
2	1- 4
3	5- 9
4	10-20
5	> 20

127 exch. Na^+ (cmol(+) kg^{-1})

0	nil
1	< 1
2	1- 9
3	10- 24
4	25-100
5	> 100

128 exch. K^+ (cmol(+) kg^{-1})

0	nil
1	< 0.5
2	0.5- 0.9
3	1.0- 2.4
4	2.5-10.0
5	> 10.0

129 exch. AL^{+++} (cmol(+) kg^{-1})

0	nil
1	< 1.0
2	1.0- 4.9
3	5.0- 9.9
4	10.0-20.0
5	> 20.0

130 exch. acidity (cmol(+) kg^{-1})

0	nil
1	< 5.0
2	5.0- 9.9
3	10.0-14.9
4	15.0-19.9
5	20.0-30.0
6	> 30.0

129 CEC soil (cmol(+) kg^{-1})

1	< 4
2	4- 9
3	10-19
4	20-40
5	> 40

130 soluble CO_3^- (cmol(-) L^{-1})

0	nil
1	< 0.5
2	0.5- 1.0
3	1.0- 2.5
4	2.5-10.0
5	> 10.0

133 sol. HCO_3^- (cmol(-) L^{-1})

0	nil
1	< 2
2	2- 4
3	5-14
4	15-50
5	> 50

134-135 sol. SO_4^- (cmol(-) kg^{-1})

0	nil
1	< 1
2	1- 4
3	5- 19
4	20-100
5	> 100

135 sol. Cl^- (cmol(-) L^{-1})

0	nil
1	< 2
2	2- 7
3	8-20
4	20-100
5	100-500
6	> 500

136-137 total and active Ca CO_3 equiv. (%)

0	nil
1	< 1.9
2	2.0- 7.9
3	8.0-14.9
4	15.0-40.0
5	> 40.0

138 gypsum (g kg^{-1})

0	nil
1	< 20
2	20-250
3	> 250

1395 organic carbon (%)

0	nil
1	≤ 0.2
2	0.3- 0.5
3	0.6- 2.9
4	3.0- 7.9
5	8.0-15.9
6	≥ 16.0

140 total N (g kg^{-1})

0	nil
1	< 2
2	2- 4
3	5-14
4	15-50
5	> 50

141 total P (mg kg^{-1})

0	nil
1	< 1
2	1- 4
3	5- 19
4	20-100
5	> 100

142 P retention (%)

1	≤ 85
2	≥ 85

143,145 extractable Fe (%)

0	nil
1	< 0.4
2	0.4- 0.9
3	1.0- 2.4
4	2.5- 5.9
5	6.0-15.0
6	> 15.0

144, 145 extractable Al (%)

0	nil
1	< 0.2
2	0.2-0.4
3	0.5-0.9
4	1.0-2.4
5	2.5-5.0
6	> 5.0