

"Human factors in the Interpretation of Physiography by Symbolic and Numerical Representations within an Expert System"

by

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" ...nothing is great or little otherwise

than by Comparison " In GULLIVER'S TRAVELS [29]

1 Introduction

This chapter examines the role of human factors in both symbolic and numerical terrain representations for the interpretation of physiography from remotely sensed images. In illustrating the human factors involved it draws heavily on the work of the authors on expert terrain interpretation systems and physiographic feature quantification through image processing, geomorphometric and fuzzy set techniques.

This chapter is organized as follows. The introduction presents the photointerpretation tasks and problems for physiography and landforms, earlier efforts in knowledge based terrain representation, and the detailed objectives of the chapter. Then, follows the knowledge-based physiographic representation including the description of the study area and the implementation of the symbolic and numerical representations. Human factors and subjectivity in terrain representation and quantification are addressed throughout the chapter.

During the early part of this century, the study of regional-scale geomorphology was termed "physiography" [9]. Physiographic analysis was based on the partition of terrain to physiographic units by taking into account the form and spatial

distribution of their component features through fieldwork and visual interpretation of topographic maps and aerial photographs [11]. Today, physiography is being stimulated by the need to explain enigmatic landscapes, newly explored on the surfaces of other planets through remotely sensed data [9].

While physiographic analysis is concerned with regional scale geomorphology, terrain analysis is concerned with local (medium scale) geomorphology and it involves the systematic study of image patterns relating to the origin, morphologic history and composition of distinct terrain units, called landforms [2], [15], [20]. Landforms are natural terrain units, which when developed from the same soil and bedrock or deposited by a similar process, under similar conditions of climate, weathering, and erosion exhibit a distinct and predictable range of visual and physical characteristics on aerial images, called pattern elements [33]. Typical pattern elements examined include topographic form, drainage texture and pattern, gully characteristics, soil tone variation and texture, land use, vegetation, and special features [33].

The shaded relief map of Figure 1 [27] shows a part of the Basin and Range physiographic province and the landform alluvial fan commonly found in this province with its typical pattern elements: fan-shaped form, semiconical 3D shape, dichotomic drainage pattern, medium soil tones, and barren landcover.

Insert Figure 1 about here.

Problem solving for landform and physiographic region interpretation is an art [7]. The procedural framework for terrain interpretation problem solving is missing: books do not elaborate on the strategies needed to guide a novice to the terrain interpretation process through a step by step question and answer scenario. Landforms, pattern elements, physiographic features and relevant indicators are vital and poorly described components of the landscape. Interpretation of pattern elements of a site relies on the education and experience of the interpreter, his perceptual skills, his ability for trial-and-error experimentation, his use of interpretation heuristics, his personal judgement and his intuition. The use of prior knowledge on a specific geographic region and the use of available maps (physiographic, landcover, geologic, etc.) and bibliographic information can greatly assist terrain interpretation.

There is, therefore, a need to methodically study the physiographic and terrain-analysis reasoning process and, to better understand and formalize these processes and guide novice interpreters in terrain problem solving, develop computer-assisted interpretation procedures.

Knowledge-based expert-systems (KBES) are a field of artificial intelligence that addresses complex, domain specific, problem solving that requires unique expertise [12], [14]. Knowledge-Based Expert Systems offer methods and tools for representing problem solving procedures within interactive computer programs and thus can assist in the discovery and formalization of terrain interpretation procedures. Expert system success is largely determined by the effective computer representation of domain knowledge. Knowledge representation takes place by employing facts, objects, frames, rules, and inexact reasoning procedures.

For the past twenty five years, scientists working toward knowledge-based landform interpretation have implemented expert system prototypes for terrain analysis using different methods of knowledge representation such as rules, frames, Bayesian reasoning under uncertainty, and fuzzy descriptors [2], [6], [7], [21]. These earlier developed prototype terrain expert systems assisted the interpreter to infer the landform of a site through a step by step question and answer scenario. The user was queried for all pattern element values of a site and the degree of certainty ascribed to each value. Based on the user's responses the system inferred the landform of the site indicating also a certainty value for each decision e.g., the inferred landform is sandstone with certainty 0.95.

In this research effort while the earlier developed landform interpretation procedures are still used, knowledge related to the physiographic region of a site and to the spatial pattern of related landforms is also represented, formalized and programmed.

Building this new physiographic expert system involved identifying, naming, describing, and organizing knowledge pertaining to physiographic regions (provinces and sections), and their component features in terms of their distinguishing indicators. The conception of the various indicators encompassed a study of physiographic books and reports and it was achieved through trial and error experimentation [3]. The compiled factual and structural descriptions were represented within an expert system tool by using appropriate definitions of classes, subclasses, hierarchies, spatial relations, and rule structures [3], [4], [5].

The expert system representation has the drawback in that it employs mostly qualitative terrain indicators which occasionally could be vague and ambiguous to novice and inexperienced interpreters. There are three different approaches to partially assist in the representation of ambiguity of these terrain terms.

- The first is the use of a terrain visual vocabulary composed of definitions, diagrams, and aerial images describing each terrain term that can be used concurrently with the consultation of the expert system to enhance the perceptual

and mental models of the novice. Such a terrain visual vocabulary was implemented through a hypermedia system [6].

- The second approach, discussed in the following, is the computer-assisted segmentation of digital elevation models into discrete landforms through image processing operators and geomorphometric techniques and the subsequent quantification (parametric representation) of the discrete landforms and physiographic regions based on geomorphologic attributes [16], [17].
- The third approach, discussed also in the following, is using fuzzy sets [34] to handle the ambiguity or lexical uncertainty of terrain indicators. In particular, fuzzy sets are used as a calculus for the representation of a natural geomorphic language in the Great Basin geomorphologic context [17], [18].

Despite the common misconception that computer representation, symbolic or numerical, makes terrain interpretation "objective", it entails much human intervention and subjectivity. The resulting subjectivity affects (a) The symbolic representation of physiography within an expert system, (b) The surface parameterization into spatially discrete landforms, and (c) The fuzzy set representation of the physiographic indicators in the Great Basin context. Human factors and subjectivity are addressed throughout the chapter.

2 Knowledge-based Physiographic Interpretation

2.1 Study area

The methodology was implemented for the Basin and Range Province of Southwest USA. Basin and Range is centered principally on the State of Nevada (Figure 1). It is a large area, approximately one tenth of the USA, occupied mostly by wide desert plains, generally almost level, interrupted by great, largely dissected, north trending, roughly parallel mountain ranges (Table 1). The Province of Basin and Range is further subdivided to five sections, each at a different erosion stage, such as the Great Basin (mainly in the youthful erosion stage) and the Sonoran Desert (maturity erosion stage) [11]. The Great Basin is known as such because its drainage waters do not reach the sea but evaporate in saline lakes on the plains between the mountain ranges. The space taken by the mountains is about half of the total. The Sonoran Desert has mountain ranges that are smaller and perhaps older, occupying the 1/5 of the space. Moreover large areas are without concave basins of internal drainage and the section belongs to the maturity erosion cycle.

Insert Table 1 about here.

Each physiographic section was partitioned into its component physiographic features, and each physiographic feature into its component topographic forms, and each topographic form into its component landforms [23]. The physiographic features observed within the Basin and Range Province are (1) the Mountain Ranges, (2) the Major Desert Valleys and (3) the Intermontane Basins. Close Intermontane basins are also called bolsons while open basins are also called semi-bolsons. The topographic forms observed within an Intermontane Basin are (1) the Piedmont Slope, a gross topographic form, forming a gently sloping surface parallel to mountain front and surrounding the mountain belts and (2) the Basin Floor. Figure 2 shows typical Mountain Ranges, Intermontane Basins, Piedmont Slopes and Basin Floors. The common landforms expected within the Piedmont Slope are the alluvial fan, pediment, and bahada, while the common landforms within the Basin Floor are the valley fill, the playa and the saline lake. Death Valley is a typical (closed) intermontane basin of the Basin and Range Province. Figure 2a shows the landforms and topographic forms interpreted from a Landsat Thematic Mapper image [30] and Figures 2b shows the relief and spatial relationships between these landforms and topographic forms.

A conceptual framework for the representation of factual, structural, inferential, and strategic knowledge is now presented.

Insert Figures 2a, 2b about here.

2.2 Factual and Structural Knowledge Representation

For the factual and structural representation of physiographic knowledge an object-oriented representation structure was developed that uses frames as classes, subclasses, objects, sub-objects, and slots as properties.

First, we named and described, by their properties (Table 1), and organized into class-subclass hierarchies the following terrain classes (Figure 3):

- Class of Physiographic Provinces and Sections; subclass of Basin and Range; subclasses: Basin and Range youthful stage, Basin and Range maturity erosion stage.
- Class of Physiographic features; subclass of Intermontane Basins; subclasses of Bolson and Semibolson, and
- Class of Topographic forms; subclasses of piedmont slope, basin floor, and
- Class of Landforms with subclasses alluvial fan, playa, etc.

Through the class-subclass hierarchy these properties are inherited down each hierarchy so that to be shared by all the members of each class.

Then, we defined an object-subobject or whole-part hierarchy thus defining the whole-part terrain organization(Figure 3). For

example, each topographic form is composed of a set of landforms and conversely each landform is part of a topographic form.

Finally, we defined class members or instances of each class or subclass so that the expert system to use them for symbols as it infers features of each class during our consultation. These instances are dynamic objects generated during the consultation of the expert system. Thus when a topographic form is inferred, the system creates an instance TF1 belonging to the proper topographic form class and when a landform is inferred, the system creates an instance LF1 belonging to the proper landform class (Figure 2a).

Insert Figure 3 about here

2.3 Inferential and Strategic Knowledge Representation

Having defined the classes, subclasses, objects, and component objects we use them now to describe the inferential and strategic knowledge through a rule-based formalism.

We have conceived four distinct aspects of strategic physiographic reasoning:

a) Physiographic Province and Section inferencing and refining to either youthful or maturity erosion stage by specific physiographic indicators,

- Rules were developed inferencing physiographic regions (provinces and sections) from their physiographic indicators (Figure 4). Rules were also developed which refined the concept of the province to that of a physiographic section of that province. In the case of the Basin and Range concept, the refinement rules inferred the concept of a youthful (Great Basin) or mature erosion stage (Sonoran Desert).

b) Physiographic Feature inferencing by their indicators,

- Once a physiographic Province or Section was inferred and/or refined by physiographic indicators, the system queries the user for the identification of the possible physiographic features that could be evident in the study area.

c) Topographic Form inferencing by spatial association and

- Once a physiographic feature (e.g. an Intermontane Basin) was inferred based on the user's input of the relevant indicators, the possible types of topographic forms that could be evident within that physiographic feature would be posed for examination to the user.

d) Landform inferencing by pattern elements, geomorphologic indicators, and spatial association to interpreted landforms.

- Once a topographic form was inferred then the user was guided for the identification of the expected landforms

within that topographic form according to user-specified pattern elements and spatial constraints.

Insert Figure 4 about here

2.4 Formalization of Physiographic Knowledge with Nexpert Object

The earlier developed object oriented representation structure and the associated inference rules were programmed in the expert system tool NEXPERT OBJECT (recently renamed to Smart Elements) [22].

Nexpert Object provides a graphical representation of both the object and rule structure as it exists before the program execution or as it unfolds during the dynamic consultation of the expert system. These graphical networks are more declarative than the alternative textual representations and therefore they are used in the figures to demonstrate the system operation. Classes and subclasses are shown in circles while the class-subclass relationships are shown with links (lines) connecting a class (circle) with another class. Class properties are indicated with the little squares, while inherited properties are shown replicated in the subclasses as they appear in the parent class. Dynamic class instances (objects) are shown as little triangles and they are created during consultation. They are assigned

(linked) to the proper class they belong to based on the inference process.

The inferential knowledge for determining the physiographic context of the Basin and Range Province was expressed in rules. Figure 4 shows a graphical representation of a typical rule for establishing the Basin and Range province. Any rule like this in Nexpert Object is composed of three parts: the hypothesis to be established or rejected PH_Basin_and_Range in the right, the physiographic conditions (indicators) in the left to be asked to the user in order to prove/disprove the hypothesis (e.g., frequency of mountain ranges, presence of desert basins), and the 'Then' actions of the rule, shown to the left with the prefix "+=>", executed if and only if the rule fires. Once the hypothesis of the Basin and Range is verified, a rule is triggered by the hypothesis PH_Basin_and_Range_Refinement that refines the Basin and Range context to either maturity (Great Basin) or youthful (Sonoran Desert) stage.

The outcome of a hypothesis that was proved true is the creation of a dynamic object e.g., an instance of the relevant class established during execution. For example in Figure 5a we observe the dynamic object PH1 derived by the rule in Figure 4 that was assigned to the class Basin and Range. In Figure 5b we see that the dynamic objects are linked with part-of relationship to each other based on their spatial association. So the dynamic

object LF_1 is a kind-of alluvial fan established from pattern elements (LF_Alluvial_Fan_PE), geomorphologic criteria (LF_Alluvial_Fan_GM), and spatial association criteria (LF_Alluvial_Fan_SR). At the same time LF_1 is part-of the topographic form TF_1 which is a kind-of piedmont plain. TF_1 and TF_2 (basin floor) are part-of of the physiographic feature PF_1 that is a kind-of intermontane basin of bolson type.

Insert Figures 5a and 5b about here.

2.5 Testing and Evaluation

The lack of a detailed published procedure used by experts conducting physiographic analysis precludes the comparison of our own research prototype to such a source. We have tested the developed system for a number of interpretation scenaria mostly in the Basin and Range Province. For the cases tested the system's reasoning was satisfactory and conformed to our interpretations. Further testing with other users need to be conducted to evaluate the features of the system.

2.6 Human factors in building the physiographic expert system

The developed landform and physiographic interpretation expert systems are characterized as research prototypes in the sense that they are exploratory tools of the potential of the expert system paradigm in the typology, structuring, and

formalization of photointerpretation knowledge. The formalized knowledge of the physiographic expert system was compiled from examples and cases studies found in engineering, physiographic, and geomorphologic books [3], [4], [5] and reports and mainly from Fenneman [13], and Peterson [23]. Our own education, experience, expertise, trial-and-error experimentation, heuristics, and intuition have also contributed greatly to the developed representations. We did not generate any new knowledge, instead, we have turned the implicit knowledge available in books and in our mental models into explicit knowledge formalized through terrain classes and hierarchies, and inferential and strategic rules. These formal representations were implemented in an expert system tool and the resulting prototype expert system guides the novice interpreters in a step-by-step question and answer procedure to investigate various strategic interpretation scenarios and inferential paths for physiographic reasoning. We have captured within the rule system what we conceived as reasonable stages in terrain interpretation and have made available this interactive consultation guidance to novice users through the physiographic expert system. Despite this subjectivity the physiographic expert system prototype contains a partial formal backbone object and rule structure for experimentation, evaluation, revision, improvement and extension. What is important is that this backbone structure contains

explicit and declarative terrain knowledge in the form of classes, objects, and rules and as such it is easier to be inspected, criticized, expanded, transferred, and understood than if it was available in textual form.

Terrain representation with an expert system paradigm entails much human intervention and subjectivity. At the level of terrain problem identification is subjective in the selection of the geographic scale of the problem studied, the terrain features to be reasoned with, the tasks, subtasks, and hypotheses that the system considers, the choices given to the user, and the assumptions made within the problem solving space. At the level of conceptualization is subjective in the selection of the hypotheses and reasoning paths to be investigated, the class-subclass and whole-part relations adopted, and the approach for handling uncertainty and inexactness. At the level of knowledge formalization is subjective in the selection of a specific tool chosen for programming the developed representations.

The developed physiographic expert system representation has the drawback in that it employs mostly qualitative terrain indicators, such as those appearing in Table 1, which occasionally could be vague and ambiguous [26], [32] to novice and inexperienced interpreters. The next section presents surface parameterization into spatially discrete mountain ranges, and a fuzzy set representation for the natural geomorphic language used

in the expert system. The application was made for the Great Basin section of Basin and Range.

3 Physiographic Feature Quantification

According to Hoffman and Pike [13] the task of automating all parts of the terrain analysis process requires (a) an analysis of the language used to describe terrain and (b) an analysis of the optical information about terrain that is available to the perceiver. In this particular study the language that describes the mountain ranges in the Great Basin Section was related to set of attributes concerning their size, shape and geomorphologic characteristics [11]. These attributes were used earlier for the representation of physiographic reasoning within an expert system.

The symbolic representations are quite vague and ambiguous although interpreters communicate successfully [26]. In addition the imprecision that is inherent in most words (lexical uncertainty) is context dependent [1]. For example, in the expression of Fenneman [11], "there are more small than larger ones (mountain ranges)" the words "small" and "large" are both perceived in a specific physiographic context, that of the Great Basin Physiographic Section. In a different province, it is possible for the largest mountain ranges observed in the Great Basin to be comparatively very small. Thus, there is the need for capturing a geomorphometric terrain description (perceived

optical information) and relate it to the symbolic representation (language). That is achieved by the use of fuzzy sets that relate the symbolic representations to the numeric representations and thus producing "digital words" that can be used for reasoning in a digital computer system [32].

In order to quantify the natural geomorphologic language in the Great Basin context, the mountain features will be interpreted from digital elevation models [17] and will to be numerically represented by a set of attribute values [16]. These values will allow to specify the fuzzy set representation of the Fenneman's attributes in the Great Basin's physiographic context [18],[19].

3.1 Mountain Feature Extraction

The data used for the extraction of mountain features was the GTOPO30 DEM with spacing 30 arc-seconds since it provides a digital global representation of the earth's relief at a regional scale [31] and it is appropriate for regional scale (1:1,000,000) comparative studies. In a mountain, two parts are often distinctive: a) the gently sloping summit and b) the steep mountainsides [10, page 435]. The process for the identification of mountains is based on the assumption that the summit or ridge pixels form the initial set of mountain pixels which needs to be expanded downslope taken into account the gradient values present in their neighborhood. The employed algorithms first identify the

summits and then label the pixels around the summits as mountain pixels as long as their gradient was greater than the certain threshold [17]:

- The summits were extracted and labeled by implementing runoff simulation. In this approach, a single water unit is imported in every cell of the DEM and travels according to the upslope aspect pointing direction. The water units imported in each cell are counted and finally, the derived values represent the runoff per cell. The cells with runoff values greater than a certain threshold should belong to the ridge network. Human expertise is required in order to judge if the resulting ridge network resembles the usual ridge network observed on maps in the current physiographic context. In this case study, it was found out that the threshold should be equal to 9 [17] and the resulting ridge pixels are given in Figure 6a.
- Then the gradient was computed (see Figure 6b). The gradient value depends on (a) the computation method and (b) the accuracy specification and grid size of the DEM. Due to the accuracy specification of the GTOPO30 [31] a larger kernel of size 9*9 was selected for gradient computation. So the gradient values represented in Figure 6b differ to a degree from the values an interpreter observes in the field and additional expertise should be developed by landform specialists in order to deal with this kind of artificially

derived image. Statistical analysis of training areas indicated that the gradient of the mountainsides should be greater than 6 degrees [17]. Note that if the gradient threshold was chosen greater than 6 degrees then the resulting mountains would have been smaller in size while if it was chosen lesser than 6 degrees then the resulting mountains would have been larger in size. This threshold is by no means applicable to other physiographic regions since their mountainsides could be less or more steep than the mountainsides observed in the Great Basin. Additionally, if a different relief representation and/or a different algorithm for gradient computation were going to be used then a different gradient threshold would have been derived even for the Great Basin.

- Then, an iterative region growing segmentation algorithm was applied to label the mountain pixels [17], the boundary of the mountain features was delineated and a unique integer identifier was assigned to each mountain (Figure 6c).

Insert Figures 6a, 6b, 6c, 6d, about here.

Visually comparing the extracted mountain features to the mountain ranges compiled by Atwood [8] and shown in Figure 6d, it is observed that there is a fairly good correspondence between

them, e.g., for each of the Atwood ranges there is at least one range in the map of extracted mountain ranges. It is however observed that some of the mountain ranges of Atwood appear rather broken in the map of extracted mountains. This discrepancy could be explained either by the level of generalization induced by human and machine or by the intrinsic nature of the mountain ranges in Great Basin [11]. Atwood [8] could have used human expertise and fieldwork and thus, he might have connected isolated mountains and adjacent mountain ranges applying a generalization process.

The mountain feature extraction techniques are subjective to a degree. Human expertise is needed in order to deal with the discrete representation of the terrain at various scales and select the most suitable algorithms that could deal with the elevation and positioning errors of the available datasets. Usually one has to use a specific dataset that is available and thus a particular expertise should be developed in order to deal with the derived images and models. The selection of thresholds for gradient or for runoff is performed through a trial and error procedure and through comparison of the derived images to our mental images and models for this particular physiographic context. In the next section quantitative attributes for the mountains will be defined.

3.2 Mountain Feature Parametric Representation

To create a parametric representation of the extracted mountain features one first needs to select their attributes. We have selected such attributes for the Great Basin mountain ranges based on the descriptions of Fenneman [11], some of which appear briefly in Table 1. The selected attributes were then defined quantitatively after study of published geomorphometric parameters [9] and image processing operators as following [16]:

1. Size. The natural logarithm of object's diameter was used for the quantification of size.
2. Elongation. Eccentricity (E) was used for the quantification of elongation.
3. Orientation (Φ).
4. Mean Elevation (H).
5. Roughness (R). The standard deviation of elevation.
6. Local Relief (LR). The difference between the highest and the lowest elevation occurring in a mountain feature.
7. Hypsometric Integral (HI). Pike and Wilson [25] defined it as the ratio of {Mean Altitude-Lowest Altitude} to {Local Relief}. HI reflects the stage of landscape development. Areas with HI values above 0.6 are in the "youthful" erosion phase, values below 0.35 correspond to the "monadnock" phase while HI values in the range 0.6 to 0.35 correspond to 'equilibrium' [28].

8. Mean Gradient (G).

Table 2 shows the attribute values computed for a subset of the mountain features extracted. The presented parametric representation as a computed abstraction of reality, simplifies their shape and morphologic complexity while at the same time it leads to their numeric representation which allows the use of (a) statistics and (b) algorithms to further process and analyze them. Furthermore mountain feature parametric representation techniques are subjective in many respects. First human expertise is needed in the selection of an attribute (for example elongation and size). The attributes selected are by no means universally applicable to other physiographic contexts. For example elongation is well-accepted attribute for the Great Basin physiographic context but it might be meaningless for a context with eroded almost circular mountain remnants. In the next section, an effort will be made to use the parametric representation for the quantification of the geomorphologic words in Great Basin.

Insert Table 2 about here.

3.3 Fuzzy Set Representation of Mountains

Fuzzy sets have been developed as a calculus for the representation of natural language in various domains and are

being used in the following for representation of the imprecision of the qualitative mountain attributes (linguistic variables) used in our knowledge base. A variable is called linguistic if it can take words in a natural language as its values [26]. The words are represented by fuzzy sets defined in the domain of the linguistic variable. More specifically, a linguistic variable is characterized by [34]:

1. the name of the variable (e.g., Local Relief),
2. the set of linguistic labels that the variable takes (e.g., low, moderate, high),
3. the actual physical domain in which the linguistic variable takes its quantitative values (e.g., {300, 1200}), and
4. a semantic rule that relates each linguistic label of a variable with a fuzzy set in the actual physical domain.

Thus in order to quantify the natural geomorphologic language all four elements should be determined. The names of the linguistic variables and their labels were determined directly by physiographic descriptions (Table 1). The quantitative values of the actual physical measurements were computed through the geomorphometric parameterization of each extracted mountain feature to a set of attribute values (Table 2).

A fuzzy partition of the physical domain was next implemented and a sub-domain for each linguistic label was

derived. This was achieved based on geomorphological knowledge and trial and error experimentation.

The semantic rules that relate each linguistic label with a fuzzy set in the actual physical domain were expressed through membership function [34]. For a continuous variable (x), the membership function (MBF) describes the compatibility between the linguistic label ($DMB=MBF(x)$). DMB is called the degree of membership and its values are in the interval 0 to 1. The membership function of a linguistic label is a) subjective, b) context-dependent, and c) influenced by new numerical data and knowledge [32]. There is no general method to determine an MBF [1]. Its specification is a matter of definition, rather than of objective analysis [32].

Many different shapes of MBFs have been proposed in the literature and the most practical implementations use the so-called "Standard MBFs" [1] that are normalized (maximum is always 1 and minimum 0). The definition of a standard MBF includes the following steps [1]

- Define the value of the domain that best fits to the meaning of the label and assign DMB equal to 1.
- Define the rightmost and the leftmost values ($DMB=0$) of each linguistic label assuming that adjacent labels have usually 60% overlap.

For example, for the fuzzy sets that correspond to each label of the linguistic variable Size of the Mountain Ranges in the Great basin physiographic context [18] are given in Figure 7.

Insert 7 about here.

The fuzzy sets allowed the fuzzy partitioning of the domain of geomorphic variables in Great Basin and the quantitative representation of the geomorphic language in that geomorphic context. Their definition was based on both (a) well-accepted geomorphic knowledge and (b) the geomorphometric data acquired for the study area (physical domain).

Thus, the geomorphic language describing the mountain ranges was quantified for the Great Basin context [18]. So a user of a computer system could be assisted during the interpretation process by recalling the knowledge base of Great Basin and by the numerical values observed in the photo he tries to interpret. The computer system projects the values he gave to the domain of the Great Basin digital words and would give responses like this mountain feature is small in size and elongated in a Great Basin physiographic context [19].

Human factors are crucial for the fuzzy partition of the domain and for the selection of the MBF types. The last selection influences the interpretation process and is performed by a trial

and error procedure on the basis of human expertise and the derived quantitative data (domain). Although there is degree of subjectivity, a novice interpreter could be assisted and make judgements on the basis of the relative (context-dependent) knowledge base of "digital words". In the future when perhaps a more complete and tested knowledge base could be made available for various physiographic regions it will lead to the creation of an absolute definition (non-context dependent) of the geomorphic words and terms.

4 Conclusion

This chapter has demonstrated some of the lessons learned in attempting to conceptualize, represent, interpret, segment, and quantify terrain features from DEM and satellite imagery through expert systems, and geomorphometry. All the procedures employed involved judgement calls.

The hardest part of conceptualization, and quite subjective in nature, is the identification of terrain-related objects, their organization, their relations, and their combinations in creating inference and strategic rules. Identification of this conceptual structure involves both discovery and invention of the key abstractions and mechanisms that form the vocabulary of terrain analysis problem solving and it strongly depends on the bibliographic sources and mental models of the knowledge engineers and the terrain analysis experts. We have made an extra

effort in capturing a number of "intermediate-level concepts" in physiographic reasoning which are perhaps the most important tools available for organizing knowledge bases, both conceptually and computationally.

The numerical description of mountain features involves subjectivity in both (a) the discrete representation of the earth surface (DEM) including methods of preprocessing and generalizing and (b) the segmentation of the DEM into mountain ranges through selected algorithms and associated thresholds, (c) the selection of parameters of 3D form, (d) the computation of these parameters through selected geomorphometric and image processing operators

The subsequent fuzzy set representation resulted in the quantification of geomorphologic words and concepts, by assigning to each numeric representation a linguistic label that interpreters easily conceive and computer systems are able to process. Subjectivity is also induced, however, since in the fuzzy partitioning of the physical domain, the linguistic labels and the membership functions are also subjective and context dependent. Their specification is a matter of definition, rather than of objective analysis. "Definition" indicates human expertise and evaluation by trial and error procedures.

Quantification is one more approach for thinking and reasoning with subjectivity. Expertise is needed in order to deal with geomorphometric descriptions those are by no means a black

box. The main advantage of quantification is that (a) it approaches the complexity of the real world while at the same time simplifies it to a degree, and (b) it provides numerical representations that can be used for statistical comparisons.

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TABLES

Table 1. Physical and perceptible characteristics of the physiographic features in the Great Basin section by Fenneman

[11].

<u>Mountain Range</u>	1. Size	Lengths of 80 to 110km and width of 10 to 24km are common. The mountain ranges are of all sizes from mere hills or buttes up to ranges and <u>there are more small than larger ones.</u>
	2. Shape	Ranges are elongated and oriented mainly in N-S direction.
	3. Elevation	Ranges most frequent altitudes are 2000 to 3000 meters above sea level.
	4. Relief	The local relief of ranges is between 910 to 1500 meters.
	5. Roughness	Within its length there is no great variation in height.
	6. Process	The mountains in the Great Basin are either in the first erosion cycle (youthful) or in the second erosion (maturity) cycle).
<u>Basin</u>	The average gradient of a basin is about 3 degrees. Each basin has its own base level.	
<u>Spatial arrangement</u>	Roughly parallel mountain ranges separated by desert basins. The total area of the section is about evenly divided between mountains and basins. Piedmont slopes occupy narrow belts some miles in width surrounding the mountain ranges.	

Table 2. Parametric representation of some of the mountain features (Figure 6C) in the Great Basin [16].

No	Ln D	E	Φ	H	R	LR	HI	G
	Km ²	0..1	Deg	M	m	m	0..1	Deg
1	3.60	0.32	58.3	1769	172	852	0.37	9.1
2	5.02	0.57	68.6	2231	355	1625	0.32	15.7
3	3.16	0.08	48.2	1601	221	954	0.33	13.2
4	3.73	0.24	54.9	1817	296	1415	0.34	13.2
5	5.16	0.60	70.2	1634	292	1445	0.43	14.0
6	3.48	0.26	34.6	1671	217	762	0.39	12.1
7	4.68	0.66	72.9	1954	185	1065	0.37	9.3
8	3.53	0.05	47.2	1797	254	1034	0.38	12.7
9	4.58	0.29	56.6	1841	248	1491	0.29	11.0
10	4.15	0.48	64.9	1778	306	1679	0.36	14.9

Figure Captions

Figure 1. Study area.

The state of Nevada as it appears in the color landform atlas of U.S.A. [27]. The Death Valley intermontane basin is pointed out and an enlarged view of the basin in a Landsat TM image is provided. A block diagram is included showing an alluvial fan (A).

Figure 2. The Death Valley intermontane basin.

- a) Landforms (LF) and topographic forms (TF) of Death Valley interpreted from a Landsat TM image [30].
- b) Block-diagram simulating the 3-D representation of Figure 2a.

Figure 3. Organization and spatial relationships of physiographic provinces and features, topographic forms, and landforms for Basin and Range.

Figure 4. Physiographic rule inferring the Basin and Range Province. Indicators like 'frequency of mountain ranges', 'shape of a mountain ranges', etc. as used by Fenneman in his physiographic descriptions (Table 1) could be inferred from the shaded relief map of Figure 1 or from Landsat Thematic Mapper Images such as the one shown in Figure 2.

Figure 5. Dynamically created objects.

- a) Inferred objects PH_1 and PH_2 are members of the Basin and Range physiographic class. Object PH_2 was further refined and assigned to the Youthful Erosion stage class.
- b) The landform object LF_1 is an alluvial fan inferred from pattern elements (PE), geomorphology criteria (GM) and spatial associations (SP) while LF_4 is a playa inferred only from pattern elements (PE). LF_1 is a part-of a Piedmont Plain object (TF_1) while LF_4 is a part-of a Basin Floor object (TF_2). Both objects TF_2 and TF_1 are parts of the physiographic feature PF_1 that is a-kind-of closed Intermontane Basin (Bolson).

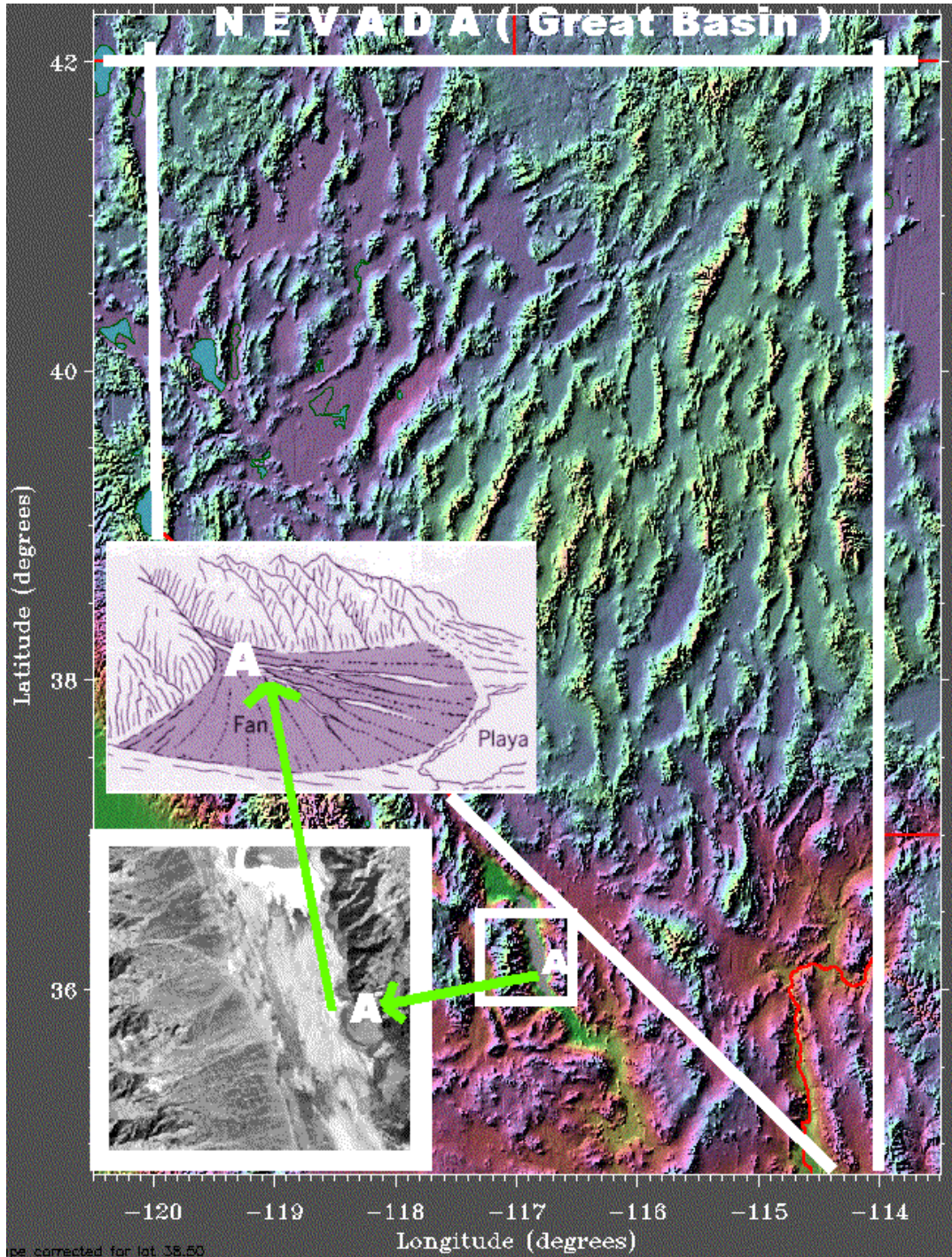
Figure 6. Extraction of Mountains.

- a) Initial set of mountain seeds generated by runoff simulation in the upslope direction.
- b) Gradient derived from the GTOPO30 DEM. Gradient values (minimum is 0 and maximum is 35 degrees) were rescaled to the interval 255 to 0 (the lighter a pixel is the lower its gradient is).
- c) Boundary and label identification of mountain objects in the study area.
- d) Physiographic map of the study area [8].

Figure 7. Fuzzy set representation of the linguistic variable Diameter (size) of the Mountains in the Great Basin physiographic context [18].

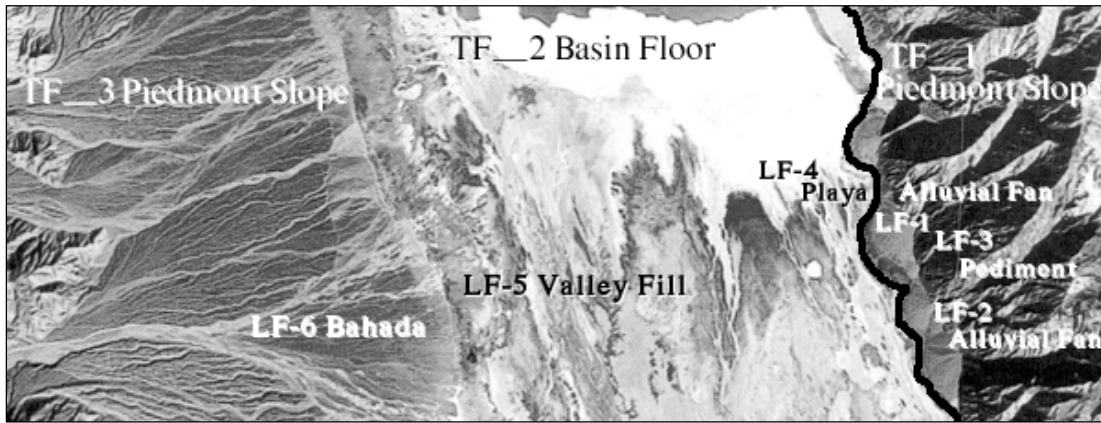
Figures

Figure 1

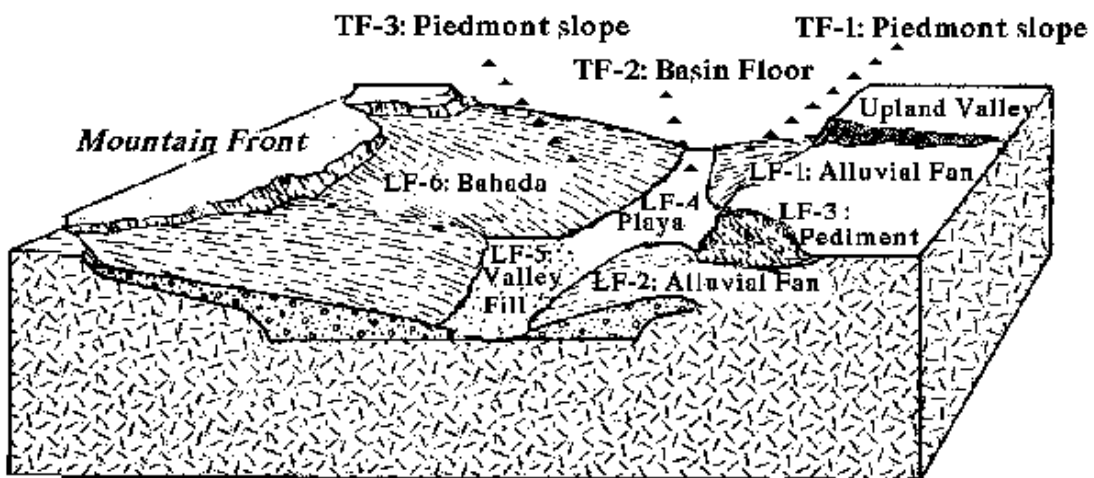


pe corrected for lat 38.50

Figure 2



(a)



(b)

Figure 3

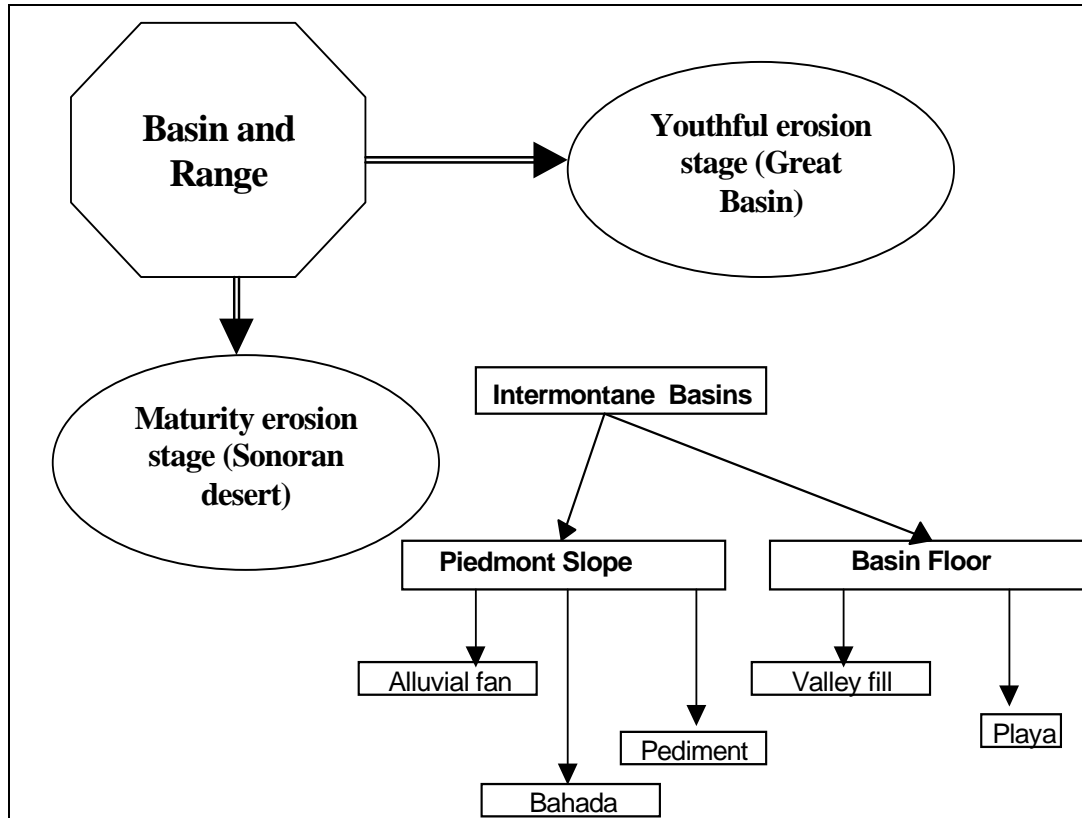


Figure 4.

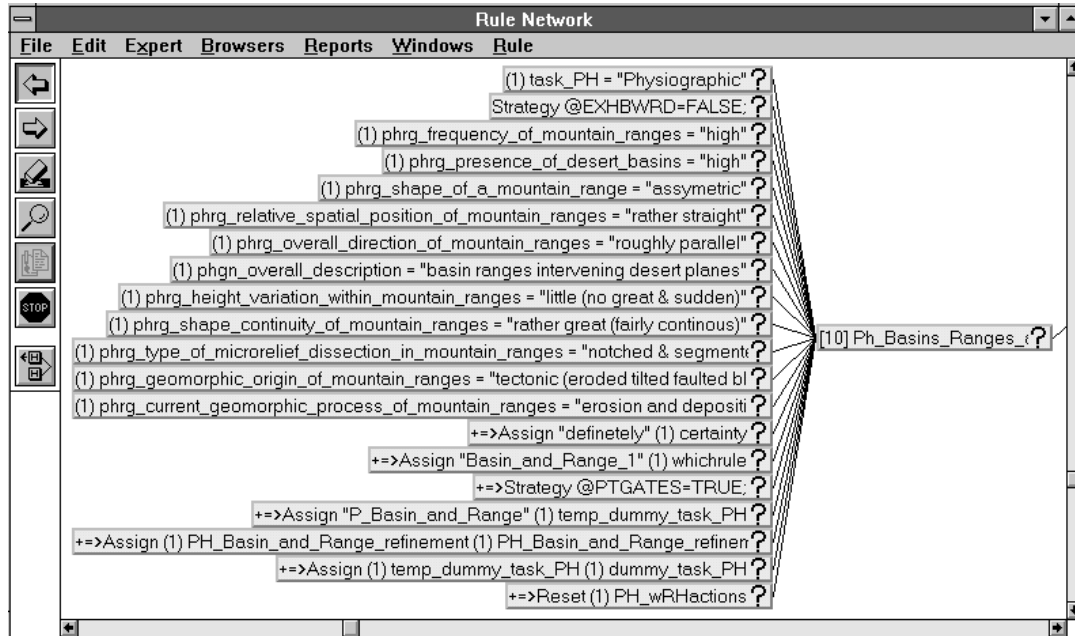
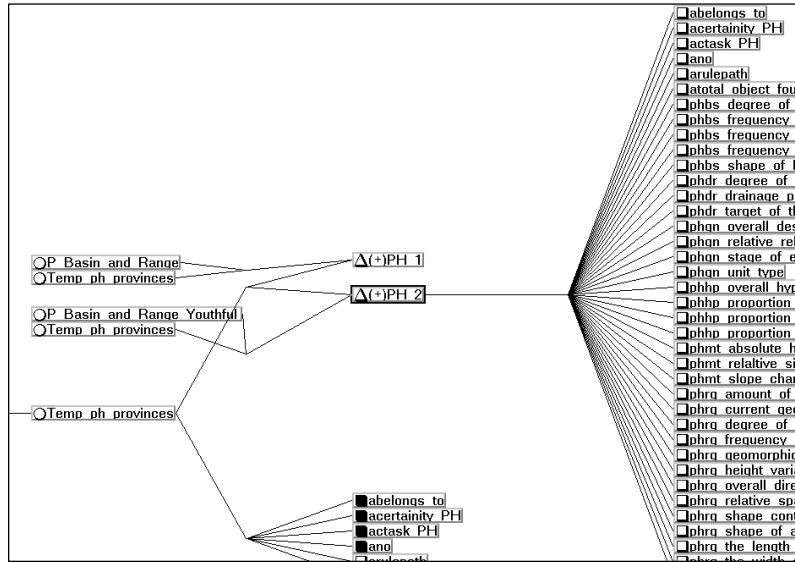


Figure 5.

(a)



(b)

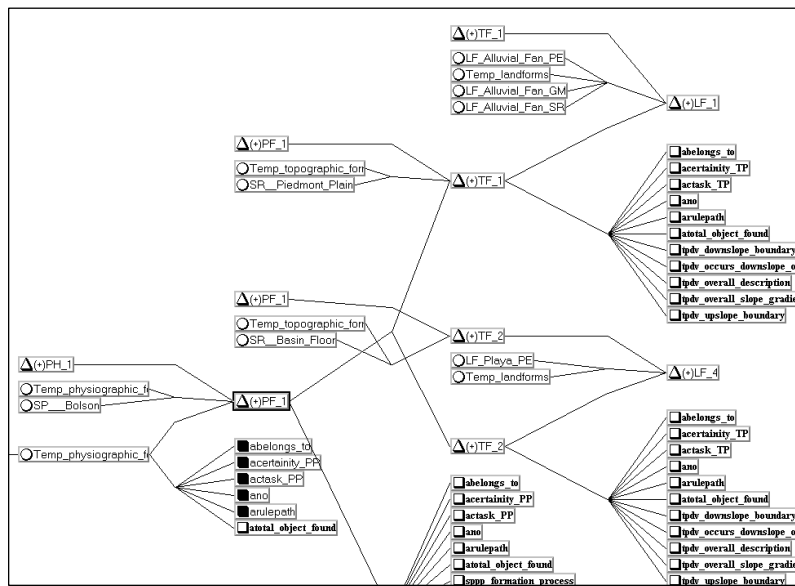
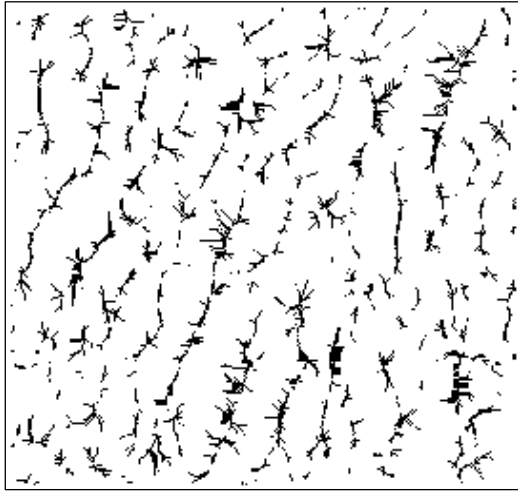
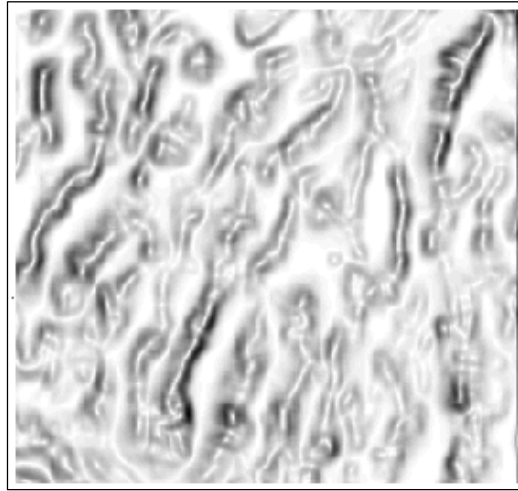


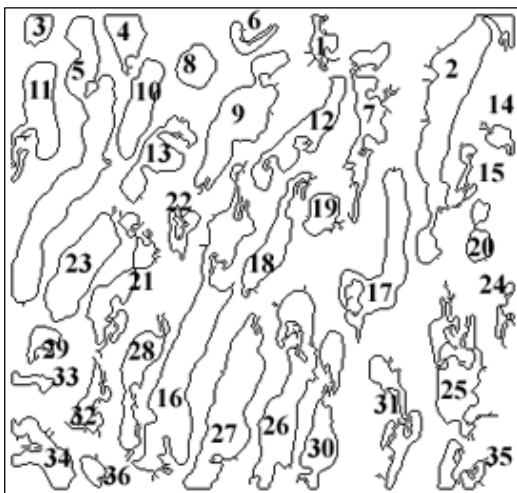
Figure 6.



(a)



(b)

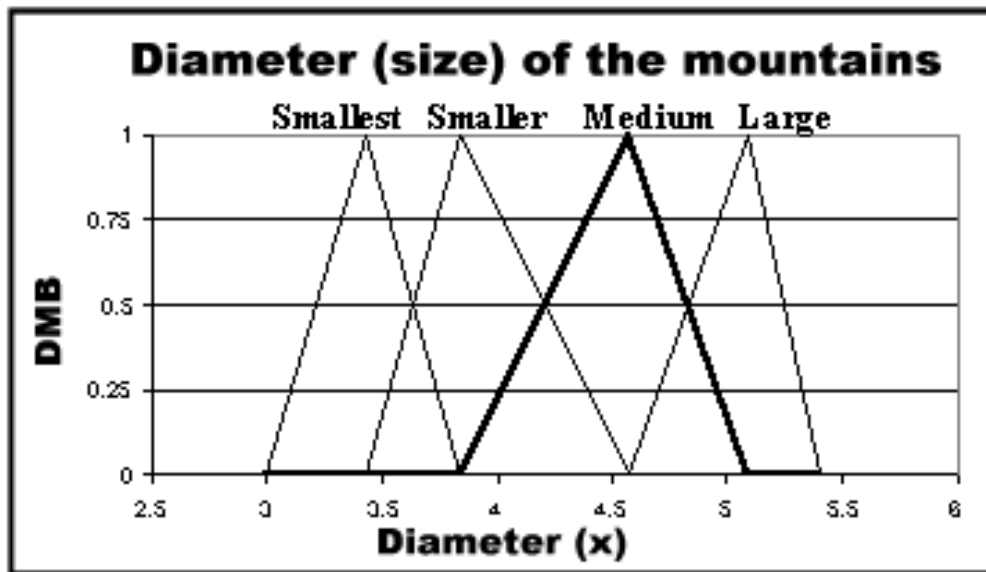


(c)



(d)

Figure 7.



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