# A reference landform ontology for automated delineation of depression landforms from DEMs

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## Abstract

The reference landform ontology presented here is intended to guide automated feature delineation algorithms for digital elevation models (DEMs). Since only form related information is available from DEMs, the categories of this reference ontology are defined based only on morphological criteria. The choice of landform categories is informed by ethnophysiographic and spatial cognition research. Currently incorporated categories reflect the current focus on semantic querying and automated mapping of depression landforms (e.g., basins, valleys and canyons).

## 1. Background

GeoVoCamps provide a forum for building ontologies or controlled vocabularies for tractable knowledge domains. This paper reports initial findings from a GeoVoCamp meeting held in College Park, MD in November 2016 to guide the US Geological Survey with its design of a conceptual reference ontology. The primary purpose of this reference ontology is to support natural language topographic information retrieval and context-sensitive algorithms for user-controlled automated delineation of cognitively salient landforms (e.g., hill, mountain, valley). The first step at this GeoVoCamp meeting was to refer and reuse concepts from the *surface network* (SN) and *surface water feature* (SWF) terrain ontologies that resulted from previous GeoVoCamps. The SN ontology (Sinha et al. 2017) formalizes the minimum mereotopological semantics for describing the shape of a surface. The SWF ontology (Sinha et al., 2014) formally distinguishes between terrain features that act as containers (channel, depression, and interface) and the contained bodies of water (stream segment, water body, and fluence). This work further combines these ideas with the formal ontological approach to geo-physical objects and the negative parts – so-called holes or voids – they may host (Casati and Varzi, 1994; Hahmann and Brodaric, 2012).

## 2. Conceptualization of the reference landform ontology

The primary category of this reference ontology is *landform*, which represents entities that are three-dimensional features located on the solid surface of the Earth or similar planetary bodies. Landforms may be material (e.g., mountains) or have both material and immaterial parts, such as a water body that consists of a river bed, the depression it hosts, and the water therein (Brodaric et al., 2017). Landforms may be assigned some characteristic geometric, topological, mereotopological, temporal and material properties. Knowledge of the agents and types of processes that create landforms or in which landforms participate should also be specified when possible to support geoscientific conceptualizations. However, because this is a reference ontology intended for broad usage in both scientific and naïve geographic contexts, only a few landform properties that people can intuitively sense and cognize are used to define the top-level categories.

Figure 1 is a graphical representation of the taxonomic relationships identified (thus far) for this reference landform ontology. The choice of these fundamental categories is based on landform categories and descriptions from multiple languages and cultures, especially as revealed from ethnophysiographic research of one of the authors (Mark and Turk, 2003; Mark et al., 2007). Since delineating landforms from DEMs is an important motivation for this ontology, only the fundamental criterion of form (shape) is used to define the categories of this reference ontology. Other important categories that people define using material, color, and cultural qualities are, therefore, not currently included in this reference landform ontology.

As shown in Figure 1, there are three fundamental types of landforms that people have been found to conceptualize across cultures and languages: *convex landform*, *concave landform*, and *plane landform*. These categories are covert in the sense that most languages do not specifically have terms recognizing these abstract, top-level landform categories. However, the various landform categories and related concepts encountered in ethnophysiographic research provide strong evidence for explicit modeling of these categories in a reference landform ontology. Convex and concave landforms cover an overwhelming majority of landform categories, with plane landforms covering remaining (perceptually) flat areas. This categorization also suggests the need for designing different methods for searching and delineating concave, convex, and plane landforms.

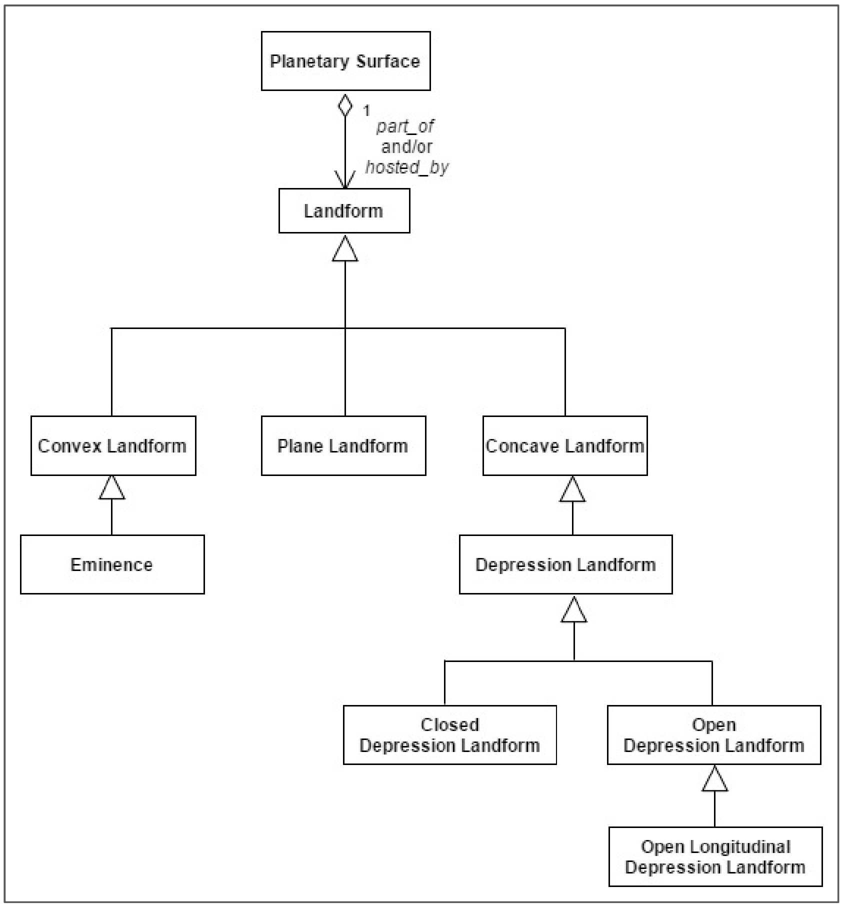


**Figure 1. Relationships between categories of the reference landform ontology**

## 2.1 Convex and Concave Landforms

Convex landforms protrude outward or upward from the surface. *Eminence* covers an important sub-group of convex landforms (e.g., mountain, hill, butte) that stand above their surroundings. Eminence ontology is still being developed as part of another project. The reference landform ontology described here reflects this group's focus on clarifying concepts that are critical for designing methods for delineating different kinds of *depression landforms* (defined below).

In contrast to convex landforms that protrude out, concave landforms are indented, necessarily hosting holes and giving rise to a sense of material missing from the surrounding host surface. The most significant subcategory of concave landforms is *depression landform*, which covers low-lying landforms surrounded by higher land (e.g., basin, river-bed, valley). Examples of concave landforms that are not depressions would be caves or tunnels.

Depression landforms can be further classified as *closed* or *open.* Note that the *closed depression landform* category specializes the *SN:Basin* category and is conceptually identical to the *SWF:Depression* category. For terminological simplicity and specificity, in this reference ontology, the term *depression landform* refers to the superordinate category of *all* depressions.

A *closed depression landform* is surrounded by higher ground, and has, as part, one level rim (represented by a *SN:contour*) marking the depression's upper edge, one pour point at the level of the rim, and a wall or basal surface that is impermeable enough to allow water storage. In sufficiently wet conditions, closed depression landforms store water and may be perceived to form still water bodies (e.g., puddles, lakes, ponds) with the water they contain, consistent with the view proposed in a recent ontology of water features and their parts (Brodaric et al., 2017). All other depressions are examples of *open depression landform* because they lack either an enclosing rim or their basal surface is sufficiently permeable. Thus, open depression landforms cannot store water for long periods of time (e.g., sink-holes).

Both open and closed depression landforms can be further categorized by their planimetric shape to distinguish landforms that are elongated, that is, have a single primary "length axis" from those that are not elongated. Elongated open depression landforms (e.g., valley, canyon, ravine, canal, trench, fissure, fault) are frequently referenced in natural language and are captured in this reference ontology by a named subcategory of open depression landforms: *open-longitudinal depression landform*. These depression landforms have a primary, sloping longitudinal axis bounded by upward sloping sides, and are generally open at both longitudinal ends. In wet conditions, they contain or host flowing bodies of water (e.g., rivers, streams). Most instances of the *SWF:Channel* category are examples of and also parts of instances of *open-longitudinal depression landform*.

## 3. Ontology extension, alignment and application for delineation of depression landforms

How can such a conceptual reference ontology help in landform delineation? Its usefulness lies in specifying a controlled vocabulary and categorical relationships and properties that can help in reasoning about which automated delineation tools must be chosen or which type of landforms can be delineated. For example, delineation of closed and open depression landforms requires different methods. Valley, canyon, gorge, ravine, gully, hollow, gulch, chasm, rill, canal, and trench in the English language are possible sub-categories of *open-longitudinal depressions*. Differentiating between instances of these types maybe quite challenging, requiring detailed three-dimensional morphometric measurements, and possibly knowledge of geomorphological agents and processes.

If such specific information is not available, as an alternative, based on semantic similarities between landform categories (e.g., valley/canyon/ gorge, gully/gulch), delineation requests for one category could return instances of all related categories, or recommend searching for only the superordinate category (i.e., all types of *open longitudinal depression landforms*, instead specifically search for only valleys, canyons, or gorges). On the other hand, geoscientific classifications may be more precisely specified and supported for delineation.

An important next step is to formalize this ontology with specification of all classes and properties and linking it to previously developed ontologies such as the SN and SWF reference terrain ontologies, and more generally applicable reference ontologies of voids (Hahmann and Brodaric, 2012) and water features (Brodaric et al., 2017). These ontology alignments will not only capture the detailed semantics of the categories but also extend inferencing capabilities to provide deeper insights about when, where and how to delineate landforms based on semantic queries. For example, a search for lake boundaries can be automatically inferred as also requiring delineation of a closed depression landform; or a query for a valley floor can be simplified as delineation of an area within a certain distance and/or depth of a *SN:CourseLine*.

It is also anticipated that this group (and others) will continue to add more specialized landform categories to extend the scope of this reference ontology. Some of the categories will necessitate inclusion of non-morphological criteria such as size, material (e.g., sand dune, drumlin), color, geomorphological origin, or culturally significant factors, and therefore, require supplementary data in addition to DEM datasets. On the other hand, ethnophysiographic research has shown that diverging ontological assumptions about landforms must be contended with when recognizing such specialized landform categories. Thus, diverse multilinguistic, multicultural and multimodal (e.g., using text, maps, photos, videos) human subject experiments must also be conducted to validate the contexts in which delineation methods might be guided by this reference ontology.

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