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LETTERS TO ESEX

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Landscape domains and information surfaces: Data collection, recording and citation using decimal latitude-longitude geolocation via the FAIR principles

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Abstract

There is a need for geomorphology to integrate better with related disciplines, especially in Critical Zone science. To help satisfy this integration, geomorphology's knowledge-base should extend into biotic as well as geological processes via 'open data'. To aid information exchange between disciplines, the use of decimal latitude-longitude (dLL) topographic geo-referencing is advocated to identify locations of investigations, images and data in accord with the FAIR principles for data: findability, accessibility, interoperability and reusability. While local place names (toponyms) have their uses, they do not provide good location information. Identification of detailed locations using dLL referencing should be used in written, especially published, reports of investigations. Author-date citations are traditionally used to identify geomorphic knowledge, which can be enhanced when linked to dLL-specified locations and data such as sample sites and laboratory data. Ways in which dLL specifications might be used in geomorphology and associated disciplines are explored and some geomorphological problems associated with 'steepland' landscape domains are presented. Examples show how dLL data can be incorporated into the literature, whereby authors can help provide and develop geomorphic 'information surfaces' by using geo-referencing to enhance 'open' science via the FAIR principles.

KEYWORDS
Critical Zone, decimal latitude-longitude, FAIR data principles, geomorphological information, information surfaces, landscapes, landscape domains

1 | INTRODUCTION

The visual landscapes studied by geomorphologists have a distinctive role in Critical Zone (CZ) science; a multidisciplinary approach to earth surface processes (Giardino & Houser, 2015; Whalley, 2022a). Here, I explore how geomorphologists might improve interdisciplinarity and engagement with other scientists in the CZ and earth sciences and beyond, including social sciences (Donaldson et al., 2010) and in dealing with 'wicked problems' (Kawa et al., 2021). Many studies in earth and environmental sciences use locations and spatial data; observations relate to digitally-specified topographic domains. These domains are 'geomorphic information landscapes'. Geolocation, specified by decimal latitude-longitude (dLL), can be easily incorporated into the FAIR data principles: findability, accessibility, interoperability and reusability (Wilkinson et al., 2016). These principles can involve the growing movement of 'open science' (Mons et al., 2017) and its benefits (McKiernan et al., 2016) as well as ICON attributes (integrated, co-ordinated, open and networked data; Burberry et al., 2022).

This letter examines some ways information, *within* geomorphology *and* across borders, can be set up to help share knowledge for the future using a dLL location convention. Mainly mountain/steepland landsystems are examined; those subject to substantial boundary shifts in response to climate change and anthropogenic activities (Aguilar & Giardino, 2023). I suggest how geomorphology can also better 'explain' landforms at a variety of scales. Thus, Siqueira et al. (2022):

> The correct delimitation of landforms has great importance for Earth surface study, since these spatial entities define the boundary conditions for a series of environmental processes at landscape scale (Evans, 2012).

To establish earth surface ecosystems, it is necessary to establish reference systems which encompass topography and onto which information can be mapped to establish 'geomorphic information fields' (or surfaces) within the CZ. Sharing geomorphic information is also required to link earth surface features elsewhere, for example to those on Mars (Balme et al., 2011; Conway et al., 2019). No attempt is made to provide a comprehensive discussion, rather the examples and references provided are indicative of how dLL specifications can and might be used widely and to incorporate the FAIR data principles of findability, accessibility, interoperability and reusability.

1.1 | Some background problems in geomorphology

Geomorphology has no equivalent to molecular biology's 'central dogma', or atomic physics' 'standard model', although it does share with engineering that complex 'processes', based on physics, chemistry and biology, can be modelled. Geomorphology has no rigorous classification schemes or taxonomies in which observations can be discussed. Material-movement connectivity is complicated by involving information on 'magnitude-frequency' and time-scales (Thornes & Brunsden, 1977). Such complexity applies to *location* and geometrical, landform, changes of displaced bodies and the materials involved. As in engineering, there is a need to structure and record data/information in a consistent manner. Some of these issues are of long-standing (Baker & Twidale, 1991; Brunsden, 1996) and research into 'processes' needs to be focussed on problems of landform development (Douglas, 1982), an aspect particularly important in linking to CZ investigations.

Prediction of the magnitude/frequency and locations of events is a problem in hazard research and sustainable landscapes (Boardman & Vandaele, 2023), but some landforms ('geomorphic entities') are remnants of in situ weathering and scale-time changes in boundary conditions; tors on a small scale, erosion surfaces more widely (Rapp, 1996) for example. Yet in this, geomorphology is a little different from astronomy and cosmology. New views of familiar astronomical features are being made by the JWST in the IR spectrum and expected for the Square Kilometre Array (SKA) for radioastronomy. Both telescopes rely on integrating digital sensor data, 'big data', to help investigate the universe perhaps using citizen science, for example, galaxy identification using 'Hubble's tuning fork' classification (NSO, 2023). Many aspects of geomorphology, especially related to spatial distributions and temporal changes, require *co-ordinated data integration* better to explain changing environments to other scientists and the public. For example, Fryirs et al. (2019) have discussed big data and the role of human data integration in river studies. Classifications help organise data, imposing order when new items are discovered, highlighting cases where the data fit is not good. Any knowledge is cognitive and personal;

> Your knowledge alters how you see things. The things you see become part of your knowledge. Your knowledge alters how you see things. You can never see the things themselves (Stone, 2012, p. 155).

Such a statement is particularly applicable to geomorphologists, who have to ask from where they get their knowledge. Plant taxonomists re-classify species between one genus (even family) and another and hybridization occurs. Organisms' shapes and colours are often misleading; genetics and cladograms provide different and more informative classifications and viewpoints. Hybrids occur in landforms; a *mudslide* may become a *mudflow* (flow-slide) according to the water content, materials properties and thus behaviour. Engineering geomorphological classifications are visual ('reading the ground') as well as related to earth materials (Hutchinson, 2001) where fieldwork, mapping and visualising (Hungr et al., 2014) are important parts of 'understanding' (Fookes et al., 2000; Griffiths, 2014), perhaps related to Cézanne's conceptualizations of Montagne Sainte-Victoire (Elderfield, 2020). I now examine some visualisation examples within information landscape and landsystem approaches before looking more closely at linking geomorphic data to organise, store and share data with context (Honti & Abonyi, 2021).

1.2 | Reading landscapes: 'What do you mean by…?'

Nomenclature problems are common in geomorphology. Examples in mountain/steepland geomorphology include both specific and generalised concepts; U-shaped valley, rock glacier, periglacial and even 'mountain'. Much geomorphological interpretation depends upon analogical reasoning and ill-defined, phenetic, landform 'classification'. Visual cognitive impressions of a site, between locations, and in landscapes (and what others have thought) need to be linked. Although geomorphological attention is on 'processes', how processes operate at the level of *mechanisms* is necessary to explain topographic forms and landscape development over varied timescales. For geomorphology to be a partner in environmental and CZ studies, linking processes and mechanisms to environmental configurations, ecosystems and environmental management (Brighenti et al., 2019) as well as species adaptations to cold environments (Ornaghi et al., 2023) is required. Knowledge of biota and organic mechanisms is necessary in the soil components of the CZ.

Although most landforms are identified by topographic form-geometry, and are generally mapped as such, I have argued for the explanatory interplay between materials (M), processes (and detailed mechanisms, P) and the resultant geometry (G) (Whalley, 2022a). Considering the CZ, biota (B) should be added (Figure 1). Viewpoints involving soils/vegetation/animal/microorganism interactions with mineralogy, temperature and biogeochemical weathering mechanisms extend into the hydrosphere, lithosphere and atmosphere. A related 'functional unit' approach is taken by Pöppl and Parsons (2018) in their consideration of connectivity in the 'geomorphosphere'. Further discussion on weathering is included by Pope (2015) and Tchakerian and Pease (2015) and, in the context of CZ, by Frings and Buss (2019). Figure 1 suggests why simple, process-landform, classifications

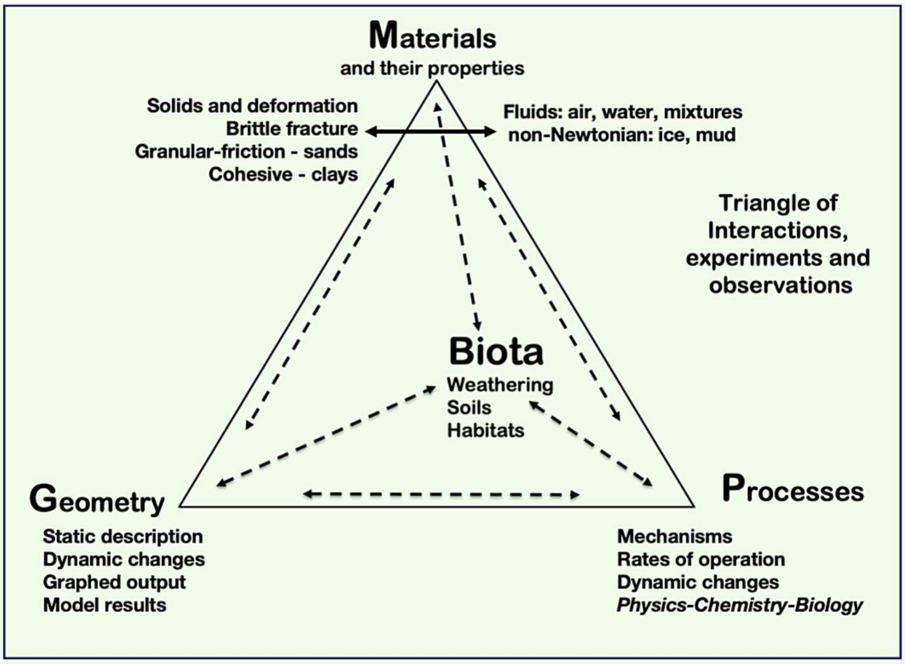

FIGURE 1 The MPGB tetrahedron, modified from Whalley (2022a) showing the main interactions. A 'biota' element (B) accounts for interactions in the Critical Zone and elsewhere. Some links between MPGB, with various aspects of landscapes, are shown together with decimal between latitude longitude (dLL) locations to facilitate the production of 'information landscapes'.Locations shown:Mendip Hills, Burrington Coombe, England [51.3195,-2.7492]Plateau summits, Lyngen Peninsula, Norway [69.3670,19.7779]Image: ©W Brian Whalley (orcid: 0000-0003-3362-3527) CC BY-NC-ND 4.0. 2023. Image of mountain Critical Zone by courtesy of © Jenny Parks and Roger Bales, University of California, Merced.

in geomorphology may be problematic and that communication between workers is important.

The biota may be important in discussing habitat changes via biogeochemical mechanisms as well as riverbank stability (crayfish) and flood control with natural dams (beavers). In general, MPGB relationships suggest links within and between investigations in associated disciplines, such as CZ sciences. The relationships may also impinge upon planning, aesthetics, art and literature, as discussed by Tooth et al. (2016) and Whalley (2022b) require particular communication skills between scientists as well as the public and varied audiences (Slack, 2021), geoheritage in particular (Gordon, 2012; Gordon & Baker, 2015).

Multi-layered network interdisciplinary sustainability and climate change projects, in which geomorphology was a significant component, have been examined by Honti and Abonyi (2021). Their analysis took account of data hierarchies to examine linked data (LD) and the resource description framework (RDF) data model. The RDF model uses universal resource identifiers (URI) based on the subject-predicate-object triple to encapsulate information about an 'object'. However, academic citations are generally of the form (author-date-title-source), typically found in a *Google Scholar* (GS) search, are linguistically linked (Cimiano et al., 2020) and are used in phrases such as, '… in investigations by X, Y, Z' to support, or oppose, an author's viewpoint or perhaps identify a landform, landscape or process. The LD principles state that web technologies; HTTP, RDF and URIs, should be used to structure data, which is interlinked to become more useful through semantic queries, typically associative and contextual being machine-readable, and which can also be 'open' (Lausch et al., 2015). Data may be 'open'—openly accessible, exploitable, editable and sharable—for any purpose. This applies not only to sources of information, as in journals, but also to the data used to provide the information in books, tables, graphs and analytical reports. Researchers of the future can then obtain useful information for each resource. To extend the range of linguistically-LD beyond traditional geomorphology and to discover related resources or entities, such as landform or process (Figure 1), further data need to be explicitly added to an investigation. I propose that one way to enhance data utility is via unique digital locational referencing as outlined below.

1.3 | Taxonomies and ontologies in geomorphology

Campos, Quesada-Román, and Granados-Bolaños (2022) provide an example of 'classical' and 'digital' geomorphological mapping and 'morphology dynamics and boundaries' that are germane to geospatial explanations (Rhoads, 2022). Quantitative geography led to spatial analysis: morphometry was applied to climate by Chorley (1957) and landform mapping (Evans, 2012). Mapping and GIS sophistication has a geographical, spatial viewpoint. Although we might visualise tors with virtual or augmented reality (Moore & Gerrard, 2002), it does not mean they can be 'explained' better. Communicating geomorphology widely involves interpretation to varied audiences (Slack, 2021) and curation of geomorphological assets in geoheritage (Gordon, 2012; Whalley, 2022b).

A recent curation of geomorphic assests of the periglacial landscapes of Europe (Oliva, Nývlt, & Fernández-Fernández, 2023), 'Offers a valuable reference guide for scientists from all disciplines interested in cold climate processes, as well as readers outside academic (territorial managers, environmentalists, mountaineers, politicians, engineers etc)' (back cover information). This very comprehensive study relies on a traditional (author-date-title-source; adts) format to capture the information about features, landform typologies and processes although lying behind a paywall. The book 'Periglacial Landscapes of Europe' (PLoE) (Oliva et al., 2023) can be considered as an example of a geomorphological 'folksonomy', when collaborative 'landform tagging' produces a user-generated classification system. Although there is a digital (Kindle) book version, there is no index to facilitate data searching. The tagging of an object, such as a landform, is done with author-date-title-source referencing, that is, linguistic linking. Both physical and electronic book versions are examples of an 'information bundle' (Gorman et al., 2002, p 1248). Bundles are 'organized, highly selective collections of information to help solve problems and maintain situational awareness'. Unfortunately, the 'periglacial' compendium of PLoE is not digitally searchable, thus reducing its effectiveness. As PLoE has no index to list landforms or locations, the searcher must rely on manually sifting through the accumulated knowledge. What might be called a 'messy bundle' is a mixture of resources, some references being searchable but with imprecise definitions and un-referenced locations. Despite having an ISBN and digital object identifier (DOI), the *PLoE* volume does not provide a digital, searchable source of papers to provide an information surface of periglacial features for Europe.

As elsewhere in the geomorphic literature, the location of a landform of interest is almost always a linguistic, toponym, tag, even if an image is used as an illustration of the landform (as in *PLoE*). This was acceptable when there were few investigators, but the literature is now increasing rapidly, with citations occurring in journals well beyond the traditionally 'geomorphological'. For example, the realms of machine learning (ML), remote sensing and GIS as well as CZ journals may have reference to 'periglacial landforms'. This diversity makes it difficult to use 'Linked Data' methodologies in the searching process.

I now examine some landform relationships in mountain/steep slope landsystems. I argue that the complex nature of geomorphology, as with the periglacial landforms just visited, needs to account for the nature of 'information' and data in a digital age (Eisenstein, 2022). Yang, Cormican and Yu (2020) point out that, 'Extant systems engineering standards are so fragmented that the conceptualization of a cohesive body of knowledge is not easy' and propose an 'ontology learning methodology' to progress to digital systems that will aid interoperability. For contemporary and future geomorphology, ontologies should include digitally-referenced locations and, as far as possible, be uniquely referenced to aid literature and database searching to aid site comparisons, climatic controls and hazard evaluation within a linked, open data, information landscape.

1.4 | Geomorphic information surfaces and their specifications

In general, geomorphology lacks robust concept models for knowledge representation, that is, a data model (Richard, 2006) and requires a better ontological basis for investigations and data management (Garcia et al., 2020; Raskin, 2006) as suggested previously. The MPGB tetrahedron (Figure 1) is indicative of research areas and is recorded in publications labelled by individuals or teams, which can be identified via literature searches, traditionally by author-date-title-source but also by DOIs. Topographic locations are usually identified by toponym 'local labels'; 'Yosemite', 'Wrightwood' or 'Perth Amboy'—but may have varied significance, perhaps generational or related to research topics. Locations rarely coincide with toponyms from other research areas, such as 'Galapagos'.

A GS search, for 'red mountain geomorphology' gives different locations and in Wikipedia *Red Mountain* gives many possibilities. In Scotland, *Monadh Ruad* and *Beinn Ruadh* (*monadh* = *moor; beinn, bheinn, ben* = *mountain; ruad* = *red* = *coch* in Welsh) might also confuse. A GS search for 'protalus rampart bheinn' (or Baosbheinn) produces several examples. Hence, providing a dLL is *much* more useful than local names alone, although it may also elicit terminological difficulties associated with the tagging, 'what is a protalus rampart?'. Mapping poorly-defined geomorphological information onto imprecise topographic and information surfaces contrasts with the specificity necessity for airlines for example.

The lack of clear landform classifications indicates a need to reference features uniquely so investigators can see unambiguously 'what is meant by…'. The different URIs for the feature 'rock glacier' is an example. These limitations also apply to features within other mapped surfaces: geologic, climatic, tectonic and so forth. Zonal limits and biome extents have changed, along with definitions and classifications. This transience of *zonality* represents problems similar to morpho-climatic ideas in geomorphology, particularly in mountain domains. However, other interpretations of climatic geomorphology (Bekseitova et al., 2014; Mahala, 2020) *are* important with respect to climatic conditions. Climatic record data come from specific locations in an information field. Problems in data-driven landslide susceptibility (Lima et al., 2023) also come into this purview.

The European Soil Data Centre (ESDA, 2023) presents several ways to classify landforms (Mücher et al., 2010) where, 'Landscapes are ecological meaningful units where many processes and components interact… landscapes themselves have resulted from long-term interactions of natural abiotic, biotic, and anthropogenic processes'. This statement shows the need for good locational specification for experimental design and data integration (Figure 1).

1.5 | dLL and landscape domains

Geo-referenced locations of features or images should use dLL formatting, being more compact and typographically unambiguous than the degree-minute-second style. The tuple (51.1788, −1.8261) uses a csv-separated decimal pair (Whalley, 2021a, 2021b), the number of decimal places showing the ambiguity or 'dilution of precision' of a location. Negative values are west of the prime meridian and for southern hemisphere locations. (The negative sign should be a keyboard, 'hyphen-minus' unicode 002D; print journals may use an 'em-space dash', which has a different character value.) This is analogous to the declination (latitude) and right ascension (longitude) in astronomy. A dLL geolocation provides:

- a unique location, according to the decimal places, obtainable from handheld devices
- values that can be used to identify locations in Google Earth (GE) and Open Street Map
- a data format allowing transferability and interoperability for information integration
- data points that can be visualised (via augmented reality perhaps) and analysed.

A dLL specification can be associated with information about a point. The Global Land Ice Measurements from Space (GLIMS; Raup et al., 2007) glacier atlas provides information about locations and mapped extents. But what does a 'glacier location' mean if a glacier (<0.5 km^2) ceases to exist? Rather than inventory locations, reports need dLL information such as glacier snout locations over time. With a dLL tag, geomorphological information could be added; dated moraines, debris input quantities and dates mapped. Recent work (Dietzen & Rosing, 2023) suggesting the use of glacial silt to enhance weathering for CO_2 uptake provides only place labels for sampled Greenland glacier sites. On a wider glacial basis, Hotaling et al. (2017, 2943) discuss the diverse microbial habitats in glacial ecosystems where, 'mountain glaciers remain one of the most understudied, yet arguably most imperilled and rapidly changing, ecosystems on Earth'.

1.6 | Topographic searching

Geological mapping for specific purposes such as coal mining (Oldroyd, 2013) occurred before William Smith's classificatory map. Bayesian and ML techniques are methodologies that rely on digital data (Kirkwood et al., 2022) for mapping in three dimensions. Such ML approaches can also be used to exploit auxiliary variables in geochemical mapping (Kirkwood et al., 2016) and emphasise interpretability and interoperability. A dLL-located site allows borehole or outcrop and other data to be added. The same is true of a geological section or cutting to add geomorphic data. Such digital surface and sub-surface information might be used for other purposes than the original. Papers in Whitmeyer et al. (2012) explore possibilities of using Google Earth and visualisation in geoscience education and research. More recently, Open AI's *ChatGPT* and Google's *Bard* suggests possibilities of large language literature searching and investigation, although ChatGPT is *not* a search engine; it is predictive not retrodictive. The 'Obsidian' knowledge-base note-taking (using markdown) software can already be used for making links and knowledge graphs for personal and shared use. Bergen et al. (2019) outline ML and data-driven discovery in earth geoscience where, 'Physical, chemical, and biological processes interact and have substantial influence on this complex geosystem'. The following sections suggest how locational linkages might be used in practice to add geomorphological information to landscapes.

Specifying the location of *any* geomorphological feature or assemblage of features, should use a dLL when referring to it in the literature, whether paper, popularisation or thesis. Local surveys typically use local co-ordinate systems and refer to paper map locations but, in future, dLL locations should align with the FAIR principles. This is especially important for assessing relationships between entities in different landscapes and in specifying inventory data. Using appropriate dLLs should become part of citing research information and reporting sample points and image locations. Doing so would help control the degrees of freedom for spatial data and allow better knowledge sharing between disciplines.

1.7 | Adding information with a dLL: rock glaciers and information landscapes

Locations identify features of interest on the earth's surface as part of 'information fields' and, as dLLs, they can act as database identifiers; locations to be catalogued and shown in relation to other landforms. How should links to 'the literature' be made? Literature citations drive institutional, commercial and personal fame and worth. We have problems with uniqueness, or not, of locational names, geomorphic terminology and linking information *between* disciplines. Where the proliferation of literature and journals grows apace, terminology may not align easily with the FAIR principles, as noted in previous examples.

In the mountain domain, there has long been debate about the origin and significance of 'rock glaciers'; whether they have a glacier ice core or not. This is a problem of observation, information mapping and investigations (held in papers) onto a topographic form. Identification is visual; 'I know a rock glacier when I see one' (Colucci et al., 2019), and Machine Intelligence (MI) may still have identification problems (Erharter et al., 2022). Concisely, the set of features with the visual characteristics of *rock glacier* can be denoted by the digraph label, RG, used for mapping and feature identification (Whalley, 2021b). More generally, a class (or type) has attributes within an associated information container: RG{attribute 1,... attribute *n*} equivalent to the set {RG, attribute 1,... attribute *n*}. The set may also contain landform examples (or tokens), usefully dLL locations rather than toponym labels. Specifically, RG[44.642,−109.791] specifies a token RG at that dLL. In the literature, this is usually termed 'Galena Creek Rock Glacier' (in a paper perhaps given the local label *GCRG*).

A location on the information landscape can also have author attributes, abbreviated author-date-title-source, for example {**RG** [44.642,-109.791], (Barsch, 1987; Barsch, 1996; Potter, 1972)}, here denoting authors with differing viewpoints about that **RG**. Specifically, Potter's paper indicates a glacier origin for the rock glacier, but the Barsch citations state that only a permafrost origin is possible. Others subsequently confirmed Potter's view: {**RG** [44.642,-109.791], (Ackert, 1998; Cecil et al., 1998; Clark et al., 1998; Petersen et al., 2020; Potter et al., 1998)} and further citations and information could be added. The findings of these authors are linked to the investigation site, that is, on or within the geomorphic information landscape.

Topographic landscapes, especially regarding modelling approaches (diffusional, CA and non-local), sites will benefit from dLL-specified site references and with the ability of points to be considered in Eulerian or Lagrangian reference systems. For example, Gray et al. (2022) have recently used a dLL (although not in the tuple format) to specify an investigated fault-scarp site on a hillslope. The AGU 'Landslide Blog' (Petley, 2023) regularly uses the dLL format for identification of reported events and features. Conversely, investigations of 'static' landforms, such as tors, would benefit from being able to locate individual sites by using dLL location. Again, we may ask, 'what do you mean by a tor?' Illustrations of tors in *PLoE* (Oliva et al., 2023) sometimes have place labels but, more often, do not. The recent work by Máčka et al. (2023) identifies tors in the Bohemian-Moravian highlands with a map and locations in a table (their table 2) but with six place decimal degree specification in two columns, which is not easily findable. The cosmogenic data (their table 4) have laboratory identifiers but no locational data at all. Such data need to be shared and available for comparison with other to locations, rock types and 'ages'.

Although the dLL information in most citation-references is lacking (as noted previously in the periglacial landscape book and the previous example), this does not mean that it cannot be added retrospectively or used to provide access to new information. Using a dLL appended appropriately to a feature or reference/citation will be of value for the future, and especially for good scientific communication. Information contained within book compilations tend to be closed for the future use.

1.8 | Adding field evidence to the information landscape at RG[44.642,−109.791]

The glacier ice core site reported by Steig et al. (1998, figure 1), at Galena Creek Rock Glacier is seen in Figure 2a. Figure 2b is a 2020 GE image showing the site location and a surface melt pool that developed since about 2006 and was used for ground truth in a seismic study (Petersen et al., 2020). These images (especially if given DOIs) also add to the site attribute data set: {**RG**[44.642,-109.791], ice core[44.6444,-109.7926], melt pond[44.63981,-109.79135]}. The example shows new information added to a site specified by a landform label (**RG** for rock glacier; Whalley, 2021a) and geolocation: **RG** [44.642,-109.791]. Such landform-locations are potentially searchable as is the caption metadata for Figure 2. The image *and* its caption provide information about the locality, where the investigations and observations are mapped onto the dLL in information space. Currently, we use place/toponym labels very loosely (as above). Once the site of interest (e.g., a landform) is dLL-located then searching for the relevant tuple can be automated. Information from a paper, report or thesis, associated with a location is shareable. Further data can be added, via the **RG**[dLL] container {information about the feature} as illustrated in Figure 2 and where the images and caption metadata themselves might be given a DOI.

1.9 | Classifications, feature inventories

Rock glaciers and tors are not the only landform to offer definitional problems. Thwaites et al. (2022) list many papers on what is, and what is not, a 'gully' and the need for classification. To the mountain domain digraph list (Whalley, 2021a), **GY** could be added for gullies and the concept **GY** could be discussed at geolocated points. Blong et al. (1982) provide data on gullies near Wellington, NSW, [−32.6,148.94] but with insufficient precision to allow a resurvey. ML and related techniques (Arabameri et al., 2020; Li et al., 2019) might be used to identify and provide inventory data on gullies, as has also been employed for rock glaciers (Erharter et al., 2022). The importance of communication between scientists investigating terrestrial and Martian features is evident in the recent volume about Martian gully systems (Conway et al., 2019) although the terrestrial examples do not have geo-referencing.

There has been a recent interest in rock glacier inventories. Some offer geo-located data points, but there is no uniform data configuration so they cannot easily be merged. Where bivariate data plots are provided, the tendency is to concentrate upon the data's regression/trend. Identification of outliers—which would be most informative—is not possible. Overall, such inventories do not yet comply with FAIR principles for data exchange to examine information; again pointing to the lack of feature organisation and communication in geomorphology. Gully data compilations should, as with rock glacier inventories, provide dLL-located data points. Not only would it then be possible to examine the importance of statistical outliers, but ML data mining and searching may well provide new insights into feature formation and significance from large data set ontologies.

FIGURE 2 (a) Noel Potter with a core showing information, 'evidence'; glacier ice and sedimentation banding at [44.6444,-109.7926] on Galena Creek rock glacier, **RG**[44.642,-109.791], 1996 reported in Steig et al. (1998, figure 1). This is the first time this field evidence has been openly published. Photo ©W. Brian Whalley (orcid: 0000-0003-3362-3527) CC BY-NC-ND 4.0. 2023. (b) Google Earth view of 2020 imagery of a surface melt pool (**p.**) on Galena Creek Rock Glacier at **RGp** [44.63981,-109.79135]. The arrow points downstream to the edge of the pool rim. The 2009 imagery shows the pool with a rim diameter of ∼8 m, 2015 imagery ∼33 m (with diameter shown) and ∼35 m in 2020. The circled drop pin shows the location of Figure 2a. Ground length between features is ∼350 m, distance from 2006 image to 2020 is ∼23 m over 14 years = ∼1.6 m/year. {Distance [44.6444,-109.7926], [44.63981, -109.79135] = 520 m}. Image ©Google Earth.

2 | DISCUSSION

2.1 | Data integration and information acceptance

Geomorphic landscapes provide complex data (Figure 1). The information contained in Figure 2, when geo-referenced, becomes part of the information set: {**RG**[44.642,-109.791](=Galena Creek Rock Glacier = *GCRG*)}. Similarly, any data (dates, boreholes, seismic lines, isotopic analyses etc.) should be dLL-tagged, to become part of a geomorphic information surface. Probabilistic, Bayesian, inferences (Bárdossy & Fodor, 2006) could be used to explore relationships with balance of evidence being appropriate, as in Toulmin's (2003) 'claim-data-warrants' argumentation. Using this object-information-based approach, Barsch's denial of the glacier ice core model is not substantiated and selective citations in reference lists allowing 'confirming the consequent' errors (Oreskes et al., 1994). As Tarantola (2006) has it, 'Practitioners usually seek the 'best solution' implied by the data, but observations should only be used to falsify possible solutions, not to deduce any particular solution'. In general, open data availability will be useful for testing ideas and concepts via procedures from medicine such as 'systematic reviews' (Bearman & Dawson, 2013) as with 'Cochrane Collaborations' (Shah & Chung, 2009).

2.2 | Data sets, graph theory and epidemiology

The organisation of geomorphological data using dLL geolocation will enhance the number of data points and thus ways of analysing multi-variable data sets. Andrews and Estabrook (1971) examined some moraine sequences using graph and information theory. Recent reviews of graph theory (Heckmann et al., 2015; Phillips et al., 2015) suggest useful ways of analysing geomorphological information surfaces. As geo-located sites represent nodes, vertices follow from their specification. Relationships in information fields could also be interrogated. Graph theory has been used in epidemiology (Maheswaran et al., 2009) and large data sets with dLL-tagging suggests that it could be used in exploring geomorphic information surfaces. Google Earth Engine has been used to generate information in fluvial (Boothroyd et al., 2021) and landslides (Wu et al., 2022); new ways of data mining locations need to be explored (Ma, 2018, 2022). Epidemiology is concerned with the *incidence* of disease in populations and not the question of the *cause* of an individual's disease—although it may help. The recent epidemics of COVID-19 (SARS-CoV-2) and 'avian flu' (HPAI A[H5N1]) show the need for contact identification, location and contagion-path tracking. Epidemiological approaches may be useful in discovering emergent data patterns to investigate causality. Thus, tracking developing melt ponds on rock glacier surfaces (Figure 2b) in warming climates may be significant with respect to rock glacier origins as glacier ice melts below a surface debris cover (Whalley, 2023). These principles will not be considered further, other than to point out the similarities with interpreting information fields to aid geomorphic knowledge by using large data sets.

2.3 | Future prospects

Historically, geological maps were driven by the need to determine minerals and similar resources, yet soil mapping was also important in driving 'a new visual language' (Rudwick, 1976). Latterly, maps are important,

> 'for our understanding of Earth and its processes, but it is generally the case that we are unable to directly observe the variables we are interested in at every point in space. For this reason we must use models to fill in the gaps.' (Kirkwood et al., 2022 p.508).

Data generation, especially from remote sensing and via Google Earth Engine have been mentioned above. Visualisation and data integration into existing and new ontologies and knowledge systems is already with us (Wang et al., 2018a, 2022) and geomorphology should play an important part in this as the topographic 'substrate' (Figure 1) for observations and knowledge-information construction (Wang et al., 2018b) using dLL location methods as advocated in this Letter.

Most paper citations tend to relate to 'recent' literature searches and may be incomplete. This is probably compounded by the effect of the GS algorithm (Anders & Evans, 2010; Beel & Gipp, 2009) and related search effects (Mikki, 2009). However, if papers use dLL locations to match author citations, databases will benefit future scientists, in general, not just geomorphologists (Figure 1). Additionally, journal reading would be made much simpler if dLL locations were given, even if locational maps are included under 'study site'. The 'closed' nature of information and data in books has already been mentioned.

Tools need to be developed to accommodate data interrogation, which fits in with the proposals of Paola et al. (2006). Information field theory (IFT) may help, where,

> 'information theory, logic under uncertainty, is applied to fields. A field can be any quantity defined over some space, such as the air temperature over Europe… or the matter density in the Universe. IFT describes how data and knowledge can be used to infer field properties' (MPA, 2023).

The information surface and IFT (Bayesian) approaches can be used with reference to geomorphological features. Certainly, 'intelligent systems' need to come on the research agenda for geomorphology (Gil et al., 2019).

The traditional referencing (author-date-title-source) may be convenient for many academics, but because much of the literature is behind some form of paywall, this information is not open, not

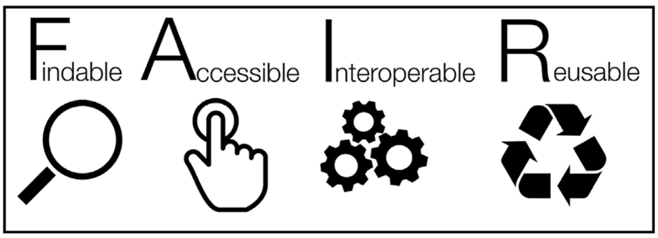

FIGURE 3 The FAIR data principles. Image: ©Sangya Pundir 2016 CC BY-SA 4.0. FAIR/O data is sometimes used to indicate that the data (including dataset or database) complies with the FAIR principles with an explicit data-capable, 'open licence'.

accessible by all, especially if the investigator, whether of the public or academic is in an institution without substantial resources (Figure 3).

3 | CONCLUSIONS

Geomorphology needs to communicate with many audiences, including the public and non-specialists, so geomorphological information should be preferably 'open' and in particular; findable, accessible interoperable and findable, now and in future communications. The geomorphological community itself needs to share its research findings of the past into the future and explore linkages with cognate disciplines in space and time. Building landscape domains and information surfaces using dLL location devices allows this. ML systems will need to have digital data available for exploring these data, old and new. Geo-referencing using dLL format in reporting sites, landforms and data in publications makes knowledge transfer easier. The form [dLat, dLong] conveniently represents locational data that can be linked to author citations and used in data recording, inventories and reviews. A dLL can be used to identify features on a specific image or specify data points; reference to locations might also be specified as a dLL list in publications. The use of dLLs allows:

1. Location identification and tagging supporting reader viewing and understanding
2. Location identification repeat observations, especially by new methods
3. Backwards compatible and forward compatible for locations, data and knowledge transfer
4. New methods of observation used on recorded sites of interest in diverse subjects
5. Data analysis and re-analysis by augmented reality in multi-dimensional spaces
6. Comparisons and establish relations between locations and sciences (MPGB)
7. Comparison of data in datasets, for example, for meta-analysis
8. Validity testing of theories and ideas within and across disciplines
9. Integration with and extension of the FAIR and ICON concepts (Burberry et al., 2022)
10. Building physical landscapes and models from dLL-tagged data using AI/ML tools.

Inclusion of dLLs into 'the literature' requires little extra work for authors and editors and provides distinct advantages for readers (as they can locate and visualise data more easily) and especially for future workers. This approach, linking location to information on information surfaces, needs to be implemented by authors, developed and extended. It is hoped that this paper initiates discussion and evolution by authors adding dLL locations to their publications. Those using geomorphological information and knowledge need a better way of recording and accessing information than just a GS search.

Geomorphological knowledge increases daily and extends into the Critical Zone via increasing publication outlets. This Letter suggests ways knowledge integration might be achieved but also become more 'open' with regard to accessing the scientific literature. Linking the FAIR principles into data accessibility, ICON (integrated, co-ordinated, open and networked) together with JEDI: (Justice; Equity; Diversity; and Inclusion) and IDEA (Inclusion; Diversity; Equity; and Accountability) heuristics (Goldman et al., 2022) allows a more socially-aware geomorphology to be developed.

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CONFLICT OF INTEREST STATEMENT

I confirm that I have no conflicts of interest regarding the ideas or material presented in this paper.

DATA AVALABILITY STATEMENT

Data in this paper are presented in the paper or the references cited.

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