Metadata for Users

This document describes metadata for Open-File Report 2013-1306, Geologic Map of Oldonyo Lengai (Oldoinyo Lengai) Volcano and Surroundings, Arusha Region, United Republic of Tanzania. It is intended to be more user friendly than the conventional metadata text document (filename: Metadata_ODL_20131231.txt). Key data herein are presented in tabular format. Ideally a GIS-oriented user would glance through this text, print a few tables or open them on an adjacent computer screen, and then begin analyzing the data contained in the GIS databases. Explanations in this document may prove helpful for understanding decisions made during the compilation of the geologic map.

Projection and datum

For polygons and polylines, GIS attributes are stored as zone 36 of the Universal Transverse Mercator (UTM) scheme, transverse Mercator projection, Arc 1960 datum (table 1). The corresponding EPSG code is 21036 (*http://spatialreference.org/ref/epsg/21036/*). Point data are in spreadsheet format with geographic coordinates given both as meters of easting and northing (UTM, zone 36, Arc 1960) and as degrees latitude/longitude (WGS84).

Files and file structure

The 19 databases needed to assemble the geologic map are summarized in table 2. Discussion here addresses those that have some complexity or the need for look-up tables. The datasets are enumerated fully in the standard metadata document (filename Metadata_ODL_20131231.txt).

Coding for Stratigraphic Units and Dikes (ODL_geomap_poly; ODL_dikes)

Map units are given a map-unit symbol in the columnar data (table 3), which allows the myriad polygons to be labeled according to age and formation or lithology (for example, Qa_1, Quaternary alluvium). Each map unit also has an integer value for stratigraphic coding (strat_code) in the GIS file, for users who prefer keying by numeric values. Full unit names in the GIS file match those in the Description of Map Units that appears on the geologic map sheet. The map-unit symbol is that used on the printed or viewing version of the map.

A brief lithologic description is included as columnar data. The column labeled Source is populated chiefly with “this map,” corresponding to our field work. Some polygons in the northwest corner of the map area, however, are transcribed faithfully from a small-scale map by Isaac (1967) and fitted to topography; those have “Isaac, 1967” as referable source. Seven small areas of debris-avalanche deposits near Lake Natron that appear on the map of Kervyn and others (2008a) apparently were overlooked in the making of our preliminary photogeologic map. They are added to our map and credited to the Kervyn publication.

A GIS layer (polyline file) shows three dikes (intrusions, unit QTei) that were emplaced into vent deposits (unit QTev) exposed in the Natron escarpment 6–7 km northwest of Oldonyo Lengai. They are coded accordingly in that file (feature = dike; strat_code 3212; unit symbol QTei).

Table1. Projection and datum.

Element	Definition
Projection:	Transverse Mercator
Grid Coordinate System	Universal Transverse Mercator
UTM Zone Number	36
Unit	meter
Scale Factor at Central Meridian	0.9996
Origin Longitude	33
Latitude of Projection Origin	0
False Easting	500,000
False Northing	10,000,000
Horizontal Datum Name	Arc 1960
Ellipsoid Name	Clarke 1880
Semi-major Axis	6378249.145
Denominator of flattening ratio	293.465
EPSG code	21036

Coding for map-unit contacts (ODL_GeounitContacts)

Given the reconnaissance nature of our mapping, most contacts can be shown uniformly, such as by solid line, with accuracy defined as “precisely or approximately located” (table 4). A few contacts, described as inferred and shown by short-dashed lines on the map, are drawn chiefly on the basis of geomorphology. For example, an inferred contact is used to map the outline of Oldonyo Lengai itself, a gradational boundary across which deposit character changes from chiefly primary volcaniclastic rocks to debris flows and alluvium. An inferred contact is also used to demarcate two stratigraphic units known only from single points of observation; thus the boundary is highly imprecise. Buried contacts, shown dotted, allow us to show features completely buried by younger tephra deposits on the flanks of Oldonyo Lengai; or to connect separately mapped outcrops of vent deposits into a single vent outline where debris-avalanche deposits mask the intervening ground.

Scratch contacts (lines with no stroke; table 4) are used to show the limit of our mapping within the area of geologic map neatline. Polygon color fill on the map terminates without a visible contact. The intent is to show that the map unit extends outward beyond our limit of knowledge.

Coding for structural features (ODL_structure)

Faults are the common structural feature in the map area, and they are coded by integer value (21, 22, 23, 24) and matching description to indicate mainly the accuracy of location (table 5). Additional structural features are gaping cracks (integer code 31, field checked) and other lineaments of uncertain origin (code 34) that were mapped on air photos but not field checked. One lineament has pebbles and sand associated with it, as do many of the gaping cracks. This lineament surely is tectonic in origin but lacks the visible opening of a crack, so it is coded separately (35). Not mapped are many lineaments that align with emplacement direction of debris-avalanches; these likely are related to the avalanche deposits and not to tectonic features (Kervyn and others, 2008a).

Age information is provided chiefly to distinguish Holocene faults (youngest structures), which are shown in red on the geo-

Table 2. Files used to produce GIS version of geologic map.

No.	Filename	Format	Feature Type	Contains	Explanation
1	ODL_Geomap_poly	shp	Polygon	Geologic map units, including open water	Intended for presentation at 1:50,000 scale
2	ODL_GeounitContacts	shp	Polyline	Map-unit (polygon) boundaries coded according to type	Lines as solid, dashed, dotted, and so on to show the characteristic feature of geologic contact accuracy and type
3	ODL_dikes	shp	Polyline	Line elements showing trace of dikes	Three dikes mapped in association with vents in unit QTev
4	ODL_structure	shp	Polyline	Structural elements such as faults, cracks, lineaments	Coded by type; separate column indicates age as Holocene, Pleistocene, or Quaternary (if not confidently assigned to H or P)
5	ODL_CraterRims	shp	Polyline	Hachured lines tracing rim of craters	Highlights topographic rims of volcanogenic craters that might not show well at existing topographic-map detail
6	ODL_LeveeCrests	shp	Polyline	Lines demarcating margins of lobate landforms (probably mostly debris-flow edges) and levee crests	From photogeologic mapping, adds textural grain in area of Oldonyo Lengai volcano
7	ODL_Roads	shp	Polyline	Line elements for roads and trails	Coded according to road quality
8	ODL_hypso	shp	Polyline	Topographic contours	Digitized from Mosonik and Oldonyo Lengai 1:50,000-scale quadrangles, 20-m contour interval
9	ODL_hydro	shp	Polyline	Stream and gully network	Digitized from Mosonik and Oldonyo Lengai 1:50,000-scale quadrangles
10	ODL_11kaShore	shp	Polyline	Latest Pleistocene shoreline determined by stromatolite and gravel occurrences	Digitized from Hillaire-Marcel and others (1986); neither mapped nor studied by us
11	ODL_strikedip	xls	Point	Sites with bedding attitude information	Coded for strike and dip
12	ODL_NotableSites	xls	Point	Some places mentioned in text	Geographic reference to sites of interest, as a guide for future workers
13	ODL_fluxgate	xls	Point	Location and polarity of sampled lava flows	Fluxgate magnetometer determinations of presumably thermal-remanent magnetization
14	ODL_PrevAges	xls	Point	Location, age, and analytical error for previously published ages	Ages from published literature, located according to source data or by georeferencing sample-location maps that appear in source publication
15	ODL_StromatoliteAgeLocs	xls	Point	Location, age, and analytical error for previously published ages	Radiocarbon ages from stromatolites, located by georeferencing sample-location maps that appear in source publication
16	ODL_NewAges	xls	Point	Location, age, and analytical error for newly determined ages	See appendix 5 (explanatory pamphlet) for methods and data
17	ODL_geochem_prev	xls	Point	Location and sample number	Locations published by Klaudius and Keller (2006)
18	ODL_geochem_new	xls	Point	Location and sample number	See appendix 3 (explanatory pamphlet) for methods. Full chemical analyses in spreadsheet that accompanies the databases for this map
19	ODL_GeogrNames	xls	Label point	Location (summit or centroid) of named feature	See appendix 2 (explanatory pamphlet) for naming conventions. On geologic map, position of names commonly displaced from centroid, for visual presentation

logic map. The distinction between Holocene and Pleistocene age for structures is in part estimation, since no trenching was undertaken. The term Quaternary is used in those cases where we lacked confidence about a Holocene age assignment but accept Holocene as possible or likely.

Data for “side down” show the side of the fault trace that has moved relatively downward. The scheme is stated simply as E (east) or W (west), since most structural grain in the map area is broadly north trending. The marker S (south) was used in the one case where a fault was nearly east striking. Gaping cracks have

Table 3. Numeric code values and map-unit symbols and names for stratigraphic units.

Strat code	Unit symbol	Map unit	Age
1	ow	Open water (Lake Natron)	1990 shoreline
101	Ql_1	Younger Lake Natron deposits	Holocene
102	Ql_2	Lacustrine deposits perched by debris-avalanche deposits	Holocene? and Pleistocene
103	Ql_3	Older Lake Natron deposits	Pleistocene
200	Qa_1	Young alluvium	Holocene
201	Qa_1-stipple	Young alluvium rich in angular to subangular blocks	Holocene
202	Qa_2	Alluvium of areas rarely alluviated in past 200–2,000 years or more	Holocene
203	Qa_3	Perched sand and gravel	Pleistocene
204	Qa_4	Gelai sandstone and cobble veneer	Pleistocene
205	Qa_5	Pebbly sandstone of high erosional surface	Pleistocene
301	Qsd	Sand dune	Holocene
401	Qls	Landslide deposit	Holocene or Pleistocene
1051	$Qoda_1$	Debris-avalanche deposits filling modern drainage and banked against midslope cone	Holocene or Pleistocene
1052	$Qoda_2$	Debris-avalanche deposits on east-northeast flank	Holocene or Pleistocene
1053	$Qoda_3$	Debris-avalanche deposits on north-northeast flank	Holocene or Pleistocene
1054	$Qoda_4$	Debris-avalanche deposits on south and southeast flanks	Pleistocene
1055	$Qoda_5$	Main avalanche sheet	Pleistocene
1056	$Qoda_6$	Blocks in ancestral lake deposits	Pleistocene
1101	Qot	Tephra	Holocene and Pleistocene
1102	Qol	Mica-rich lahars	Holocene
1201	Qom	Main-cone volcaniclastic rocks and lava flows	Holocene and Pleistocene
1202	Qom-stipple	Pyroclastic-flow(?) deposits of 2007–08	Holocene
1203	Qoml	Lava flows	Holocene and Pleistocene
1211	Qomlc	Carbonatite lava flows	Holocene
1212	Qomlu	Nephelinite of upper flanks	Holocene or Pleistocene
1213	Qomlp	Phonolite lava flow on lower east-southeast flank	Pleistocene
1221	Qomnc	Nasira tephra cones and spatter mounds	Holocene

Table 3. Numeric code values and map-unit symbols and names for stratigraphic units.—Continued

Strat code	Unit symbol	Map unit	Age
1222	Qomnl	Nasira lava flows	Holocene
1230	Qomv	Flank vent deposits	Holocene? and Pleistocene
1231	Qomv?	Likely buried vent deposits on basis of circular or semicircular landforms	Holocene? and Pleistocene
1250	Qomc	Central-crater beds	Pleistocene
2001	Qnc	Natron-Engaruka tephra cones	Holocene? and Pleistocene
2021	Qnl	Natron-Engaruka lava flows	Pleistocene
2031	Qntr	Natron-Engaruka tuff rings	Pleistocene
2041	Qnet	Natron-Engaruka extensive tuff	Pleistocene
2051	Qpne	Phonolite lava flow 10 km northeast of summit	Pleistocene
3010	Qvg	Volcanic rocks of Gelai volcano	Pleistocene
3020	Qvk	Volcanic rocks of Kerimasi volcano	Pleistocene
3030	Qsk	Sekenge tuff ring deposits	Pleistocene
3100	Qbs	Basaltic sedimentary strata	Pleistocene
3201	QTel	Volcanic rocks of the Natron escarpment, lava flows	Pleistocene and Pliocene
3211	QTev	Volcanic rocks of the Natron escarpment, vent deposits	Pleistocene and Pliocene
3212	QTei	Volcanic rocks of the Natron escarpment, dikes (in file ODL_dikes)	Pleistocene or Pliocene
3251	Tek	Lava of Endukai Kiti	Pliocene
3301	Tmc	Mosonik conglomerate	Pleistocene or Pliocene
3311	Tmv	Mosonik volcanic rocks	Pliocene or Miocene
4001	Qtse	Tuff and sandstone atop escarpment	Pleistocene
4011	Qmiu	Moinik Formation, upper tuff	Pleistocene
4012	Qmin	Moinik Formation, nephelinite lava flow	Pleistocene
4013	Qmic	Moinik Formation, claystone and tuff	Pleistocene
5011	Qh	Humbu Formation	Pleistocene
5012	Qhl	Humbu Formation, interbedded lava flows	Pleistocene
5021	Tnnm	Nephelinite lava north of Mosonik volcano	Pliocene
6011	Tsh	Sambu and Hajaro Basalts	Pliocene

Table 4. Numeric code values for map-unit contacts.

Line Code	Line Feature	Line Symbol	Explanation
10	Contact, precisely or approximately located	Solid	Contact exposed or can be estimated closely on basis of outcrops in adjacent units. In some places contact corresponds to abrupt break in slope and was placed on basis of air-photo mapping. Position has been determined by field work to within 50 m on the ground (1.0 mm at 1:50,000 scale)
11	Contact, inferred	Short-dashed	Geologic relations or ground surface morphology suggest contact present but not exposed and too uncertain to determine position more precisely than 100 m with confidence (2 mm at 1:50,000 scale)
12	Contact, concealed	Dotted	Trace of contact concealed by younger stratigraphic unit; positional accuracy uncertain but within 2 mm at 1:50,000 (100 m on the ground) and commonly within 1.0 mm (50 m on the ground)
15	Internal contact	Dash-dot	Geomorphic boundary between coalescing vent deposits (in unit Qomnc or Qnc) or alluvial fans (in unit Qa_1).
19	Scratch contact	None (no stroke)	Map unit extends beyond limit of mapping.

no measurable vertical displacement at current levels of exposure, so side down is noted as "O." The abbreviation n.d. (not determined) applies to some faults shown as concealed and also to lineaments not field checked. The abbreviation n.a. (not applicable) is assigned to shallow faults that bound a circular subsidence pit.

Data source: Most mapped features derive from our fieldwork, so the columnar data indicates "this map" as source. Some faults in the northwest corner of the map area are traced from Isaac (1967) and so credited.

Hypsography (ODL_hypso)

The hypsography layer contains vectorized contours that depict topography of the map area. Linework was traced manually from two topographic quadrangle maps: Mosonik and Oldonyo Lengai. Although machine scanning would have been preferable, efforts to obtain a base negative of the contours were frustrated (for Mosonik quad, the metric contour base negative was reported as lost or misplaced). Ray-tracing programs that might operate on a digital raster image scanned from the printed map produced erratic lines that would have required substantial clean-up time to obtain satisfactory copy.

Topographic contours are in meters above mean sea level (orthometric altitude). Contour interval is 20 m except on the upper part of Oldonyo Lengai volcano, where contour interval is 40 m on source maps—undoubtedly a decades-old decision made to improve legibility of the printed quadrangle maps. Key columnar data for the hypsography GIS layer are shown in table 6.

Discontinuous contours. The published topographic maps use the device of discontinuous contour lines in areas of steep terrain, such as the Natron escarpment. This common cartographic convention avoids a crowded appearance where the printed contours would fall too close together. The effect in the GIS file is a series of gaps along contour lines where contour information has been dropped by the cartographer. The choice of which contours to drop is systematic; particular contours are chosen to run continuously. The continuous contours, at 40-m intervals, lie at meter altitudes 600, 640, 680, 720, and so on. A consequence of this decision is that alternating 100-m contours (700, 900, 1100, and so on) are shown discontinuously in steep terrain.

Closed depressions. The few contours that define depressions entirely closed within the area of the map are coded by two methods, integer and text. Such contours are typically displayed as hachured lines (hachures pointing into depression). These contours have integer code 1 and text code Y (table 6).

Coding as a Way to Speed the Culling of Contours

We have chosen to add a numeric "index contour" to the hypsography datase, in order to provide a quick way to select contours of specific intervals. Choosing "index contour = 200," for example, selects all contours showing meter altitude 600, 800, 1000, and so on. If instead a 100-m contour interval were desired, the user would select for index 200 and 100 to obtain contours at meter altitude 600, 700, 800, 900, 1000, and so on. To pick all lines suitable for 40-m contour spacing, the appropriate index-contour selection would be 200, 100, and 40.

Complete Set of Topographic Contours at 100-m Intervals

Technical illustrators may desire a simplified topographic dataset for purposes of page-size maps. The 100-m contour interval is a common selection because spacing is suitable across the range of the map area. But the aforementioned discontinuous tracing of some contours and the lack of 20-m contour interval on the upper part of Oldonyo Lengai results in a GIS file that cannot be simplified to show continuous contours at 100-m intervals across the area of the map. To overcome this shortcoming we have created a separate GIS file (Topo_100m_intervals) solely for the purpose of illustrators; it is not used in the geologic map production. The file Topo_100m_interval is completed by interpolation between contour lines on the presumption that the topographic slope has constant gradient between existing contour lines. Consequently, those few contours needed to complete the 100-m aspect lack the accuracy of other contours in the dataset. In steep terrain this loss is minimal, since the map distance between adjacent continuous contours is never more than 50 m. On the upper slopes of Oldonyo Lengai, distance between continuous contours is locally as great as 100 m, which thus is the accuracy we assign to contours added by interpolation.

Hydrography (ODL_hydro)

The hydrography GIS layer contains vectorized line traces that depict stream courses as they appear on the Mosonik and Oldonyo Lengai topographic quadrangle maps. The stream lines on the base maps provide no distinction between perennial, intermittent, or usually dry water courses. Indeed, only two streams in the map area are permanent: Engare Sero and Leshuta; and most of the time they infiltrate completely into alluvium before reaching their ultimate sink, Lake Natron. Therefore the streams shown in the hydrography GIS layer serve mostly as a way to depict gullies and topographic trends on the map. Several stream courses anastomose in their lower reach, so that the common pattern in which stream junctions form a vee pointing downstream is matched by vee upstream across the broad alluvial plain of the southern Natron basin.

The Mosonik and Oldonyo Lengai topographic quadrangle maps have numerous stream lines (gullies) on the upper flanks of Oldonyo Lengai volcano. Some users may wish to simplify this presentation. Therefore we have coded the stream lines to show relative importance (1 highest rank, 4 lowest rank). Unlike the Strahler stream order system, which increases in number downstream from tributary to main stem, our numbering begins with mainstem (1) and proceeds upstream with increasing numbers according to stream significance. Geographic names are included for mainstem reaches of Engare Sero and Lashuta streams, the two perennial streams in the map area.

Table 5. Numeric code values and descriptions for structural features.

Line code	Feature	Line style	Explanation
21	Normal fault, well located	Solid	Fault exposed or displaced stratigraphic units sufficiently close that position has been determined by field work to within 50 m on the ground (1.0 mm at 1:50,000 scale)
22	Normal fault, approximately located	Long-dashed	Ground surface morphology sufficiently distinct that fault may be traced as escarpment on air photos or topographic map with confidence that position lies within 50 m on the ground (1.0 mm at 1:50,000 scale)
23	Normal fault, inferred	Short-dashed	Geologic relations or ground surface morphology suggest fault present but not exposed and too uncertain to determine position closer than 100 m with confidence (2 mm at 1:50,000 scale)
24	Normal fault, concealed	Dotted	Trace of fault concealed by younger stratigraphic unit; positional accuracy uncertain but within 2 mm at 1:50,000 (100 m on the ground) and commonly within 1.0 mm (50 m on the ground)
31	Gaping crack, well located	Tracked	Ground crack with no vertical separation. May grade into normal fault along strike. Cracks are a subset of structural lineaments, in this case of known origin
34	Lineament of uncertain origin	Dash-dot	Mapped on air photos but not visited. Feature most likely results from faults or ground cracks
35	Lineament of liquefaction origin	Tracked	Not a gaping crack but has pebbly sand layer (sand boil?) associated with it.

Latest Pleistocene Shoreline (ODL_11500yrShore) and supporting stromatolite-age locations (ODL_StromatoliteAgeLocs)

A single vectorized line depicts an ancestral shoreline. The shoreline features are described in a pair of papers (Hillaire and others, 1986, 1987); the latter has the more detailed page-size map (1987, their fig. 6-2). A latest Pleistocene age was deter-

Table 6. Characteristics of hypsometric data file.

Altitude, m	Index Contour	Closed Depression Integer	Closed Depression Letter	Map Sheet
800	200	0		Mosonik
700	100	1	Y	Mosonik
720	40	1	Y	Mosonik
1420	0	0		Mosonik
1440	40	0		Mosonik
2800	200	1	Y	Oldonyo Lengai

mined by radiocarbon dating of stromatolites, which, when calibrated (Calib v. 6.0.2 software, with 2-sigma error), indicate a shore occupied intermittently from about 13,900 to 11,500 yr ago. Positional representation by us may locally have error as poor as 500 m owing to the small scale (~1:450,000) of the page-size map and the commonly poor match between geographic features shown on the page map and our 50,000-scale geologic map. The shoreline trace coincides with an occurrence of light-brown sandstone and algal(?) limestone (see map, No. 1 in Index of Notable Features).

A few of the 46 stromatolite radiocarbon ages described by Hillaire-Marcel and others (1986) fall within the geographic reach of the map area. Their coordinates are compiled in spreadsheet format. Positional uncertainty is a problem in our rendition, in the range 350-900 m, because the page-size map (Hillaire-Marcel and others, 1987) seemingly points to a general geographic area, not a point-specific site. Some of the sample locations fall far upslope of the traced shoreline feature.

Whole-rock geochemistry

Whole-rock geochemical analyses are compiled into spreadsheet format (filename: ChemAnalyses_OldonyoLengai_20101221.xls). For decades, publications with geochemical data have failed to report sample-location coordinates or even depict the locations on suitably crafted map figures. Separate GIS layers show the exceptional cases: Klaudius and Keller (2006), as “ODL_geochem_prev.xls”; and our data as “ODL_geochem_new.xls.” The headers for columnar data of geographic coordinates are self explanatory. From them the user can choose the columns needed to create points in a GIS layer.

Radiometric ages—K–Ar and $^{40}Ar/^{39}Ar$ data

Complete age data for previously dated samples in the map area are compiled in table 2 of the explanatory pamphlet. Methods used to determine geographic coordinates for previously published ages are described in appendix 4. The database table for the GIS (ODL_PrevAges.xls) includes several samples from well beyond the map area, for this reason: Once a published sample location map is georegistered, it is efficient to digitize all the locations. Not listed in the GIS database are even rudimentary coordinates for ages reported by Isaac and Curtis (1974), which lack suitable geographic reference.

No effort was made to compile the few radiocarbon ages from the area (aside from the aforementioned stromatolite ages). Readers interested in them will wish to read carefully through three publications: Hay (1976, p. 192; and 1989) and Keller and others (2006).