UNITED STATES DEPARTMENT OF THE INTERIOR

GEOLOGICAL SURVEY

Spatial Geologic Data Model for the Gunnison, Grand Mesa, Uncompahgre National Forests Mineral Resource Assessment Area, Southwestern Colorado and Digital Data for the Leadville, Montrose, Durango, and Colorado Parts of the Grand Junction, Moab, and Cortez 1^{o} X 2^{o} Geologic Maps

by

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INTRODUCTION

The digital geologic and geographic information system (GIS) data presented here were prepared to aid in Grand Mesa, Uncompahgre, Gunnison National Forest (GMUG) mineral resource assessment Project studies by the U.S. Geological Survey Mineral Resource Program. The goals of the GMUG Project is to provide mineral resource data and an assessment for undiscovered mineral resources in U.S. Forest Service (USFS) and Bureau of Land Management (BLM) lands in southwestern Colorado. The Project area covers a large region in southwestern Colorado that is bounded by latitudes 37^{o} 45' to 39^{o} 30' north and longitudes 106^{o} to 109^{o} west. The study area is covered by all or parts of six 1^{o}x2^{o} topographic and quadrangle geologic maps, which include geologic maps for the Leadville (Tweto and others, 1978), Montrose (Tweto and others, 1976), Durango (Steven and others, 1974), Grand Junction (Cashion, 1973), Moab (Williams, 1976), and Cortez (Haynes and others, 1972) quadrangles. These geologic maps were used inasmuch as a complete remapping and compilation effort for this study area was beyond the scope of the Project.

Two possible geologic map data sets are currently available that cover the study area—the digital version (Green, 1992) of the 1:500,000 scale Colorado State geologic map by Tweto (1979), and the aforementioned six 1:250,000 scale geologic maps, which were previously not in digital form. The USFS and BLM asked for the data and interpretive derivative maps from the GMUG Project to be at least at 1:250,000 scale. In compiling the Colorado State geologic map, Tweto used a 1:500,000-scale topographic map as his base map, which has map accuracy standards that differ from those of the 1:250,000 scale topographic maps. Tweto also generalized the geologic map units and structural data to provide detail at the broader scale, which reduced the amount of detail and accuracy portrayed on the original 1:250,000-scale maps. Simply reprojecting the State compilation to the larger scale (1:250,000) was found to be unsatisfactory for this Project. Not only did the "stretched" map not accurately overlie the 1:250,000 scale topographic base map, but the details felt to be important to the Project objectives were eliminated by the generalization necessary for the State geologic map compilation.

Therefore, to obtain suitably accurate 1:250,000 scale geologic map coverage for the GMUG Project area, we used the Colorado parts of the above mentioned six $1^o x 2^o$ geologic quadrangles. Each was digitized in its native projection to produce ARC/INFO format geologic coverages attributed with the original map unit labels, which were not always common throughout the GMUG study area. The six coverages were then merged into a single digital geologic coverage, for which additional attributes were assigned, including a common rock unit label applicable throughout the study area as well as lithologic, economic, and aggregate quality parameters. Because the six source maps were independently developed, discontinuities exist at the boundaries between adjacent quadrangles. No attempt was made to reconcile these differences.

The utility of the digital data presented here goes well beyond the needs of the GMUG Project. Several of the critical building blocks for developing the spatial databases are provided in this report. Digitization of the original six geologic quadrangles has not only contributed to the GMUG Project, but also has provided a set of data that are potentially useful for a variety of other purposes. Digital rock unit descriptions can be used to build digital databases able to be queried for purposes other than the mineral resource assessment.

Building a digital geologic data model (database structure) for the entire region allowed the GMUG Project to undertake a GIS-based mineral resource assessment and aided the environmental studies for the area. However, the utility and power of this database is not limited to the goals of the GMUG Project. For instance, the map unit descriptions can be searched to find user-defined key phrases and features can be selected using these as criteria. As an example, generalized geologic maps based on rock unit ages or rock types (regardless of the age) can be easily produced. Derivative maps depicting slope stability, roadbed stability, and possible landslide potential might also be developed from these data sets based on the known lithologic character (for example, shales fail easier than granites). These auxiliary uses of the basic geologic and GIS data allow users to more fully utilize the scientific information contained in geologic maps even though the data were developed before GIS tools were available.

BACKGROUND

The geologic map (1:500,000 scale) for the State of Colorado was compiled by Tweto (1979) by using $1^{o}x2^{o}$ geologic quadrangle maps (1:250,000 scale) that were generated mainly during the 1970's. Green (1992) digitized Tweto's original linework and attributed the polygons with the rock unit labels, thus creating one of the first topologically structured state geologic maps. Green's digital version of Tweto's State map facilitated its use in geographic information systems applications. Langer and others (1997) added attributes that estimate the suitability of those rock units exposed along the Front Range urban corridor for natural aggregate used in Portland cement concrete. These attributes included evaluations of the physical and chemical qualities of each map unit and a generalized lithologic descriptor for each unit. With these attributes, that part of the digital data for the Geologic Map of Colorado that corresponds to the Front Range urban corridor can be searched for potential natural aggregate sources, as well as for units with broadly classified lithologic characteristics. Following the method of Langer and others (1997), Knepper and others (1999) further annotated the digital Geologic Map of Colorado of Green (1992) by adding attributes for the lithologic units, including information on the mode of formation, composition, texture, and variability of the mapped units. They also added a second set of attributes characterizing the physical and chemical properties of each rock unit for use as natural aggregate in Portland cement concrete and identifies other known uses of each unit for construction materials to evaluate natural aggregate potential on a statewide basis. For this report, we used a similar procedure to create a digital geologic map model for the GMUG study area.

To make the spatial database more powerful, map units were attributed using a hierarchical lithologic classification scheme being developed by Bruce R. Johnson (U.S. Geological Survey, written communication, 1999) (see Appendix C). Using these added attributes, the user can search on either general rock categories (for example, metamorphic, sedimentary, or igneous) or specific rock types (for example, basalt, granite, or quartz latite).

METHOD

The digital geologic data model was constructed for the GMUG Project area using the six original Colorado parts of the 1^{o}x2^{o} geologic quadrangle maps (Leadville, Montrose, Durango, Grand Junction, Moab, and Cortez) using the attributes given in Appendix A. The six maps were then merged, clipped to the study area boundary (latitudes between 37^{o} 45' and 39^{o} 30' north and longitudes between 106^{o} and 109^{o} west), and projected into a Lambert conformal conic projection. The Lambert conformal conic parameters used standard parallels of 33^{o} 0' 00" and 45^{o} 0' 00", central meridian 108^{o} 0' 00" west, latitude of origin 0^{o}0' 00", false eastings and northings of 0 meters, units used were meters, and the Clark 1866 spheroid.

The next step was to enhance the digital data by providing attributes for lithologic descriptions, lithologic character, economic geologic information contained in the original map unit text, and natural aggregate quality for Portland cement. To do this, a correlation matrix (similar to a correlation chart common on compiled geologic maps) was developed (Appendix B) that relates each of the original map units to a common map unit label (attribute Total; Appendix A, B). The source geologic map unit labels were retained to identify what the original authors labeled the units (attribute Type; Appendix A). The original map unit name and entire descriptions were recorded for each unit for each map (see spreadsheet mapunits.xls). From this, a new generalized map unit description (attributes Unit_1, Unit_2, Unit_3; Appendix A) was developed for the common unit name (attribute Total; Appendix A). Each of the new map units was then assigned attributes for age, lithologic descriptions for the primary and secondary rock types within each unit, general economic geology characteristics, and the physical and chemical characteristics of each unit for possible development as a natural aggregate resource for Portland cement (see Appendixes A and C). The digital geologic map of the GMUG Project study area is included on this CD as an Arc Interchange file, gmug_geol.e00.

The Federal information spatial data transfer standard (SDTS) files given on the CD in directory entitled XYZ are stored in the geographic coordinate system (decimal degrees of latitude and longitude) instead of the Lambert Conformal Conic projection used for the Arc/Info export format for the geologic data. The reason for this is that the ESRI Arc/Info implementation of the SDTS format does not support Lambert Conformal Conic projection with units of meters.

DESCRIPTION OF DIGITAL FILES

This database was developed to enhance the usefulness of the Colorado parts of the six $1^{o}x2^{o}$ quadrangle digital geologic maps for the purposes of conducting a mineral resource assessment of the GMUG study area by combining the rock unit descriptions and correlating each geologic map unit into a generalized unit description and series of attributes. Several of the data sets were developed using Microsoft EXCEL (version 97) and are included. The ARC/INFO interchange files are given as *.e00 files in the arc_file directory and the individual quadrangle geologic map digital data are in the quads directory.

Definitions of the attributes in spreadsheet mapunits.xls applied to the ARC/INFO digital geologic map (gmug_geol.e00) are listed in Appendix A. The map unit attributes are presented in the spreadsheet mapunits.xls. The individual rock unit descriptions for the Colorado parts of the maps were each entered into individual worksheets within the spreadsheet. Each worksheet is titled for the $1^{o}x2^{o}$ geologic quadrangle map from which the data were transcribed within the main spreadsheet. A unique numeric value (attribute G1), an age (attribute Age), and generalized map unit description (attributes Unit_1, Unit_2, and Unit_3) were assigned to each unit. The Geologic Map Unit Classification being developed by Bruce R. Johnson (U.S. Geological Survey, written communication, 1999) and reproduced in Appendix C was employed to describe the lithologic character for each unit (attributes Litho_1; Litho_2; Primary, and Secondary). Attribute Notes is a comment field reserved for each unit. Economic geologic characteristics, such as the presence of stratabound oil shale or coal, types of mineral deposits in individual units, are added using attributes Econ_1, Econ_2, and Econ_3. These economic geologic attributes are only those mentioned in the text of the source geologic map unit descriptions given in the original geologic quadrangle maps and do not necessarily represent the entire suite of mineral deposit types within each unit.

Many of the bedrock units within the study area are appropriate for utilization as natural aggregate in Portland cement concrete. Each of the general units (attribute Total) was characterized for physical quality (attribute Aggphys) and chemical quality (attribute Aggchem) suitability as aggregate. Estimates for natural aggregate potential are based on the general suitability of common rock types and sedimentary deposits for use as aggregate in Portland cement concrete as outlined in USGS Open-File Report 95-582 (Langer and Knepper, 1995). See Knepper and others (1999) for more details on applying the methodology to the geologic maps. Most of the geologic map units are compound units composed of several formations. Therefore, only parts of some rock units in the study area are actually of satisfactory physical and chemical quality, and the spatial distribution of these units provides a maximum estimate of where quality aggregate source rock may be present; detailed geologic maps must be consulted to determine the exact locations of quality natural aggregate sources.

CONTENTS OF THE CD-ROM

Main Directory

contents.txt	Text file that contains this section, Contents of the CD-ROM text.
OF99-427.DOC	This document, Open-File 99-427, in MS Word format.
OF99-427.WP5	This document, Open-File 99-427, in WordPerfect 5.1 format.
mapunits.xls	Excel (version 97) spreadsheet containing several worksheets of geologic map unit information. Worksheets titled Leadville, Montrose, Grand Junction, Moab, Cortez, Durango contain entire texts from rock unit descriptions for the Colorado part of each map. Worksheet Total contains a correlation matrix, for the map units, a generalized map unit name, generalized geologic map unit descriptions, economic geology and estimates

for suitability of the generalized unit for use as aggregate in Portland cement production.

av_lengd.avl — ArcView legend for shade set used for constructing an ArcView Project

gmugmeta.txt — Metadata file, which is a spatial data description file containing projection, lineage, authorship, and other data for the digital geologic data files

/arc_gmug — Directory containing the following ARC/INFO data files

- gmug.meta — GIS metadata information
- project.txt — Map projection information
- gmuggeol.e00 — Geologic data model and spatial geologic map for the GMUG study area.
- gmugfltl.e00 — Faults for GMUG study area
- gmugdisl.e00 — Fault displacement decoration for faults in GMUG study area
- stdybndl.e00 — Polygon for study area boundary
- frstbndl.e00 — Approximate location of USFS boundaries within the study area
- fnt003.e00 — Font set used
- mapbar.aml — ARC/INFO aml file that builds the scale bar for the map
- gmugl.aml — ARC/INFO aml file for building plot file of geologic map
- load.aml — ARC/INFO aml file for loading the datasets into ARC/INFO
- gmugshd.e00 — ARC/INFO shadeset used for plotting the geologic map

/arc_quad — Directory containing ARC/INFO data sets for the $1^{o}x2^{o}$ geologic maps

- /cortez/ — Subdirectory containing Colorado part of the Cortez$1^{o}x2^{o}$ geologic map geologic, fault, and fault displacement data
  - /cort_bed.e00 File containing strike and dip point data
  - /cort_dis.e00 File containing point data for down thrown side of faults
  - /cort_flt.e00 File containing arc data for traces of faults
  - /cort_geo.e00 File containing for arc data for contacts, polygons, and formation name attributes (type and code)
- /durango/ — Subdirectory containing Durango$1^{o}x2^{o}$ geologic map geologic, fault, and fault displacement data
  - /dura_dis.e00 File containing point data for down thrown side of faults
  - /dura_flt.e00 File containing arc data for traces of faults
  - /dura_geo.e00 File containing for arc data for contacts, polygons, and formation name attributes (type and code)
- /grandj/ — Subdirectory containing Colorado part of the Grand Junction$1^{o}x2^{o}$ geologic map geologic, fault, and fault displacement data
  - /gran_dis.e00 File containing point data for down thrown side of faults
  - /gran_flt.e00 File containing arc data for traces of faults
  - /gran_geo.e00 File containing arc data for contacts, polygons, and formation name attributes (type and code)
- /leadvlle/ — Subdirectory containing the Leadville $1^{o}x2^{o}$ geologic map geologic, fault, and fault displacement data
  - /lead_con.e00 File containing arc data for geologic contacts
  - /lead_dis.e00 File containing point data for down thrown side of faults
  - /lead_flt.e00 File containing arc data for traces of faults
  - /lead_geo.e00 File containing arc data for contacts, polygons, and formation name attributes (type and code)
- /moab/ — Subdirectory containing Colorado part of the Moab$1^{o}x2^{o}$ geologic map geologic, fault, and fault displacement data
  - /moab_bed.e00 File containing strike and dip point data
  - /moab_dis.e00 File containing point data for down thrown side of faults

/moab_flt.e00 File containing arc data for traces of faults

/moab_geo.e00 File containing arc data for contacts, polygons, and formation name attributes (type and code)

/montrose/ Subdirectory containing Montrose1^{o}x2^{o} geologic map geologic, fault, and fault displacement data

/mont_con.e00 File containing arc data for geologic contacts

/mont_dis.e00 File containing point data for down thrown side of faults

/mont_flt.e00 File containing arc data for traces of faults

/mont_geo.e00 File containing general geology for arc data for contacts, polygons, and formation name attributes (type and code)

/sdtsgmug/ Directory containing Federal information spatial data transfer standard format for US Forest Service land boundaries, outline of study area, and geologic data for the GMUG study area

/forstbnd/ Subdirectory containing US Forest Service land boundaries

/gmug_flt/ Subdirectory containing fault traces

/gmug_geo/ Subdirectory containing polygon data and attributes for geologic data

/studybnd/ Subdirectory containing study area boundary

/sdtsquad/ Directory containing Federal information spatial data transfer standard format geologic data for the 1^{o}x2^{o} geologic maps

/cortez/ Subdirectory for Cortez 1^{o}x2^{o} geologic map data

/flt Subdirectory containing SDTS files for fault traces

/geo Subdirectory containing SDTS files for geologic data

/durango/

/flt Subdirectory containing SDTS files for fault traces

/geo Subdirectory containing SDTS files for geologic data

/grandj/

/flt Subdirectory containing SDTS files for fault traces

/geo Subdirectory containing SDTS files for geologic data

/leadvlle/

/flt Subdirectory containing SDTS files for fault traces

/geo Subdirectory containing SDTS files for geologic data

/moab/

/flt Subdirectory containing SDTS files for fault traces

/geo Subdirectory containing SDTS files for geologic data

/montrose/

/flt Subdirectory containing SDTS files for fault traces

/geo Subdirectory containing SDTS files for geologic data

REFERENCES CITED

Cashion, W.B., 1973, Geologic and structure map of the Grand Junction quadrangle, Colorado and Utah: U.S. Geological Survey Miscellaneous Investigations Series I-736, 1:250,000.

Green, G.N., 1992, The digital geologic map of Colorado in ARC/INFO format: U.S. Geological Survey Open-File Report OF-92-0507.

Haynes, D.D., Vogel, J.D., and Wyant, D.G., 1972, Geology, structure,and uranium deposits of the Cortez quadrangle, Colorado and Utah: U.S. Geological Survey Miscellaneous Investigations Series I-629, 1:250,000.

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Langer, W.H., and Knepper, D.H., Jr., 1995**,** Geologic characterization of natural aggregate – A field geologist's guide to natural aggregate resource assessment: US Geological Survey Open-File Report OF-95-582, 32p.

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Tweto, Ogden, 1979, Geologic map of Colorado: U.S. Geological Survey Special Geologic Map, 1:500,000.

Tweto, Ogden, Moench, R.H., and Reed, J.C., Jr., 1978, Geologic map of the Leadville $1^{o}x2^{o}$ quadrangle, northwestern Colorado: U.S. Geological Survey Miscellaneous Investigations Series I-999, 1:250,000.

Tweto, Ogden, Steven, T.A., Hail, W.J., Jr., and Moench, R.H., 1976, Preliminary geologic map of the Montrose $1^{o}x2^{o}$ quadrangle, southwestern Colorado: U.S. Geological Survey Miscellaneous Field Studies MF-761, 1:250,000.

Williams, P.L., 1976, Geology, structure, and uranium deposits of the Moab quadrangle, Colorado and Utah: U.S. Geological Survey Miscellaneous Field Studies MF-360, 1:250,000.

APPENDIX A

Properties and data definitions for the add-on lithology and aggregate quality attributes file as applied to the digital data sets for the GMUG study area.

GENERAL ATTRIBUTES

TYPE - The label used on the original individual geologic quadrangle maps as supplied by the digitizing contractor. Contains some errors when check to original map. Retained for thoroughness.

CODE – Corrected map unit label of the original geologic quadrangle map.

QUAD – Name of the original Leadville (l), Montrose (mr), Durango (d), Grand Junction (gj), Moab (m), and Cortez (c) geologic quadrangle maps incorporated in the final coverage for the feature.

G1– Unique numeric value for each combination of map unit labels from each quadrangle map.

TOTAL – Generalized unifying geologic map symbol for each of the geologic units.

AGE- That part of the SYMBOL (above) that indicates geologic age. Symbol can be a combination of youngest (first character) and oldest (second character) for units that span more than one age period.

UNIT_1 - The formations, or the broad description of lithologies that are not formally named, included in the mapping unit.

UNIT_2 –The continuation of UNIT_1, where necessary.

UNIT_3 – The continuation of UNIT_2, where necessary.

LITHO_1 – General rock category for predominant rock type in map unit.

LITHO_2 – Specific rock category for predominant rock type in map unit.

PRIMARY– Dominant rock type(s) or texture(s).

SECONDARY–Subordinant rock type present in unit.

NOTES – Comment field.

ECON_1 – Economic commodity contained locally within map unit.

ECON_2 – The continuation of ECON_1, where necessary.

ECON_3 – The continuation of ECON_1, where necessary.

Aggphys - An estimate of the physical quality of a map unit as a potential source of aggregate for use in Portland cement concrete based on the lithologic descriptions for the unit (see Langer and Knepper, 1995):

satisfactory - Particles are hard to firm, relatively free from fractures, and not chiplike; capillary absorption is very small or absent; and the surface texture is relatively rough.

fair - Particles exhibit one or two of the following qualities: firm to friable; moderately fractured; capillary absorption small to moderate; flat or chiplike; surface relatively smooth and impermeable; very low compressibility; coefficient of thermal expansion approaching zero or being negative in one or more directions.

poor - Particles exhibit one or more of the following qualities: friable to pulverant; slake when wetted and dried; highly fractured; capillary absorption moderate to high; marked volume change with wetting and drying; combine three or more qualities under "fair".

Aggchem - An estimate of whether a map unit contains constituents that react adversely with Portland cement concrete (Chemical Quality) based on the lithologic descriptions for unit (see Langer and Knepper, 1995):

Innocuous—Particles contain no constituents which dissolve or react chemically to a significant extent with constituents of the atmosphere, water, or hydrating Portland cement concrete while enclosed in concrete or mortar under ordinary conditions.

Deleterious—Particles contain one or more constituents in significant proportion which are known to react chemically under conditions ordinarily prevailing in Portland cement concrete or mortar in such a manner as to produce significant volume change, interfere with the normal course of hydration or Portland cement, or supply substances which might produce harmful effects upon concrete or mortar.

APPENDIX B

Correlation matrix for the geologic map unit labels used in the Colorado parts of the Leadville (Tweto and others, 1978), Montrose (Tweto and others, 1976), Durango (Steven and others, 1974), Grand Junction (Cashion, 1973), Moab (Williams, 1976), and Cortez (Haynes and others, 1972) $1^{o}x2^{o}$ geologic quadrangle maps. Map unit names for each quadrangle correspond to a unique numeric value (G1). Inasmuch as the map units varied greatly for each individual map, the generalized map unit label (Total) can be a non-unique combination of map unit labels from the individual quadrangles. Data given in spreadsheet entitled mapunits.xls. Age qualifiers for Triassic use “@”, Pennsylvanian use “&”, and Cambrian use “_”.

Leadville	Montrose	Durango	Grand Junct	Moab	Cortez	G1	Total
Qa	Qa	Qa	Qa	Qa	Qa	1	Qa
Qa	Qa	Qa	Qt	Qa	Qa	2	Qa
Qa	Qa	Qa	Qa	Qa	Qag	3	Qa
Qa	Qa	Qa	Qt	Qa	Qag	4	Qa
Qa	Qa	Qa	Qa	Qa	Qap	5	Qa
Qa	Qa	Qa	Qt	Qa	Qap	6	Qa
Qa	Qa	Qa	Qa	Qa	Qae	7	Qa
Qa	Qa	Qa	Qt	Qa	Qae	8	Qa
Qe			Qae	Qae	Qe	9	Qe
Ql	Ql	Ql	Qc	Qcl	Qc	10	Ql
Qt	Ql	Ql	Qc	Qcl	Qc	11	Ql
Ql	Ql	Ql	Qc	Qcl	Qcl	12	Ql
Qt	Ql	Ql	Qc	Qcl	Qcl	13	Ql
Ql	Ql	Ql	Qc	Qcl	Qct	14	Ql
Qt	Ql	Ql	Qc	Qcl	Qct	15	Ql
Qb				Qb	Qb	16	Qb
Qd	Qd	Qd	Qpt	Qgm2	Qgm	17	Qd
			Qbt	Qgm2	Qgm	18	Qd
			Qpt	Qgm3	Qgm	19	Qd
			Qbt	Qgm3	Qgm	20	Qd
			Qpt	Qgm2	Qgd	21	Qd
			Qbt	Qgm2	Qgd	22	Qd
			Qpt	Qgm3	Qgd	23	Qd
			Qbt	Qgm3	Qgd	24	Qd
Qg	Qg		Qd			25	Qg
			Qag			26	Qg
Qgo	Qgo		Qp	Qat		27	Qgo
Qdo	Qdo					28	Qdo
QTa	QTa	QTg				29	QTa
Tbp						30	Tbp
Tt						31	Tt
Td	Td					32	Td
	Ts					33	Tsf
Tbb	Tbb		Tb			34	Tbb
Tbbi	Tbbi					35	Tbbi
Tbr	Tbr					36	Tbr

	Tbrt					37	Tbrt
Tui						38	Tui
Taf	Taf					39	Taf
Tial	Tial					40	Tial
Tpl	Tpl					41	Tpl
Tmi	Tmi				Tgg	42	Tmi
Tmi	Tmi				Tgd	43	Tmi
Tmi	Tmi				Tmn	44	Tmi
Tmi	Tmi				Tql	45	Tmi
Tv						46	Tv
	Tiql					47	Tiql
	Twm					48	Twm
	Tos					49	Tos
		Tsv				50	Tsv
		Thb				51	Thb
		Thr				52	Thr
		Tbh				53	Tbh
		Thu				54	Thu
		Tsm				55	Tsm
		Tsu				56	Tsu
		Ten				57	Ten
		Tev				58	Tev
		Tsn				59	Tsnt
		Ts				60	Tst
		Tn				61	Tnt
		Tr				62	Tr
		Tw				63	Twt
		Tm				64	Tmt
		Tgp				65	Tgpt
		Tbc				66	Tbc
		Tcl				67	Tcl
		Tfg				68	Tfg
		Tmp				69	Tmp
		Ttu				70	Ttu
		Ttj				71	Ttj
		Ttl				72	Ttl
		Trc				73	Trc
		Tsl				74	Tsl
		Tsi				75	Tsi
		Tcr				76	Tcr
		Tcd				77	Tcd
		Tf				78	Tf
		Tbd				79	Tbd
		Trp				80	Trp
		Tsp				81	Tsp
		Ttm				82	Ttm
		Tsc				83	Tsc
		Tq				84	Tq
		Tgr				85	Tgr

		Tlp				86	Tlp
		Tlc				87	Tlc
		Tiy				88	Tiy
		Tio				89	Tio
		Ti			Ti	90	Ti
		Theb				91	Theb
		Tsd				92	Tsd
		Tbm				93	Tbm
		Tur				94	Tur
TKi	TKi	TKi				95	TKi
		TKsa				96	TKsa
		TKba				97	TKba
		TKna				98	TKna
		Tsn				99	Tsn
		Tn				100	Tn
					Ts	101	Tst
					Tsj	102	Tsj
Tu			Tge			103	Tu
Tg	Tg		Tgru	Tgr		104	Tg
Tgp			Tgp			105	Tgp
Tgl			Tgd			106	Tgl
Tgl			Tgl			107	Tgl
Tgl			Tgdl			108	Tgl
Tgl			Tgdu			109	Tgl
Tgl			Tga			110	Tgl
Tgl			Tgrl			111	Tgl
Tgl			Tgg			112	Tgl
	Tt				Tt	113	TKec
	TKtc				Tt	114	TKec
		Tsbt				115	Tsbt
Two	Two		Two			116	Two
			Tw	Tw	Tw	117	Tw
			Twr	Tw	Tw	118	Tw
Tm						119	Tm
		Kk				120	Kk
		Kku			Kku	121	Kku
		Kkf			Kkm	122	Kkf
		Kkl				123	Kkl
		Kkp				124	Kkp
		Kf			Kf	125	Kf
		Kpc			Kpc	126	Kpc
		Kl			Kl	127	Kl
		Kch				128	Kch
		Kmf				129	Kmf
		Kpl				130	Kpl
Kw						131	Kw
Ki						132	Ki
Kmv	Kmv	Kmv	Kmv	Kmvg	Kmv	133	Kmv
Kmv	Kmv	Kmv	Kmv	Kmv	Kmv	134	Kmv

Kmvu			Kmvu		Kch	135	Kmvu
Kmvu			Kmvu		Kmf	136	Kmvu
Kmvl			Kmvl		Kpl	137	Kmvl
Kmvl			Knsm		Kpl	138	Kmvl
Kmvl			Kmb		Kpl	139	Kmvl
Kmvl			Kc		Kpl	140	Kmvl
		Klmv				141	Klmv
			Kh			142	Kh
			Kmgs			143	Kmgs
			Kns			144	Kmgs
			Kf			145	Kmgs
Kp						146	Kp
Km	Km	Km	Km	Km	Km	147	Km
Km	Km	Km	Kmf	Km	Km	148	Km
Km	Km	Km	Km	Kmb	Km	149	Km
Km	Km	Km	Kmf	Kmb	Km	150	Km
Kmu		Kmu	Kmu	Kmu		151	Kmu
		Kml	Kml	Kml	Kmj	152	Kml
		Kml		Kmfe	Kmj	153	Kml
Kmfm						154	Kmfm
Kc						155	Kc
Kd	Kd	Kd	Kd	Kd	Kd	156	Kd
			Kbc	Kbc	Kbc	157	Kbc
Kdb	Kdb	Kdb	Kdb	Kdb	Kbd	158	Kdb
Kfd						159	Kfd
Jm	Jm	Jm		Jm	Jm	160	Jm
			Jmb	Jmb	Jmb	161	Jmb
			Jms	Jms	Jms	162	Jms
	Jmj					163	Jmj
		Jw				164	Jw
	Jmw					165	Jmw
	Jmwe					166	Jmwe
		Je		Je	Je	167	Je
					Jwe	168	Jwe
					Jjwe	169	Jwe
Jme	Jme	Jme				170	Jme
			Jse	Jse	Jse	171	Jse
			Jse	Jse	Js	172	Jse
KJdm	KJdm					173	KJdm
	KJdj					174	KJdj
	KJdw					175	KJdw
KJde	KJde					176	KJde
Jmce						177	Jmce
JTRmg						178	J@mg
TRc						179	@c
JTRmc						180	J@mc
		JTRmd				181	J@md
				JTRgc		182	J@gc
				JTRn	JTRn	183	J@n

				JTRn	JTRnk	184	J@n
	TRd	TRd			TRd	185	@d
	TRPdc					186	@Pdc
TRPs						187	@Ps
			TRk	TRk	TRk	188	@k
	TRw		TRw	TRw	TRw	189	@w
			TRkw	TRkw		190	@kw
					TRwc	191	@wc
			TRc	TRc	TRc	192	@c
					TRkwc	193	@kwc
				TRm	TRm	194	@m
TRPcs						195	@Pcs
		Pc		Pc	Pc	196	Pc
		Pc		PPcr	Pc	197	Pc
PPm	PPm					198	P&m
						199	P&r
PPwm						200	P&wm
TRPcm						201	@&cm
Pm						202	&m
Pb						203	&b
Pmb	Pmb					204	&mb
Pmbe	Pmbe					205	&mbe
Pe						206	&e
Pee						207	&ee
	Ph			Ph		208	&h
				Phu		209	&hu
				Php		210	&hp
		PPrm			PPr	211	P&rm
		Ml				212	Ml
		Doe				213	Doe
		PDre				214	PDre
MDr	MDr	MDle				215	MDr
	MOr					216	MOr
OCr						217	O_r
MCr	MCr					218	M_r
		Cl				219	_l
		MCli				220	M_li
	Cam					221	_am
Yg	Yg	pCtr				222	Yg
Yg	Yg	pCc				223	Yg
Yg	Yg	pCe				224	Yg
Yg	Yg	pCpr				225	Yg
	Yam	pCuc				226	Yam
	Yam	pCel				227	Yam
	YXu					228	YXu
		pCus				229	YXus
		pCuq				230	YXuq
YXg	YXg		pCr	pC		231	YXg
Xg	Xg					232	Xg

		pCt				233	Xt
		pCb				234	Xbg
Xgl						235	Xgl
Xb	Xb					236	Xb
Xfh	Xfh					237	Xfh
Xf						238	Xf
Xm	Xm					239	Xm
		pCtw				240	Xtw
Xh						241	Xh
	Xq					242	Xq
		pCi				243	Xi
		pCv				244	Xv

APPENDIX C

Geologic Map Unit Classification

The geologic map unit classification scheme employed here follows that developed by Bruce R. Johnson (U.S. Geological Survey, written communication, 1999) for digital geologic map databases. The scheme is given here to help the reader understand the map unit attributes for the joined ARC/INFO coverage gmug_geol.e00. This classification scheme is currently in draft form and should be considered as an evolving framework.

1. **Unconsolidated deposit** — A sediment that is loosely arranged or unstratified, or whose particles are not cemented together, found either at the surface or at depth.

    1.1. **Alluvium** — A general term for clay, silt, sand, gravel or similar unconsolidated detrital material, deposited during comparatively recent geologic time by a stream or other body of running water, as a sorted or semi-sorted sediment.

        1.1.1. **Flood plain** — Unconsolidated sediment deposited adjacent to a river channel, constructed by the present river in its existing regimen and covered with water when the river overflows its banks.

        1.1.2. **Levee** — A long broad low ridge or embankment of sand and coarse silt, built by a stream on its flood plain and along both banks of its channel, esp. in time of flood when water overflowing the normal banks is forced to deposit the coarsest part of its load.

        1.1.3. **Delta** — The low, nearly flat, alluvial tract of land at or near the mouth of a river, commonly forming a triangular or fan-shaped plain of considerable area.

        1.1.4. **Alluvial fan** — A low, outspread, relatively flat to gently sloping mass of loose rock material, shaped like an open fan or a segment of a cone, deposited by a stream (esp. in a semiarid region) at the place where it issues from a narrow mountain valley upon a plain or broad valley.

        1.1.5. **Alluvial terrace** — A stream terrace composed of unconsolidated alluvium (including gravel), produced by renewed downcutting of the flood plain or valley floor.

    1.2. **Lake or marine deposit (non-glacial)** — A sedimentary deposit laid down conformably on the floor of, or along the shore of, a lake, sea, or ocean, usually consisting of coarse material near the shore and sometimes passing into clay and limestone in deeper water.

        1.2.1. **Playa** — A dry, vegetation-free, flat area at the lowest part of an undrained desert basin, underlain by stratified clay, silt, or sand, and commonly by soluble salts.

1.2.2. **Mud flat** — A relatively level area of fine silt along a shore (as in a sheltered estuary) or around an island, alternately covered and uncovered by the tide, or covered by shallow water.

1.2.3. **Beach sand** — A loose aggregate of unlithified mineral or rock particles of sand size forming a beach (the relatively thick and temporary accumulation of loose water-borne material that is in active transit along, or deposited on, the shore zone between the limits of low water and high water).

1.2.4. **Terrace** — A narrow shelf, partly cut and partly built, produced along a lake shore and later exposed when the water level falls, or a wave-cut platform that has been exposed by uplift along a seacoast or by the lowering of sea level, and from 3 m to more than 40 m above mean sea level; an elevated marine-cut bench.

1.3. **Eolian** — Sediments such as loess or sand deposited by the action of the wind.

1.3.1. **Dune sand** — A type of blown sand that has been piled up by the wind into a sand dune, usually consisting of rounded mineral grains, commonly quartz, having diameters ranging from 0.1 to 1 mm.

1.3.2. **Sand sheet** — A large irregularly shaped plain of eolian sand, lacking the discernible slip faces that are common on dunes.

1.3.3. **Loess** — A widespread, homogeneous, commonly nonstratified, porous, friable, slightly coherent, usually highly calcareous, fine-grained blanket deposit, consisting predominantly of silt with subordinate grain sizes ranging from clay to fine sand.

1.4. **Volcanic Ash** — A fine pyroclastic material (under 2.0 mm in diameter). The term usually refers to the unconsolidated material.

1.5. **Mass wasting** — Deposits formed by the dislodgement and downslope transport of soil and rock material under the direct application of gravitational body stresses.

1.5.1. **Colluvium** — A general term applied to any loose, heterogeneous, and incoherent mass of soil material and/or rock fragments deposited by rainwash, sheetwash, or slow, continuous downslope creep, usually collecting at the base of gentle slopes or hillsides.

1.5.2. **Mudflow** — Deposits formed by a process characterized by a flowing mass of predominantly fine-grained earth material possessing a high degree of fluidity during movement.

1.5.2.1. **Lahar** — A mudflow composed chiefly of volcaniclastic materials on the flank of a volcano.

1.5.3. **Debris flow** — A moving mass of rock fragments, soil, and mud, more than half of the particles being larger than sand size.

1.5.4. **Landslide** — A general term covering a wide variety of mass-movement landforms and processes involving the downslope transport,

	under gravitational influence, of soil and rock material, en mass.
1.5.5. **Talus**	An outward sloping and accumulated heap or mass of rock fragments of any size or shape (usually coarse and angular) derived from and lying at the base of a cliff or very steep, rocky slope, and formed chiefly by gravitational falling, rolling, or sliding.
1.6. **Glacial drift**	A general term applied to all rock material (clay, silt, sand, gravel, boulders) transported by a glacier and deposited directly by or from the ice, or by running water emanating from a glacier.
1.6.1. **Till**	Dominantly unsorted and unstratified drift, generally unconsolidated, deposited directly by and underneath a glacier without subsequent reworking by meltwater.
1.6.1.1. **Moraine**	A mound, ridge, or other distinct accumulation of unsorted, unstratified glacial drift, predominantly till, deposited chiefly by direct action of glacial ice.
1.6.2. **Strat. glacial sediment**	Stratified glacial drift deposited by, or reworked by running water, or deposited in standing water.
1.6.2.1. **Outwash**	Stratified detritus (chiefly sand and gravel) removed or "washed out" from a glacier by meltwater streams and deposited in front of or behind the end moraine or the margin of an active glacier.
1.6.2.2. **Sub- and supra-glacial sediment**	A variety of irregularly stratified sand and gravel deposits, such as eskers, kames, etc., that were deposited by a subglacial or supra-glacial stream or pond and were left behind when the ice melted.
1.6.2.3. **Glaciolacustrine**	Deposits and landforms composed of suspended material brought by meltwater streams flowing into lakes bordering the glacier, such as deltas, kame deltas, and varved sediments.
1.6.2.4. **Glacial-marine**	Deposits of glacially eroded, terrestrially derived sediment in the marine environment.
1.7. **Biogenic sediment**	An organic sediment produced directly by the physiologic activities of organisms, either plant or animal.
1.7.1. **Peat**	An unconsolidated deposit of semicarbonized plant remains in a water saturated environment, such as a bog or fen, and of persistently high moisture content (at least 75%).
1.7.2. **Coral**	A hard calcareous substance consisting of the continuous skeleton secreted by coral polyps for their support and habitation and found in single specimens growing plant-like on the sea bottom or in extensive, solidified accumulations (coral reefs).

1.8. **Residuum** — An accumulation or rock debris formed by weathering and remaining essentially in place after all but the least soluble constituents have been removed.

1.9. **Clay, mud** — A loose, earthy, extremely fine-grained, natural sediment composed primarily of clay-size or colloidal particles and characterized by high plasticity and by a considerable content of clay minerals.

1.10. **Silt** — A loose aggregate of unlithified mineral or rock particles of silt size (1/256 to 1/16 mm); an unconsolidated deposit consisting essentially of fine-grained clastic particles.

1.11. **Sand** — A loose aggregate of unlithified mineral or rock particles of sand size (1/16 to 2 mm); an unconsolidated deposit consisting essentially of medium-grained clastic particles.

1.12. **Gravel** — A loose accumulation of rock fragments composed predominantly of more or less rounded pebbles and small stones.

2. **Sedimentary rock** — A rock resulting from the consolidation of loose sediment that has accumulated in layers.

2.1. **Clastic** — A composed principally of broken fragments that are derived from preexisting rocks or minerals and that have been transported some distance from their place of origin.

2.1.1. **Mudstone** — A general term that includes claystone, siltstone, shale, and argillite, and that should be used only when the amounts of clay-sized and silt-sized particles are not known or specified, or cannot be precisely identified.

2.1.1.1. **Claystone** — An indurated rock having more than 67% clay-sized minerals.

2.1.1.1.1. **Bentonite** — A soft, plastic, porous, light-colored rock composed essentially of clay minerals of the montmorillonite (smectite) group plus colloidal silica, and produced by devitrification and accompanying chemical alteration of a glassy igneous material, usually a tuff or volcanic ash.

2.1.1.2. **Shale** — A laminated, indurated rock having more than 67% clay-sized minerals.

2.1.1.2.1. **Black Shale** — A dark, thinly laminated carbonaceous shale, exceptionally rich in organic matter (5% or more carbon content) and sulfide (esp. iron sulfide, usually pyrite), and often containing unusual concentrations of certain trace elements (U, V, Cu, Ni).

2.1.1.2.2. **Oil Shale** — A kerogen-bearing, finely laminated brown or black sedimentary rock that will yield liquid or gaseous hydrocarbon on distillation.

2.1.1.3. **Argillite** — A compact rock derived either from mudstone or shale, that has undergone a somewhat higher degree of induration than mudstone or shale but is less clearly laminated than shale and without its fissility, and that lacks the cleavage distinctive of slate.

2.1.1.4. **Siltstone** An indurated silt having the texture and composition of shale but lacking its fine lamination or fissility; a massive mudstone in which silt-sized particles predominate over clay-sized particles.

2.1.2. **Fine-grained mixed clastic** A mixture of clastic sedimentary rocks varying from mudstone to sandstone, dominated by rocks containing clay-sized or silt-sized particles.

2.1.3. **Sandstone** A medium-grained clastic sedimentary rock composed of abundant sand-sized fragments, which may have a finer-grained matrix (silt or clay), and which is more or less indurated by a cementing material.

2.1.3.1. **Arenite** A "clean" sandstone that is well-sorted, contains little or no matrix material, and has a relatively simple mineralogic composition; specif. a pure or nearly pure, chemically cemented sandstone containing less than 10% argillaceous matrix.

2.1.3.1.1. **Orthoquartzite** A clastic sedimentary rock that is made up almost exclusively of quartz sand (with or without chert), that is relatively free of or lacks a fine-grained matrix; a quartzite of sedimentary origin, or a "pure quartz sandstone".

2.1.3.1.2. **Calcarenite** A clastic sedimentary rock that is made up predominantly of recycled carbonate particles of sand size; a consolidated calcareous sand.

2.1.3.2. **Arkose** A feldspar-rich sandstone, commonly coarse-grained and pink or reddish, that is typically composed of angular to subangular grains that may be either poorly or moderately well sorted. Quartz is usually the dominant mineral, with feldspars constituting at least 25%.

2.1.3.3. **Wacke** A "dirty" sandstone that consists of a mixed variety of unsorted or poorly sorted mineral and rock fragments and of an abundant matrix of clay and fine silt; specif. an impure sandstone containing more than 10% argillaceous matrix.

2.1.3.3.1. **Graywacke** A dark gray, firmly indurated, coarse-grained sandstone that consists of poorly sorted angular to subangular grains of quartz and feldspar, with a variety of dark rock and mineral fragments embedded in a compact clayey matrix having the general composition of slate and containing an abundance of very fine-grained illite, sericite, and chloritic minerals.

2.1.4. **Medium-grained mixed clastic** A mixture of clastic sedimentary rocks varying from siltstone to conglomerate, dominated by rocks containing sand-sized particles.

2.1.5. **Conglomerate** A coarse-grained clastic sedimentary rock, composed of rounded to subangular fragments larger than 2 mm in diameter typically containing fine-grained particles in the interstices, and commonly cemented by calcium carbonate, iron oxide, silica, or hardened clay.

2.1.6. **Sedimentary breccia** A breccia (coarse-grained clastic rock composed of angular broken rock fragments held together by a mineral cement or a fine-grained matrix) formed by sedimentary processes.

2.1.7. **Coarse-grained mixed clastic** A mixture of clastic sedimentary rocks varying from siltstone to conglomerate, dominated by rocks containing coarse sand-sized or gravel-sized particles.

2.1.8. **Olistostrome** A sedimentary deposit consisting of a chaotic mass of intimately mixed heterogeneous materials (such as blocks and muds) that accumulated as a semi-fluid body by submarine gravity sliding or slumping of unconsolidated sediments.

2.2. **Carbonate** A sedimentary rock composed of more than 50% by weight carbonate minerals.

2.2.1. **Limestone** A sedimentary rock consisting chiefly (more than 50% by weight or by areal percentages under the microscope) of calcium carbonate, primarily in the form of the mineral calcite.

2.2.2. **Dolostone (dolomite)** A carbonate sedimentary rock of which more than 50% by weight or by areal percentages under the microscope consists of the mineral dolomite.

2.3. **Mixed clastic/carbonate** An undivided mixture of clastic and carbonate sedimentary rocks.

2.4. **Mixed clastic/volcanic** An undivided mixture of clastic sedimentary rock and volcanic rock.

2.5. **Phosphorite** A sedimentary rock with a high enough content of phosphate minerals to be of economic interest.

2.6. **Chemical** A sedimentary rock composed primarily of material formed directly by precipitation from solution or colloidal suspension or by the deposition of insoluble precipitates.

2.6.1. **Evaporite** A nonclastic sedimentary rock composed primarily of minerals produced from a saline solution as a result of extensive or total evaporation of the solvent.

2.6.2. **Chert** A hard, extremely dense or compact, dull to semivitreous, microcrystalline or cryptocrystalline sedimentary rock, consisting dominantly of interlocking crystals of quartz less than 30 µm in diameter.

2.6.3. **Iron formation** A chemical sedimentary rock, typically thin-bedded and/or finely laminated, containing at least 15% iron of sedimentary origin, and commonly but not necessarily containing layers of chert

2.6.4. **Exhalite** A chemical sedimentary rock, usually containing oxide, carbonate, or sulfide as anions, and iron, magnesium, base metals, and gold as cations, formed by the issuance of volcanically derived fluids onto the sea floor or into the sea.

2.7. **Coal** — A readily combustible rock containing more than 50% by weight and more than 70% by volume carbonaceous material, formed by compaction and induration of variously altered plant remains.

2.8. **Mixed clastic/coal** — An undivided mixture of clastic sedimentary rock and coal.

3. **Volcanic rock (aphanitic)** — A generally finely crystalline or glassy igneous rock resulting from volcanic action at or near the Earth's surface, either ejected explosively or extruded as a lava. The term includes near-surface intrusions that form a part of the volcanic structure.

3.1. **Glassy** — Extrusive rock having a texture which is similar to that of glass or quartz and developed as a result of rapid cooling of the lava without distinct crystallization.

3.1.1. **Obsidian** — A black or dark-colored volcanic glass, usually of rhyolite composition, characterized by conchoidal fracture.

3.1.2. **Vitrophyre** — Any porphyritic igneous rock having a glassy groundmass.

3.1.3. **Pumice** — A light-colored vesicular glassy rock commonly having the composition of rhyolite.

3.2. **Pyroclastic** — Clastic rock material formed by volcanic explosion or aerial expulsion from a volcanic vent.

3.2.1. **Tuff** — Consolidated or cemented volcanic ash.

3.2.1.1. **Welded Tuff** — A glass-rich pyroclastic rock that has been indurated by the welding together of its glass shards under the combined action of the heat retained by particles, the weight of the overlying material, and hot gasses.

3.2.1.2. **Ash-flow Tuff** — A tuff deposited by an ash flow or gaseous cloud; a type of ignimbrite. It is a consolidated, but not necessarily welded deposit.

3.2.2. **Ignimbrite** — The deposit of a pyroclastic flow.

3.2.3. **Volcanic breccia (agglomerate)** — A pyroclastic rock that consists of angular volcanic fragments that are larger than 64 mm in diameter and that may or may not have a matrix.

3.3. **Lava flow** — A solidified body of rock that is formed by the lateral, surficial outpouring of molten lava from a vent or a fissure.

3.3.1. **Bimodal suite** — A mixed sequence of sub-equal amounts of felsic and mafic volcanic rocks, commonly rhyolite and basalt with little or no intermediate composition rock.

3.4. **Felsite** — A light-colored, fine-grained or aphanitic extrusive or hypabyssal rock, with or without phenocrysts and composed chiefly of quartz and feldspar.

3.4.1. **Alkali rhyolite**	A volcanic rock defined in the QAPF diagram as having Q/(Q+A+P) between 20 and 60% and P/(P+A) < 10%.
3.4.2. **Rhyolite**	A volcanic rock defined in the QAPF diagram as having Q/(Q+A+P) between 20 and 60% and P/(P+A) between 10 and 35%.
3.4.3. **Rhyodacite**	A volcanic rock defined in the QAPF diagram as having Q/(Q+A+P) between 20 and 60% and P/(P+A) between 35 and 65%.
3.4.4. **Dacite**	A volcanic rock defined in the QAPF diagram as having Q/(Q+A+P) between 20 and 60% and P/(P+A) > 65%.
3.4.5. **Alkali trachyte**	A volcanic rock defined in the QAPF diagram as having Q/(Q+A+P) < 20% or F/(F+A+P) < 10%, and P/(P+A) < 10%.
3.4.6. **Trachyte**	A volcanic rock defined in the QAPF diagram as having Q/(Q+A+P) < 20% or F/(F+A+P) < 10%, and P/(P+A) between 10 and 35%.
3.4.7. **Quartz Latite**	A volcanic rock defined in the QAPF diagram as having Q/(Q+A+P) between 5 and 20% and P/(P+A) between 35 and 65%.
3.4.8. **Latite**	A volcanic rock defined in the QAPF diagram as having Q/(Q+A+P) < 5% or F/(F+A+P) < 10%, and P/(P+A) between 35 and 65%.
3.5. **Intermediate**	A solidified body of volcanic rock having approximately equal light- and dark-colored minerals in its mode.
3.5.1. **Trachyandesite**	A volcanic rock defined modally by Q/(Q+A+P) < 20% or F/(F+A+P) < 10%, P/(A+P) between 65 and 90%, and M < 35.
3.5.2. **Andesite**	A volcanic rock defined modally by Q/(Q+A+P) < 20% or F/(F+A+P) < 10%, P/(A+P) > 90%, and M < 35.
3.6. **Mafic**	A solidified body of volcanic rock having abundant dark-colored minerals in its mode.
3.6.1. **Trachybasalt**	A volcanic rock defined modally by Q/(Q+A+P) < 20% or F/(F+A+P) < 10%, P/(A+P) between 65 and 90%, and M > 35.
3.6.2. **Basalt**	A volcanic rock defined modally by Q/(Q+A+P) < 20% or F/(F+A+P) < 10%, P/(A+P) > 90%, and M > 35.
3.6.2.1. **Tholeiite**	A silica-oversaturated basalt, characterized by the presence of low-calcium pyroxenes in addition to clinopyroxene and calcic plagioclase. Olivine may be present in the mode, but neither olivine nor nepheline appear in the norm.
3.6.2.2. **Hawaiite**	A basalt in which the normative and modal feldspar is andesine, and with soda:potash ratio greater than 2:1. It generally, but not always, lacks normative quartz, and commonly contains normative and modal olivine.

3.6.2.3. **Alkaline basalt** A basalt with nepheline and/or acmite in the CIPW norm.

3.7. **Alkalic** A volcanic rock that contains more sodium and/or potassium than is required to form feldspar with the available silica.

3.7.1. **Phonolite** A volcanic rock defined in the QAPF diagram as having F/(F+A+P) between 10 an 60%, and P/(P+A) < 10%.

3.7.2. **Tephrite (basanite)** A volcanic rock defined in the QAPF diagram as having F/(F+A+P) between 10 an 60%, and P/(P+A) > 90%.

3.8. **Ultramafitite (komatiite)** A volcanic rock with color index (M) greater than or equal to 90.

3.9. **Volcanic carbonatite** A rock of apparent volcanic origin composed of at least 50% carbonate minerals.

4. **Plutonic rock (phaneritic)** A rock formed at considerable depth by crystallization of magma and/or by chemical alteration. It is characteristically medium- to coarse-grained, of granitoid texture.

4.1. **Aplite** A light-colored igneous rock characterized by a fine-grained allotriomorphic-granular (i.e. aplitic) texture.

4.2. **Porphyry** An igneous rock of any composition that contains conspicuous phenocrysts in a fine-grained groundmass.

4.2.1. **Lamprophyre** A group of porphyritic igneous rocks in which mafic minerals form the phenocrysts; feldspars, if present, are restricted to the groundmass.

4.3. **Pegmatite** An exceptionally coarse-grained igneous rock, with interlocking crystals, usually found as irregular dikes, lenses, or veins, esp. at the margins of batholiths.

4.4. **Granitoid** A general term for all phaneritic igneous rocks dominated by quartz and feldspars.

4.4.1. **Alkali-granite (alaskite)** A plutonic rock defined in the QAPF diagram as having Q between 20 and 60% and P/(A+P) < 10%.

4.4.2. **Granite** A plutonic rock defined in the QAPF diagram as having Q between 20 and 60% and P/(A+P) between 10 and 65%.

4.4.2.1. **Peraluminous** A granite with aluminum oxide > sodium oxide + potassium oxide + calcium oxide; typical accessories include: muscovite, biotite, corundum, topaz, garnet.

4.4.2.2. **Metaluminous** A granite with aluminum oxide > sodium oxide + potassium oxide, but with aluminum oxide < sodium oxide + potassium oxide + calcium oxide; typical accessories include: hornblende, epidote, melilite, or biotite + pyroxene.

4.4.2.3. **Subaluminous** A granite with aluminum oxide approximately equal to sodium oxide + potassium oxide; typical accessories include: olivine, orthopyroxene, clinopyroxene.

4.4.2.4. **Peralkaline** A granite with aluminum oxide < sodium oxide + potassium oxide; typical accessories include: soda pyroxene and soda amphibole.

4.4.3. **Granodiorite** — A plutonic rock defined in the QAPF diagram as having Q between 20 and 60% and P/(A+P) between 65 and 90%.

4.4.4. **Tonalite** — A plutonic rock defined in the QAPF diagram as having Q between 20 and 60% and P/(A+P) > 90%.

4.4.4.1. **Trondhjemite** — A tonalite with color index (M) less than 15; composed essentially of sodic plagioclase, quartz, sparse biotite, and little or no alkali feldspar.

4.4.5. **Alkali syenite** — A plutonic rock defined in the QAPF diagram as having Q/(Q+A+P) < 20% or F/(F+A+P) < 10%, and P/(P+A) < 10%.

4.4.6. **Quartz syenite** — A plutonic rock defined in the QAPF diagram as having Q between 5 and 20% and P/(A+P) between 10 and 35%.

4.4.7. **Syenite** — A plutonic rock defined in the QAPF diagram as having Q < 5% or F/(F+A+P) < 10%, and P/(A+P) between 10 and 35%.

4.4.8. **Quartz monzonite** — A plutonic rock defined in the QAPF diagram as having Q between 5 and 20% and P/(A+P) between 35 and 65%.

4.4.9. **Monzonite** — A plutonic rock defined in the QAPF diagram as having Q < 5% or F/(F+A+P) < 10%, and P/(A+P) between 35 and 65%.

4.4.10. **Quartz monzodiorite** — A plutonic rock defined in the QAPF diagram as having Q between 5 and 20% and P/(A+P) between 65 and 90%, and plagioclase more sodic than An_{50}.

4.4.11. **Quartz monzogabbro** — A plutonic rock defined in the QAPF diagram as having Q between 5 and 20% and P/(A+P) between 65 and 90%, and plagioclase more calcic than An_{50}.

4.4.12. **Monzodiorite** — A plutonic rock defined in the QAPF diagram as having Q < 5% or F/(F+A+P) < 10%, and P/(A+P) between 65 and 90%, and plagioclase more sodic than An_{50}.

4.4.13. **Monzogabbro** — A plutonic rock defined in the QAPF diagram as having Q < 5% or F/(F+A+P) < 10%, and P/(A+P) between 65 and 90%, and plagioclase more calcic than An_{50}.

4.4.14. **Quartz diorite** — A plutonic rock defined in the QAPF diagram as having Q between 5 and 20%, P/(A+P) > 90%, and plagioclase more sodic than An_{50}.

4.4.15. **Quartz gabbro** — A plutonic rock defined in the QAPF diagram as having Q between 5 and 20%, P/(A+P) > 90%, and plagioclase more calcic than An_{50}.

4.4.16. **Diorite** — A plutonic rock defined in the QAPF diagram as having Q between 0 and 5% or F/(F+A+P) < 10%, P/(A+P) greater than 90% and plagioclase more sodic than An_{50}.

4.4.16.1. **Diabase** — A plutonic rock whose main components are labradorite and pyroxene and which is characterized by ophitic texture.

4.4.17. **Gabbro** — A plutonic rock defined in the QAPF diagram as having Q between 0 and 5% or F/(F+A+P) < 10%, P/(A+P) greater than 90% and plagioclase more calcic than An_{50}.

4.4.17.1. **Norite** — A plutonic rock satisfying the definition of gabbro, in which pl/(pl+px+ol) is between 10 and 90% and opx/(opx+cpx) is greater than 95%.

4.4.17.2. **Troctolite** — A plutonic rock satisfying the definition of gabbro, in which pl/(pl+px+ol) is between 10 and 90% and px/(pl+px+ol) is less than 5%.

4.4.18. **Anorthosite** — A plutonic rock defined in the QAPF diagram as having Q between 0 and 5, P/(A+P) greater than 90, and M less than 10. A group of monomineralogic plutonic igneous rocks composed almost entirely of plagioclase feldspar.

4.5. **Alkalic intrusive rock** — A plutonic rock that contains more sodium and/or potassium than is required to form feldspar with the available silica.

4.5.1. **Nepheline syenite** — A plutonic rock defined in the QAPF diagram as having F/(F+A+P) between 10 an 60%, and P/(P+A) < 50%; composed essentially of alkali feldspar and nepheline.

4.6. **Ultramafic intrusive rock** — A general name for plutonic rock with color index (M) greater than or equal to 90…

4.6.1. **Peridotite** — A plutonic rock with M equal to or greater than 90 and ol/(ol+opx+cpx) greater than 40%.

4.6.1.1. **Dunite** — A plutonic rock with M equal to or greater than 90 and ol/(ol+opx+cpx) greater than 90%.

4.6.1.2. **Kimberlite** — A porphyritic alkalic peridotite containing abundant phenocrysts of olivine and phlogopite, and possibly geikielite and chromian pyrope, in a fine-grained groundmass of calcite and second-generation olivine and phlogopite.

4.6.2. **Pyroxenite** — A plutonic rock with M equal to or greater than 90 and ol/(ol+opx+cpx) less than 40%.

4.6.3. **Hornblendite** — A plutonic rock with M equal to or greater than 90 and hbl/(hbl+px+ol) greater than 90%.

4.7. **Intrusive Carbonatite** — A plutonic rock composed of at least 50% carbonate minerals.

5. **Metamorphic rock** — A rock derived from pre-existing rocks by mineralogical, chemical, and/or structural changes, essentially in the solid state, in response to marked changes in temperature, pressure, shearing stress, and chemical environment, generally at depth in the earth's crust.

5.1. **Hornfels** — A fine-grained rock composed of a mosaic of equidimensional grains without preferred orientation and typically formed by contact metamorphism.

5.2.	**Metasedimentary**	A sedimentary rock that shows evidence of having been subjected to metamorphism.
5.2.1.	**Meta-argillite**	An argillite that has been metamorphosed.
5.2.2.	**Slate**	A compact, fine-grained metamorphic rock that possesses slaty cleavage and hence can be split into slabs and thin plates.
5.2.3.	**Quartzite**	A granoblastic metamorphic rock consisting mainly of quartz and formed by recrystallization of sandstone or chert by either regional or thermal metamorphism.
5.2.4.	**Marble**	A metamorphic rock consisting predominantly of fine- to coarse-grained recrystallized calcite and/or dolomite, usually with a granoblastic, saccharoidal texture.
5.3.	**Metavolcanic**	A volcanic rock that shows evidence of having been subjected to metamorphism.
5.3.1.	**Felsic**	A metavolcanic rock having abundant light-colored minerals, typically quartz and feldspar.
5.3.1.1.	**Meta-rhyolite**	A low-grade, felsic metavolcanic rock with preserved evidence of its original rhyolitic character.
5.3.1.2.	**Keratophyre**	Extrusive and hypabyssal rocks characterized by the presence of albite or albite-oligoclase and chlorite, epidote, and calcite, generally of secondary order.
5.3.2.	**Mafic**	A metavolcanic rock having abundant dark-colored minerals, typically feldspar, amphibole, and/or pyroxene.
5.3.2.1.	**Meta-basalt**	A low-grade, mafic metavolcanic rock with preserved evidence of its original basaltic character.
5.3.2.2.	**Spilite**	An altered basalt, characteristically amygdaloidal or vesicular, in which the feldspar has been albitized and is typically accompanied by chlorite, calcite, epidote, chalcedony, prehnite, or other low-temperature hydrous crystallization products characteristic of a greenstone.
5.3.2.3.	**Greenstone**	A field term applied to any compact, dark-green, altered or metamorphosed basic igneous rock (e.g. spilite, basalt, gabbro, diabase) that owes its color to the presence of chlorite, actinolite, or epidote.
5.4.	**Phyllite**	A metamorphosed rock, intermediate in grade between slate and mica schist. Minute crystals of graphite, sericite, or chlorite impart a silky sheen to the surfaces of cleavage (or schistosity).
5.5.	**Schist**	A strongly foliated crystalline rock, formed by dynamic metamorphism, that can be readily split into thin flakes or slabs due to the well developed parallelism of more than 50% of the minerals present, particularly those of the lamellar or elongate prismatic habit, e.g. mica and hornblende.

5.5.1.	**Greenschist**	A schistose metamorphic rock whose green color is due to the presence of chlorite, epidote, or actinolite; a common product of low-grade regional metamorphism of pelitic or basic igneous rocks.
5.5.2.	**Blueschist**	A schistose metamorphic rock with a blue color owing to the presence of sodic amphibole, glaucophane, or crossite, and commonly mottled bluish-gray lawsonite; characteristic of metamorphism in areas of unusually low thermal gradient, such as subduction zones.
5.5.3.	**Mica schist**	A schist whose essential constituents are mica and quartz, and whose schistosity is mainly due to the parallel arrangement of mica flakes.
5.5.4.	**Pelitic schist**	A schistose metamorphic rock derived by metamorphism of an argillaceous or a fine-grained alluminous sediment.
5.5.5.	**Quartz-feldspar schist**	A schist whose essential constituents are quartz and feldspar and having lesser amounts of mica and/or hornblende.
5.5.6.	**Calc-silicate schist**	A metamorphosed calcareous rock, commonly derived from argillaceous limestone or calcareous mudstone, containing calcium-bearing silicates such as diopside and wollastonite, with a schistose structure produced by parallelism of platy minerals.
5.5.7.	**Amphibole schist**	A schist whose essential constituent is amphibole with lesser amounts of feldspar, quartz, and/or mica.
5.6.	**Granofels**	A medium- to coarse-grained granoblastic metamorphic rock with little or no foliation or lineation.
5.7.	**Gneiss**	A foliated rock formed by regional metamorphism, in which bands or lenticles of granular minerals alternate with bands or lenticles in which minerals having flaky or elongate prismatic habits predominate. Generally less than 50% of the minerals show preferred orientation.
5.7.1.	**Felsic gneiss**	A gneissic rock dominated by light-colored minerals, commonly quartz and feldspar.
5.7.1.1.	**Granitic gneiss**	A gneissic rock with a general granitoid composition.
5.7.1.1.1.	**Biotite gneiss**	A granitic gneiss in which the dominant mafic mineral is biotite.
5.7.2.	**Mafic gneiss**	A gneissic rock dominated by dark-colored minerals, commonly biotite and hornblende.
5.7.3.	**Orthogneiss**	A gneissic rock formed from an igneous parent.
5.7.4.	**Paragneiss**	A gneissic rock formed from a sedimentary parent.
5.7.5.	**Migmatite**	A composite “mixed rock” composed of igneous or igneous-appearing and metamorphic portions.
5.8.	**Amphibolite**	A crystalloblastic rock consisting mainly of amphibole and plagioclase with little or no quartz.

5.9.	**Granulite**	A metamorphic rock consisting of even-sized, interlocking mineral grains less than 10% of which have any obvious preferred orientation.
5.10.	**Eclogite**	A granular rock composed essentially of garnet (almandine-pyrope) and sodic pyroxene (omphacite).
5.11.	**Greisen**	A pneumatolytically altered granitic rock composed largely of quartz, mica, and topaz.
5.12.	**Skarn (tactite)**	A rock of complex mineralogic composition formed by contact metamorphism and metasomatism of carbonate rocks. It is typically coarse-grained and rich in garnet, iron-rich pyroxene, epidote, wollastonite, and scapolite.
5.13.	**Serpentinite**	A rock consisting almost wholly of serpentine-group minerals derived from the hydration of ferromagnesian silicate minerals such as olivine and pyroxene.
6.	**Tectonite**	A rock whose fabric reflects the history of its deformation.
6.1.1.	**Tectonic mélange**	A mélange produced by tectonic processes.
6.1.2.	**Cataclasite**	A fine-grained, cohesive cataclastic rock, normally lacking a penetrative foliation or microfabric, formed during fault movement.
6.1.3.	**Phyllonite**	A rock that macroscopically resembles phyllite but that is formed by mechanical degradation (mylonitization) of initially coarser rocks.
6.1.4.	**Mylonite**	A compact, chert-like rock without cleavage, but with a streaky or banded structure, produced by the extreme granulation and shearing of rocks that have been pulverized and rolled during overthrusting or intense dynamic metamorphism.
6.1.5.	**Flaser gneiss**	A dynamically metamorphosed rock in which lenses or layers of original or relatively unaltered granular materials are surrounded by a matrix of highly sheared and crushed material, giving the appearance of a crude flow structure.
6.1.6.	**Augen gneiss**	Gneissic rock containing augen (large lenticular mineral grains or mineral aggregates having the shape of an eye in cross section).