Geologic Terranes of Puerto Rico

by

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Terrane 1. A formation or group of formations,

2. The area or surface over which a particular rock or group of rocks is prevalent, or

3. An area or region considered in relation to its fitness or suitability for some specific purpose.

Dictionary of Geological Terms-AGI

INTRODUCTION

The Commonwealth of Puerto Rico can be partitioned into several subtle but distinct 'packages' of rocks (terrane map) as a consequence of the tectonic setting and geologic history of the Caribbean region. These packages of associated map units are treated as geologic terranes having affinities based upon lithologic rock type, depositional environment, and (or) age of deposition. Terranes are used to reconstruct and understand the large-scale geologic history of Puerto Rico. Also of use to economic geologists is the knowledge that each terrane, which hosts distinct types of mineral occurrences, requires different exploration techniques.

Puerto Rico is part of an island-arc complex on the northern edge of the Caribbean plate; the geology is described in detail by Krushensky and Schellekens (geology map). The exposed part of the island arc which comprises Puerto Rico is divided into three major structural blocks (Garrison and others, 1972; Cox and Briggs, 1973, Cox and others, 1977), due to left-lateral strike-slip faulting along two northwest-southeast-trending fault zones, the

South fault zone (Seiders et.al., 1972) , which coincides with the northern boundary of the Eocene Belt and the North fault zone in

which the San Francisco – Cerro Mula Fault is the most important (Briggs and Pease, 1968) (figure 1). These structural blocks are referred to as the Northeast Igneous Province, Central Igneous Province, and Southwest Igneous Province (Schellekens, 1991, 1998). Within each of these provinces, the faults appear to be predominantly normal.

The geologic history of Puerto Rico can be summarized into several broad and general phases of development as extracted from Cox (1985):

1. Early sedimentary volcanic, and tectonic events in southwestern Puerto Rico are recorded in rocks of the Bermeja Complex of Mattson (1958, 1960a), which include radiolarian chert containing fossils of Jurassic age, serpentine, and amphibolite having a metamorphic age of 126 Ma.

2. The Bermeja Complex is overlain by volcanic and sedimentary rocks as old as Cenomanian that are part of a thick sequence of basalt, andesite, and breccia, and conglomerate, sandstone, and shale derived from volcanic rocks, which were deposited from Albian time to the end of the Cretaceous Period. Volcanism was associated with left-lateral strike-slip displacement along major northwest-striking faults that were active from Cenomanian to Eocene time.

3. This pile of volcanic rocks was intruded by plutons of tonalitic and granodioritic composition beginning in the Aptian and culminating in the Maastrichtian. Two batholiths were emplaced during Maastrichtian time: the San Lorenzo in the eastern part of Puerto Rico and the Utuado in the west-central part.

4. After emplacement of these batholiths, parts of the region were uplifted and eroded, and

during the middle to late Eocene, basaltic to dacitic lava, tuff, and volcaniclastic sediment were deposited in west-central Puerto Rico, mainly along a northwest-trending trough, 100 km long by 10 km wide. This trough may have resulted from rifting.

5. During late Eocene time, small stocks of tonalite were emplaced along the boundary between the Eocene trough and the Utuado batholith as well as in other parts of central and northeastern Puerto Rico. These intrusions, which were the latest igneous events in the history of Puerto Rico, were accompanied by hydrothermal alteration and copper mineralization in the Tanamá and Río Viví areas.

6. Uplift, erosion, and formation of extensive areas of low relief followed the termination of igneous activity in Puerto Rico. Clastic sediment interbedded with thin coal seams (San Sebastian Formation) of middle Oligocene age was overlain by thick marine limestone deposits during the Oligocene and Miocene (Lares Limestone and overlying units).

7. Renewed erosion followed arching and uplift of the island, and the present topography

began to develop. A regional saprolite weathering zone was created by intense tropical weathering.

GEOLOGIC TERRANES

A total of 151 map units, identified on the geologic map of Puerto Rico (geology map), are combined into twelve associated terranes for the main island (terrane map). The surface area covered by each of these terranes is shown in table 1 as a percentage of the total landmass and square kilometers. The map units that make up each of the twelve terranes are listed in table 2. Map unit descriptions can be found in Appendix A. The geology of the islands of Mona, Culebra, and Vieques has not been reexamined in detail in this study, and the terranes for these islands have been extrapolated from the previously published maps of Cox and Briggs (1973).

Ultramafic rocks in Puerto Rico are igneous rocks composed chiefly of mafic minerals, and amphibolite is a metamorphic rock consisting mainly of amphibole and plagioclase, containing little or no quartz. Ultramafic rocks and amphibolite, which are the oldest rocks found in Puerto Rico, are Jurassic and Cretaceous in age. They occur in the southwest corner of the island, as part of an obducted oceanic plate. These rocks have potential as hosts of podiform chromite deposits, and erode to form remnant sedimentary nickel laterite deposits. They make up approximately 87km^2 , or 1 percent of the surface area.

Basalt in Puerto Rico is dark- to medium-dark, commonly extrusive, mafic igneous rock composed chiefly of calcic plagioclase and clinopyroxene in a glassy or fine-grained groundmass. Chert is found in association with basalt in Puerto Rico. It is hard, extremely dense, or cryptocrystalline sedimentary rock. The basalts are typified by pillow structures, interbedded limestone, or related calcareous sediments. Mineral occurrences observed in basalt include vein deposits of barite. The basalt has been quarried as traprock, an industrial product.

Puerto Rico's intrusive rocks have been separated into two classes; Cretaceous, and Tertiary through Cretaceous, based upon the age of intrusion. Intrusive rock types include diorite, gabbro, granodiorite, quartz monzonite, and syenite, as well as others.

Cretaceous intrusive rocks are the largest plutonic units known in Puerto Rico and cover approximately 600 km^2, or 7 percent, of the land area. They are typified by the San Lorenzo batholith of southeastern Puerto Rico and the Utuado batholith of central Puerto Rico. Porphyry copper deposits found in these areas are thought to be related to the younger Eocene intrusions, and the older Cretaceous rocks have associated mineral deposits such as magnetite skarns.

The Tertiary and Cretaceous intrusive terrane includes known Tertiary rocks and those rocks for which age is uncertain. Although some of these rocks have not been dated, they are included in this terrane because of their stratigraphic relationship with surrounding

rocks. The age of these intrusive rocks is important, because the present potentially economic metallic mineralization of Puerto Rico has been identified with the Eocene intrusive rocks. Most important are porphyry copper systems bearing copper, molybdenum, and gold. Associated with these intrusive rocks are skarn deposits within adjacent calcareous rocks, and vein deposits in fractures and faults.

Concurrent with these two periods of intrusion was the synchronous deposition of related marine volcaniclastic rocks, which cover a substantial area of Puerto Rico. Volcaniclastic rocks are defined as any rock containing volcanic material without regard to origin or environment. Rock types that make up this terrane include volcaniclastic sandstone and siltstone, ash-flow tuff, volcanic breccia, laharic breccia, and volcaniclastic conglomerate. This terrane constitutes approximately 3,100 km^2, or 36 percent, of the surficial Puerto Rican landmass. Most of the volcaniclastic terrane was deposited in a marine environment of Cretaceous age (20 percent of the surface). Marine volcaniclastic rocks are commonly transitional or interfinger with rock types. Subaerial volcaniclastic rocks are also present in Puerto Rico, but are limited in extent.

Rocks described as alteration on the terrane map are metavolcanic rocks or hydrothermally altered rocks for which the protolith is uncertain (R. Krushensky, oral communications; 1994). Alteration is an important indicator for locating many types of mineral deposits. However, altered rocks are widespread and represent many different levels of alteration intensity throughout Puerto Rico. Only the most intensely altered rocks are identified on the 1:20,000 geologic quadrangle maps that were used to compile the 1:200,000 geologic map.

Nonvolcaniclastic terranes are composed of biogenic or clastic map units devoid of volcanic material and cover approximately 3,900 km^2 or 45 percent of the surface area of Puerto Rico. Sedimentary or epiclastic processes including weathering, erosion, transport, and deposition form these nonvolcaniclastic rocks by consolidating fragments of preexisting rocks.

Eocene through Cretaceous nonvolcaniclastic terranes were intruded by Eocene igneous rocks. These nonvolcaniclastic rocks are dominantly limestone and calcareous clastic rocks. An understanding of the vertical and horizontal dimensions of these terranes is important because they host intrusion-related deposits, such as skarns and vein deposits.

Pliocene through Oligocene nonvolcaniclastic terranes comprise approximately 1,500 square kilometers, or 17 percent, of the surface area and consist of limestone and calcareous clastic rock. These rocks cover older rocks present during the intrusion of metalliferous Eocene igneous rocks. This terrane is an important source for industrial minerals, including limestone and sand and gravel.

Quaternary nonvolcaniclastic terranes consist of surficial deposits of alluvium, beach and swamp deposits, identified landslide areas, artificial fill, and fault breccia. Quaternary nonvolcaniclastic terranes comprise approximately 2,100 km^2, or 24 percent, of the total surface area and cover underlying rocks that have a potential for economic mineral deposits. Quaternary rocks are a major source for industrial minerals.

PATTERN OF GEOLOGIC TERRANES

The terrane map, which was generated by grouping geologically similar rock types, depositional environments, and (or) ages, displays twelve distinct terranes. Rocks of similar age and similar lithologic character tend to occur together. However, it must be remembered that because many of the lithologies are transitional or interfingering, they may logically be placed in more than one terrane. Terrane type was determined by the depositional environment and age of the predominant rock type for that particular map unit. Some assignments are likely ambiguous.

An obducted plate of Jurassic age ultramafic and amphibolite rocks is found in the southwest quadrant of the island.

The volcaniclastic rocks are intruded by Cretaceous and Cretaceous through Tertiary intrusive rocks, and submarine basalts and cherts occur throughout.

The marine Cretaceous volcaniclastic sediments dominate the east and interior of Puerto Rico, and Tertiary volcaniclastic rocks are mostly restricted to a linear belt in the west. There is a broad, mixed-age, Cretaceous and Tertiary transitional volcaniclastic terrane lying between.

Eocene and older nonvolcaniclastic rocks are sporadically distributed throughout the western and central parts of the island.

The Oligocene and younger nonvolcaniclastic terrane consists of sandstone and limestone that form a well-developed transgressive carbonate wedge on the north shore of the island, and a less well-developed, limited carbonate cover on the south side of the island.

The Quarternary nonvolcaniclastic terrane forms the blanket sand deposits, beaches, and Quaternary alluvium deposits that fill the river valleys and lowlands.

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Table 1. Twelve identified geologic terranes of Puerto Rico, shown as the percentage of surface area and areal extent square kilometers. [Total adds to 98 percent due to presence of surficial water bodies and rounding error.]

Geologic Terrane		Percent of island surface area	Areal extent (km^2)
Nonvolcaniclastic Terranes:			
Quaternary		24	2,088
Pliocene through Oligocene		17	1,479
Eocene through Cretaceous		4	348
	Subtotal	45	3,915
Intrusive Terranes:			
Tertiary and Cretaceous		1	87
Cretaceous		7	609
	Subtotal	8	696
Volcaniclastic Terranes:			
Subaerial		1	87
Marine		9	783
Tertiary			
Tertiary and Cretaceous		6	522
Cretaceous		20	1,740
	Subtotal	36	3,132
Alteration		1	87
Seafloor Basalts and Cherts		7	609
Ultramafic Rocks and Amphibolites		1	87
	Total land area	98	8,526
Surface water		2	174
	Grand Total	100	8,700

Table 2. Puerto Rico geologic map units by geologic terranes
[Stratigraphic units listed alphabetically]

Map unit symbol	Map unit
NONVOLCANICLASTIC TERRANES	
Quaternary:	
Qa	Alluvium
Qb	Beach deposits
QTs	Blanket sand deposits
Ql	Landslide deposits
Qs	Swamp deposits
af	Artificial fill
Pliocene through Oligocene:	
Tcbga	Almirante Sur Sand Lentil of Cibao Formation
Ta	Aguada Limestone
Tay	Aymamon Limestone
Tcm	Camuy Formation
Tcb	Cibao Formation
Tcbg	Guajataca Member of Cibao Formation
Tgua	Guanajibo Formation
Tjd	Juana Diaz Formation
Tla	Lares Limestone
Tcbmi	Miranda Sand Member of Cibao Formation
Tcbm	Montebello Limestone Member of Cibao Formation
Tmu	Mucarabones Sand
Tpo	Ponce Limestone
Tcbq	Quebrada Arenas Limstone Member of Cibao Formation
Tcbr	Rio Indio Limstone Member of Cibao Fomation
Ts	San Sebastian Formation
Tfb	Fault breccia
Eocene through Cretaceous:	
Tco	Corozal Limestone
Kcot	Cotui Limestone
Tc	Cuevas Limstone
Tg	Guayo Formation
Klm	La Muda Formation
Kp	Parguera Limestone
Kpe	Penones Limestone

INTRUSIVE TERRANES

Tertiary through Cretaceous:

TKas	Alkali syenite
TKap	Augite andesite porphyry
TKahp	Augite-hornblende porphyry
TKat	Augite trachybasalt
Td	Porphyritic dacite
TKda	Amygdaloidal dacite
TKg	Diabasic gabbro
Tga	Gabbro
TKgm	Granodiorite quartz monzonite
TKhda	Hornblende dacite
TKh	Porphyry Hornblende quartz-diorite
Thp	Hornblende quartz diorite porphyry
TKdi	Diorite
TKqd	Quartz diorite-granodiorite
TKk	Quartz keratophyre
Trhp	Rhyodacite porphyry

Cretaceous:

Kdi	Diorite
Kdh	Diorite-hornblende gabbro
Kcag	Granodiorite of the Caguas pluton
Kmc	Granodiorite of Morovis and Ciales stocks
Kpgq	Quartz diorite - plutonic complex of Punta Guayanes
Kpsg	Granodiorite of the plutonic complex of Punta Guayanes and the granodiorite of San Lorenzo batholith, undivided
Ksl	Granodiorite-quartz diorite of San Lorenzo batholith
Ku	Granodiorite-quartz diorite of the Utuado batholith
Kib	Intrusive breccia of the Daguao Formation
Kslg	Mixed granodiorite-diorite of the San Lorenzo batholith
Kpgg	Granodiorite of plutonic complex of Punta Guayanes
Kpsq	Quartz diorite of plutonic complex of Punta Guayanes and of the Granodiorite of San Lorenzo batholith
Kslq	Quartz diorite facies of Granodiorite of San Lorenzo batholith and diorite-hornblende gabbro
Kpgqm	Quartz monzonite of plutonic complex of Punta Guayanes
Kpob	Two pyroxene olivine basalt

VOLCANICLASTIC TERRANES

SUBAERIAL:

Kcb	Cambalache Formation
Kpo	Pozas Formation

MARINE:

Tertiary

Tca	Carreras Siltstone
Tj	Jicara Formation
Tjo	Jobos Formation
Tl	Los Puertos Formation
Tm	Monserrate Formation
Tor	Ortiz Formation
Tpa	Palmarejo Formation
Tra	Raspaldo Formation
Tr	Rio Culebrinas Formation
Trd	Rio Descalabrado Formation
Trp	Rio Piedras Siltstone
Ty	Yunes Formation

Tertiary and Cretaceous:

TKa	Anon Formation
TKamo	Anon-Monserrate Formations, undivided
TKay	Anon and Yauco Formations, undivided
TKam	Anon and Maricao Formations, undivided
TKci	Cibuco Formation
TKgu	Guaracanal Formation
TKl	Lago Garzas Formation
TKaym	Anon, Yauco, and Maricao Formations, undivided
TKlam	Lago Garzas, Anon, and Maricao Formations, undivided
TKly	Lago Garzas and Yauco Formations, undivided
TKal	Anon Formations and Lago Garzas, undivided
TKm	Maricao Formation
TKmy	Maricao and Yauco Formations, undivided
TKmly	Maricao, Lago Garzas, and Yauco Formations, undivided
TKn	Naranjito Formation
TKy	Yauco Formation

Cretaceous:

Kac	Achiote Conglomerate
Kal	Alonso Formation

Kba	Barrazas Formation
Kcam	Camarones Sandstone
Kcn	Canovanas Formation
Kca	Cariblanco Formation
Kcan	Cancel Breccia
Kcar	Carraizo Breccia
Kcoa	Coamo Formation
Keo	El Ocho Formation
Kfa	Fajardo Formation
Kfr	Frailes Formation
Kg	Guaynabo Formation
Kh	Hato Puerco Formation
Kja	Jayuya Tuff
Kln	Los Negros Formation
Kma	Magueyes Formation
Kmal	Malo Breccia
Kman	Manicaboa Formation
Kmar	Maravillas Formation
Kmag	Martin Gonzalez Lava
Km	Melones Limestone
Kmo	Monacillo Formation
Kpa	Pajaros Tuff
Kpi	Pitahaya Formation
Kra	Rio Abajo Formation
Krp	Rio de la Plata Sandstone
Kr	Robles Formation
Ks	Sabana Grande Formation
Kta	Tabonuco Formation
Kte	Tetuan Formation
Kt	Torrecilla Breccia
Kto	Tortuga Andesite
Kv	Vista Alegre Formation

ALTERATION TERRANE

TKmv	Metavolcanic rock
TKha	Hydrothermally altered rock

SUBMARINE BASALT AND CHERT TERRANE

Kabcj	Formations A, B, C, & J
Kav	Avispa Formation
Kap	Avispa and Perchas Formations, undivided
Kbo	Boqueron Basalt
KJc	Cajul Basalt
Kce	Celada Formation
Kcg	Cerro Gordo Lava
Kco	Concepcion Formation
Kctt	Cotorra Tuff
Kd	Daguao Formation
Ke	El Rayo Formation
Kf	Figuera Lava
Kfd	Figuera and Daguao Formations, undivided
Ki	Infierno Formation
Kl	Lajas Formation
Klo	Lomas Formation
Kmam	Mameyes Formation
KJm	Mariquita Chert
Kper	Perchas Formation
Kso	Santa Olaya Lava

ULTRAMAFIC ROCK AND AMPHIBOLITE TERRANE

KJa	Amphibolite
KJas	Amphibolite-Serpentinite
KJs	Serpentinite
KJb	Spillitized Basalt