THE CENTRAL FALCON IGNEOUS SUITE, VENEZUELA: ALKALINE BASALTIC INTRUSIONS OF OLIGOCENE-MIOCENE AGE

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ABSTRACT

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Basaltic igneous rocks crop out in a 50 km belt within Oligocene sedimentary rocks in the central Falcon Basin of northwestern Venezuela. Outcrop patterns, structural orientations, chilled margins, baked contacts, sedimentary inclusions, igneous breccias and uniformly alkaline compositions suggest these bodies are shallow intrusives and extrusives. Potassium-Argon determinations on a sill yield a 22.9 ± 0.9 Ma age which is 5 Ma younger than paleontologic ages of surrounding sedimentary rocks. A span of igneous activity from 28 to 23 Ma is inferred from stratigraphic constraints.

Locally, normal NNW-SSE growth faults are present in Oligocene units. Features of similar regional trend and evidence of growth faulting offshore imply a tensional tectonic regime during Oligocene-Miocene time. The tensional regime, silica undersaturated, alkaline nature of the igneous rocks, and rapid basin subsidence rates suggest a pull-apart basin model for the Falcon Basin – Bonaire Trough area. This resulted from commencement of Caribbean – South American transform motion over a wide zone of offset transform faults.

INTRODUCTION

The Falcon Basin in northwestern Venezuela is a narrow, nearly east-west trending basin composed largely of Oligocene-Miocene age sedimentary rocks (WHEELER, 1963). Within the Oligocene rocks in the central part of the basin, numerous basaltic igneous intrusives and extrusives of alkaline affinities crop out (Fig. 1). Given the poor contact exposures and lack of reported contact metamorphic effects, two plausible theories concerning the nature of these igneous rocks had been suggested prior to this study. BRUEREN (1949) interpreted these bodies as igneous intrusions and extrusions within the Tertiary sedimentary sequence, whereas BELLIZZIA ET AL. (1972) inferred them to be allochthonous blocks similar to the 'ophiolite' blocks of the Siquisique – Rio Tocuyo region to the south.

This paper presents the results of field, petrographic, and isotopic studies which support an intrusive origin for the central Falcon igneous suite. In this context the compositional, spatial and temporal aspects of these rocks are important in understanding the evolution of mid-Tertiary tectonics along this part of the Caribbean – South American plate margin.

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BACKGROUND GEOLOGY

As inferred from lithofacies distributions (WHEELER, 1963; FERELL ET AL., 1969) the central part of Falcon during Oligocene – early Miocene time was occupied by a narrow marine basin, elongated in an ENE-WSW direction and bordered by highs to the south, west northwest and north. The Eocene flysch basin containing the allochthonous blocks of the Siquisique – Rio Tocuyo region (BELLIZZIA ET AL., 1972) was already deformed, uplifted and being eroded at this time. It formed the southern high. The Oligocene – Miocene stratigraphy is complicated by many lateral and vertical facies changes. In the central part of the basin where the igneous intrusions crop out, the stratigraphic section is divided into: (1) the lower Oligocene El Paraiso deltaic sands and shales which by middle Oligocene grade upward into, (2) the Pecaya marine shale sequence which eventually gives way to (3) the lower Miocene Pedregoso calcareous turbidites and shales eroded from the San Louis Formation carbonates to the north

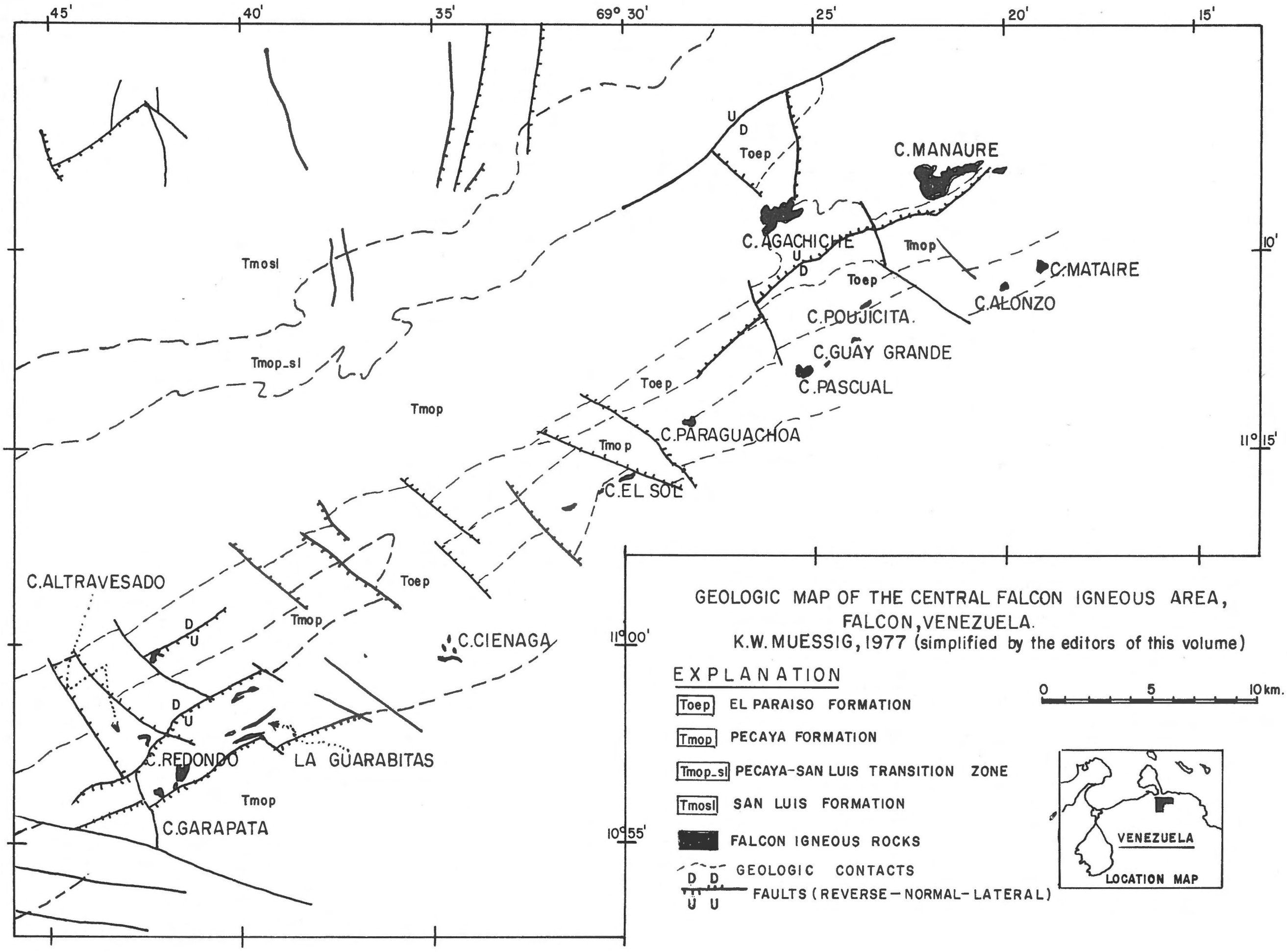

Fig. 1
Geologic map of the central Falcon igneous area showing igneous body locations.

(WHEELER, 1963; DIAZ DE GAMERO, 1977). During the Oligocene – lower Miocene time span approximately 3.5 km of sediment were deposited at rapid subsidence rates of 500 to 700 m/Ma (DIAZ DE GAMERO, 1977).

OUTCROP PATTERNS

Based on outcrop patterns many of the Falcon igneous rocks could be interpreted as either allochthonous blocks or as intrusive plugs (i.e. Cerros Alonzo, Mataire, Pascual, Paraguachoa). Map patterns (figure 1) and structural settings of other bodies however (i.e. Guarabitas, Cienaga, Agachiche, Manaure, Redondo) strongly suggest that these are intrusive diabase sills and plugs. Three diabase masses crop out at Guarabitas. One of these is less than 10 m thick and extends along strike of the El Paraiso Formation for approximately 3 km. The body is a sill concordant with the surrounding strata in that the boundary surfaces of the igneous rock yield the same strike and dip as the adjacent El Paraiso Formation.

At Cerro Cienaga an elongated diabase outcrop is exposed along a north facing, east-west striking cliff. It is underlain and overlain by El Paraiso rocks dipping gently south. These structural attitudes, supported by the contact relationships described below, suggest that Cerro Cienaga is a sill.

Cerro Agachiche displays spectacular columnar jointing, generally oriented perpendicularly to the bedding. Columnar joints normally develop perpendicularly to the isotherms of a cooling intrusion (LACHENBRUCH, 1962) and therefore perpendicularly to the contact with the country rock. The orientation of columnar joints at Cerro Agachiche therefore suggests that the intrusion is concordant with bedding. Divergences of these directions are observed in the central part of Agachiche, possibly reflecting the existence of a central feeder plug with a more complex cooling history. In addition a narrow sill projects eastward from the main part of the massive igneous sill.

Cerro Manaure is the most massive of the intrusions, covering about three square km. Sedimentary units north and south of the intrusion dip 22° to 40° north. The intrusion is concordant with the regional strike suggesting that it is a thick sill. Its injection probably either initiated or added to the development of the local faulting.

Cerro Redondo is also elongated along strike of the sedimentary bedding. An apophysis of Cerro Redondo, here named Cerro Garapata, has been disconnected from the main body by erosion. Cerro Garapata diabase is under- and overlain by El Paraiso dipping slightly north. This projection formerly extended westward from Cerro Redondo sill above the present level of erosion.

CHILLED MARGINS – BAKED CONTACTS

The chilled igneous margin and baked contact rocks at Cerro Cienaga present strong evidence for an intrusive origin. The upper contact is well exposed in a road cut through the eastern part of the body. A fine-grained diabase sample taken 20 cm below the contact from a spheroidally weathered in situ boulder, exhibits an intersertal texture. It shows none of the large, euhedral clinopyroxene phenocrysts, typical of samples collected from the more central parts of the body. Evidently the cooling rate was rapid enough to inhibit the growth of such large crystals. At this same contact, overlying shales are baked. Masses of fine-grained sericite, visible in thin section, formed as metamorphic products.

Cerro Manaure also exhibits evidence of a chilled margin. Samples containing radiating crystal-clusters of clinopyroxene are found along the southern lower contact of the intrusion. Such clusters indicate supercooling (LOFGREN, 1971, 1974; DREVER ET AL., 1972). Thus cooling at the margin was more rapid than in the interior of the body where only single euhedral crystals are found.

SEDIMENTARY INCLUSIONS

'Inclusions identical to surrounding sedimentary units are found in almost every intrusion. In particular those in Cerros Redondo-Garapata are significant. An inclusion of grey quartzite with shale chips and coal fragments was collected from the igneous border of Cerro Garapata. This lithology is identical to grey sandstones of the El Paraiso Formation found within 100 m of the contact, which contain shale chips and large carbonaceous plant remains. Surely the above inclusion was incorporated into the magma during its intrusion into the Oligocene sediments. The root zone of Cerro Redondo proper is rich in quartzite inclusions.

At Cerro Cienaga (outcrop described in previous section), inclusions of the overlying shale are found within altered igneous rock, a few cm below the disturbed contact zone. The magma intruded semi-consolidated wet shales, disturbing them near the contact and incorporating a few shale chips. During and after crystallization, water was absorbed from the surrounding sediments thereby altering the primary mineralogy most intensely near the contact zones. Cerro Agachiche, Manaure, Paujicito and Atravesado also contain inclusions.

IGNEOUS BRECCIAS

The margins of many bodies are characterized by contact zones of brecciated and re-cemented sedimentary rocks. These were apparently produced by intrusion of the magma into wet, semi-consolidated sediments. These breccias are composed of hornfels, shale or quartzite fragments cemented by a siliceous matrix sometimes containing β-quartz pseudomorphs, talc, zeolites and sericite. Excellent examples of these breccias are exhibited at the upper east side of Redondo, the south sill at Guarabitas and the body 1 km north of Guarabitas here named Cerro La Azulita. Others occur at Atravesado, Manaure, Pascual and Cienaga.

COMPOSITION AND PETROGRAPHY

Based largely on petrographic observations, the majority of the diabases are alkaline or silica-undersaturated in composition. In addition many rocks are high in potassium thereby classifying them as members of the potassic alkali olivine basalt series of IRVINE & BARAGAR (1971). Alkali olivine basaltic diabases contain olivine, titanaugite, plagioclase, amphibole and Fe-Ti oxides as both phenocryst and groundmass phases. Sometimes potassium feldspar is present in the groundmass and a few fresh basalts contain groundmass nepheline. Amphibole is seen to replace clinopyroxene and olivine. Augite is sector-zoned and sometimes glomeroporphyritic. Textures are intersertal, sub-ophitic and intergranular. This rock is typical of Cerros Agachiche, Cienaga, Manaure, Mitaire, Pascual, Paujicita and Redondo.

Other intrusions have biotite as an additional phenocryst and groundmass phase. Biotite has crystallized early and is frequently enclosed poikilitically by amphibole. According to the classification of IRVINE & BARAGAR (1971) these rocks are trachybasalts of the potassic-alkali-olivine basalt series. Atravesado, El Sol, Guarabitas and La Azulita are trachybasalts in composition.

The alkaline, silica-undersaturated nature of some more altered rocks is demonstrated by preliminary microprobe analysis of relic mineral phases. Augites are high in titanium (1.4 – 4.1% TiO_2) and kaersutite amphibole (K_2O = 2.1 %; TiO_2 = 5.8% is present. These mineralogic characteristics are typical of rocks with alkaline, silica-undersatured parentage.

Originally it was thought that basaltic andesites were present at Cerro Arachiche. However they are present only as minor border facies and could be either more acidic differentiates (i.e. trachytes) of the alkali olivine basalt or a siliceous contaminant approaching basaltic andesite in composition. It is believed that this point will be clarified once bulk rock date are available.

At Cerro Paraguachoa a poorly stratified welded tuff or ignimbrite is overlain by an unstratified volcaniclastic mudflow. Both rock types are unique in the area studied. Again bulk rock data are needed to determine their chemical affinities.

Alteration has affected many of the basaltic rocks over a range of temperatures. Actinolite, prehnite, epidote, clinozoisite, talc, chlorite, albite, sericite and carbonate are common alteration products. Olivine is usually serpentinized or replaced by iddingsite or chlorite. Analcite is ubiquitous. A detailed study of the mechanisms of alteration, the sequence of mineral breakdowns, and the factors that affect them, is in progress.

Xenoliths present in the trachybasalts at Cerros Atravesado, El Sol and La Azulita yield information on the nature of the basement underlying the Falcon area. Foliated calc-silicate xenoliths are the most abundant (over 90%) although one granite and one schist xenolith were found. These rocks indicate that the basement has continental characteristics and has experienced deformation and metamorphism prior to the intrusion of these alkaline magmas. In addition approximately 5% of the xenoliths found are ultramafic (spinel wehrlites and spinel lherzolites). Presumably these were acquired from the mantle during magma ascent or from an ultramafic fragment (similar to Siquisique) incorporated into the underlying Falcon basin crust during a previous (Eocene) tectonic event. Other xenoliths composed of 99% feldspar and about 1% biotite and amphibole were found along with xenoliths of a gabbroic nature. These are interpreted as cognate xenoliths or plutonic cumulate blocks (in the sense used by LEWIS, 1972) from a crystallizing magma chamber which fed the intrusions.

POTASSIUM - ARGON ANALYSES

In order to determine an age for the central Falcon igneous rocks, three samples of fresh trachybasaltic diabase were collected for analysis from the Guarabitas sills. Two samples are from the northernmost sill: G-770 from the central part, and G-7711 from the westernmost part about 1 km from G-770. The third sample was taken from the western end of the southernmost sill. On a microscopic scale all samples show some alteration. Sericite flakes have developed in the plagioclase phenocrysts and groundmass. Biotite microphenocrysts are *unaltered* except in sample G-7711 where they are partially chloritized. Samples were crushed, sieved and split to obtain representative, 20-40 mesh size, whole rock samples. Fresh biotite was separated from sample G-770 to check the affect of alteration on the whole rock system. The ages obtained (Table I) are consistent with the degrees of alteration observed petrographically. The 22.9 ± 0.9 Ma age for the biotite separate is considered the most accurate age of solidification and cooling. These bodies occur in the transition zone between the El Paraiso and Pecaya Formations. According to DIAZ DE GAMERO (1977), benthonic and planktonic foramini-

Table I
Potassium-argon analyses of La Guarabitas diabase sills, Falcon, Venezuela.

Sample	Size	K (%)	$^{40}Ar_{rad}$ (X10 mol/g)	$^{40}Ar_{atmos.}$ / $^{40}Ar_{tot.}$ (%)	Age Ma[1])
G770	20-40	1.93	6.41	49	
whole rock		1.92			
		av. 1.92			19.1±0.5
G770	70-140	5.80	22.28	57	
biotite		5.81	24.02	42	
		av. 5.80	av. 23.15		22.9±0.9
G752	20-40	1.72	5.65	55	
whole rock		1.69			
		av. 1.70			19.0±0.7
G7711	20-40	2.12	6.58	52	
whole rock		2.11			
		av. 2.12			17.8±0.6

Conventional procedures were used throughout. K-analysis was by flame photometry using lithium metaborate as a flux and internal Li standard. ^{40}Ar was measured by isotope dilution using a 15 cm Nier-type mass spectrometer and a ^{38}Ar tracer from a metering system. Values for the LP-6 interlaboratory, biotite standard were: 8,33 (± 0.03) % K; and, 1.895 (± 0.013) x 10^{-9} mol $^{40}Ar_{rad}$/g.
[1]) constants: $\lambda\beta = 4.962 \times 10^{-10}$/y.; $\lambda\beta = 0.581 \times 10^{-10}$/y.; $^{40}K = 0.01167$ atom%; analytical uncertainties at the 68% confidence level.

fera place this horizon at about 28 Ma. The diabases are about 5 Ma *younger* than their surrounding sediments thus strongly supporting their intrusive origin. A more extensive radiometric study would be necessary to establish the total span of igneous activity. The occurrence, however, of flows, agglomerates (Atravesado) and volcaniclastics (Paraguachoa) at approximately the same stratigraphic horizon as the Guarabitas sills indicates some igneous activity as early as 28 Ma.

STRUCTURE AND TECTONICS

The central Falcon igneous suite is found within an anticlinorium oriented N60E. This structure formed as a result of compressive forces which were initiated at the close of the Miocene and continued intermittently through the Pleistocene to the present. In the area of igneous exposures the anticlinorium is composed of many anticlines and synclines defined by resistant ridges of the El Paraiso sandstone. Numerous reverse faults paralleling the regional anticlinorium trend are found both throughout the basin and in the central basin igneous area.

Anticlinorium-trending structural features are typically cut by many NNW-SSE normal and lateral faults. These faults offset and terminate ridges and are followed by streams cutting through resistant sandstone units. Where well exposed in road-cuts (e.g. along the Aracua-Murucusa road south of Cerro Cienaga), smaller-scale normal faults of similar trend exhibit growth-fault characteristics. Significant (up to 1 m) changes in unit thickness occur across the faults. Thus some normal faulting, indicating tension, occurred during the deposition of the Oligocene-Miocene section.

On a larger scale, similar Oligocense-Miocene normal growth faults are found offshore in east-west cross-sections (figure 7a of CVP-INST. FRANÇ. PÉTROLE REPT., 1967) of the Gulf of Venezuela – Paraguana – La Vela area. Such faults may also explain some of the anomalous stratigraphic units (e.a. San Juan de La Vega Member) in the Falcon Basin proper, along with the many lithologic facies and thickness changes.

This tensional tectonic regime is consistent with the alkaline nature of the igneous rocks and the rapid basin-subsidence rates. However, one might expect that magma injected into this environment would tend to parallel the normal-fault trends (see e.g. HILL, 1977). At this stratigraphic level the Falcon igneous bodies are commonly exposed as sills and plugs. Perhaps at depth, NNW-SSE dikes are the feeders for these sills. The + 50 mgal gravity anomaly in eastern-central Falcon (BONINI ET AL., 1977; BONINI, 1978) is possibly the expression of such a dike.

The tensional nature of the Oligocene-Miocene basin, the rapid subsidence rates, the presence of alkaline basic igneous rocks, and the orientation and nature of the normal faults, suggest that the Falcon Basin developed along an irregular east-west transform boundary as a pull-apart basin (after usage of CROWELL, 1974). The Falcon Basin and offshore extension, the Bonaire Trough (SILVER ET AL., 1975), form a rhombic-shaped unit (Fig. 2) between the Caribbean Mountain – Siquisique ophiolite trend to the south, and the Paraguana-Antillean area to the north.

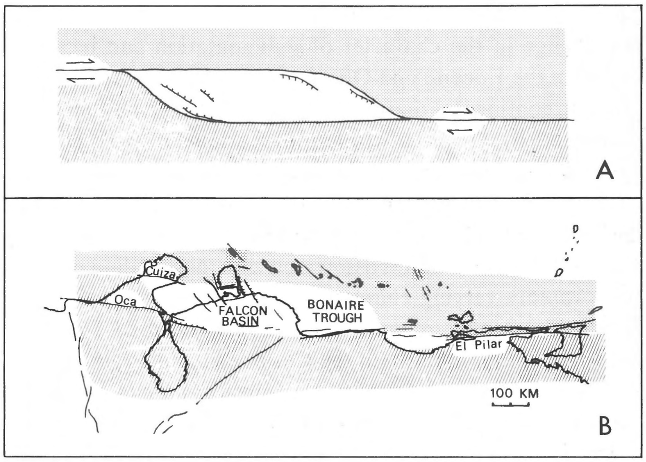

Fig. 2
(A) Idealized pull-apart basin along off-set transform faults. Unshaded area is zone of pull-apart.
(B) Generalized model of the Falcon Basin-Bonaire Trough pull-apart area.

It is suggested that the Oligocene-Miocene right-lateral motion between the Caribbean and South American plates was transferred from transform faults in western Venezuela (Oca, Cuiza) to offset more southerly transform faults in eastern Venezuela (Sebastian, El Pilar) by extension in the Falcon Basin – Bonaire Trough area. The timing of this extension as indicated by the Falcon intrusions, fits well with the post Eocene 'rifting' of the Antillean Islands from the Venezuelan mainland as suggested by SILVER ET AL. (1972) based on stratigraphic and lithologic evidence.

Offshore structures around the Netherlands and Venezuelan Antilles and in the Gulfs of Venezuela and La Vela, suggest that this pull-apart may be distributed over a larger region, of which the Falcon Basin – Bonaire Trough unit is only a part. Although more complex, this pull-apart basin shows striking similarities to other pull-apart areas along the California – Pacific transform margin (e.g. the Salton Sea – Imperial Valley – Gulf of California area; see CROWELL, 1974).

CONCLUSIONS

All aspects of the central Falcon igneous suite, including uniform rock composition, body shapes and orientations, contact relationships and surrounding sediment lithology, either indicate, or are consistent with, an intrusive origin for these rocks. K-Ar analyses in particular strongly suggest that the bodies are intrusive and not allochthonous. This is not to say that allochthonous igneous bodies do not occur to the south in the

Siquisique – Rio Tocuyo area. On the contrary, it emphasizes the change in the character of sedimentation and tectonics between the Eocene and Oligocene along the northwest Venezuela continental margin. This major change has been documented by previous workers in Caribbean geology from other lines of evidence (STAINFORTH, 1969; BELL, 1972). The presence of uniformly alkaline intrusions, the rapid basin subsidence, the thick Oligocene-Miocene sequence of sediments, the normal growth-faults associated with these sediments, and their rapidly varying character and thickness, all point to a tensional tectonic regime. This tension resulted from the transform motion between the Caribbean and South American plates along a series of offset transform faults which dissected an irregular continental margin. The Falcon Basin formed in response to these stresses and was intruded by basic alkaline magmas. The later addition of a compressional component to the Caribbean – South American transform motion caused the Late Miocene-to-present folding and thrusting within the basin.

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