period, began to dominate the turbidity values while there was continued attrition of the Mount Agung aerosols. This explanation is supported by similar radiation data from the South Pole station (*6*) which show decreasing turbidity from late 1964 through early 1966.

To estimate the magnitude of such a long-term trend two linear regression lines were fitted to the unsmoothed monthly averages. The first incorporated all data through February 1963 (the pre-eruption period), and the second included the entire data sample, except for the 3-year interval from March 1963 through February 1966 inclusive (the period arbitrarily selected as that influenced by the eruption). The regression yielded Linke turbidity changes of $0.61 \pm .19$ and $0.83 \pm .08$ per decade, respectively, where the listed accuracies are twice the computed standard error. Thus, the addition of the 1966 and 1967 data to the pre-eruption sample increases the earlier turbidity trend, suggesting either that the aerosol content was increasing more rapidly during the past several years or that a small residue from Mount Agung was still present during this time.

Our interpretation, that the observations indicate a long-term turbidity increase, is supported by additional independent data whereas none exists to support the concept of radiational effects from a volcanic eruption lasting 5 years. McCormick and Ludwig (*1*) presented data from Davos, Switzerland, and Washington, D.C., which showed turbidity increases of approximately 20 and 10 percent per decade, respectively, for the general period of 1910 to 1960. In addition, measurements by Schaefer (*9*) at both rural and urban United States locations indicate that atmospheric particulate concentrations have increased by at least an order of magnitude during the past 10 years, and Davitaya (*10*) has shown that the dustfall in the high Caucasus increased nearly 20-fold between the 1930's and the 1960's.

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Guatemela: Preliminary Zircon Ages from Central Cordillera

Abstract. *Concordia resolution of uranium-lead analyses of zircons from rocks of the Guatemalan Cordillera indicates a period of plutonism, and perhaps metamorphism, in late Paleozoic times (345 ± 20 million years). Gneisses of the Chuacús Series yield an age of 1075 ± 25 million years which may be either the age of a source terrain for the original sediments, or the age of principal metamorphism. Zircons from a Paleozoic granite intruding the gneisses appear to contain inherited or contaminating material acquired during the process of magma generation or emplacement, or both.*

Interest in the geology of Central America has increased during the past several years, not least because knowledge of this region can be expected to yield information pertinent to theories of crustal structure, crustal evolution, and continental drift. In parts of Central America, Late Paleozoic or younger formations (or both) are underlain by gneisses and schists of problematical age; thus the antiquity of the Central American crust remains unknown until these rocks are dated.

The oldest rocks of the Guatemalan Cordillera are garnet-mica schists, granitic gneisses, and associated marbles and amphibolites of the Chuacús Series (*1*). Intruding the Chuacús Series are weakly foliated to massive granites of the Rabinal and Matanzas bodies. These crystalline rocks are overlain by the Pennsylvanian or early Permian Santa Rosa Formation, which consists of coarse clastics containing fragments of schist, gneiss, and granite in the lower part of the section, and shales and thin limestones in the upper part.

The Chuacús Series grades upward

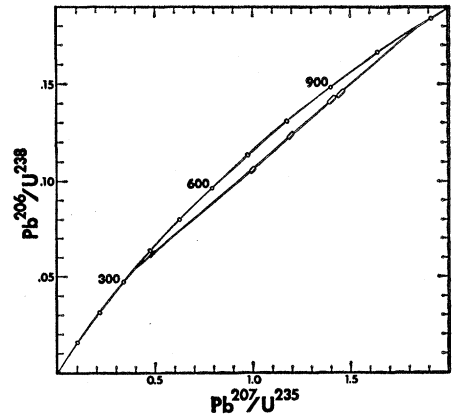

Fig. 1. Concordia representation of analytical data from Table 1.

through a zone of sheared mica schists and chloritic cataclasites into a sequence of meta-arkoses, feldspathic phyllites, and marbles. McBirney (*1*) suggested that these more weakly metamorphosed sediments may be correlative with the Santa Rosa Formation, thereby indicating the possibility of a Late Paleozoic period of metamorphism in Guatemala.

We analyzed zircons from a sample of Rabinal granite collected about 5 km north of the town of Rabinal, and from two samples of the Chuacús Series; sample 1 is a biotite-albite-quartz granite gneiss collected from a road about 109 km on Route 5 south of Rabinal and sample 2 is a biotite-albite-epidote gneiss from the crest of the Sierra de Chuacús south of Salama. Standard procedures were used, with the addition of hydrofluoric acid washes of the zircon concentrates to remove undesirable mineral impurities.

Zircons from the gneisses are white to pale brown, almost opaque, and commonly show rounded terminations or rounded to euhedral cores surrounded by overgrowth material. In contrast, zircons from the granite are deep purple, transparent, and prominently zoned. However, 1 or 2 percent of this concentrate consisted of grayish white, cloudy-opaque grains similar in appearance to the gneiss zircons.

Analytical results are shown in Table 1 and Fig. 1. A linear chord fits all the data points on the concordia diagram within analytical error (estimated to be approximately 1.5 percent in the radiogenic isotope ratios). This pattern indicates that the isotopic characteristics of the zircons are explicable in terms of two essentially episodic events which occurred at times given by the upper and lower intercepts of the chord

Table 1. Isotopic analyses of zircon fractions. Common lead correction (from borax flux): 206/204, 18.34; 207/204, 15.61; 208/204, 38.16. Abbreviations: NM, nonmagnetic split; HP, hand-picked sample. Pb^r, radiogenic lead.

Mesh size range	Weight (mg)	Observed Pb isotope ratios			Concentrations*		Atom ratios			Apparent ages (10^6 yr)†		
		206/204	206/207	206/208	Pb^r	U	206/238	207/235	207/206	206/238	207/235	207/206
					Gneiss, Chuacús Series, sample 1							
100 to 200	274	267.9	8.201	4.861	98.09	946.4	0.1060	0.9988	0.06833	655	710	895
100 to 200, NM	286	438.8	9.678	6.028	76.07	620.9	0.1236	1.194	0.07071	760	810	970
					Gneiss, Chuacús Series, sample 2							
100 to 200, NM	292	989.8	11.50	7.914	59.09	406.9	0.1453	1.452	0.07253	885	925	1020
100 to 200, M	288	809.1	11.20	7.488	66.08	465.7	0.1422	1.406	0.07164	865	905	995
					Rabinal granite							
100 to 200	199	667.7	12.69	3.427	64.29	924.6	0.06228	0.4897	0.05701	395	410	505
100 to 200, NM	283	927.4	13.81	3.637	61.14	875.4	0.06269	0.4902	0.05671	395	410	490
100 to 200, HP	331	710.3	12.96	3.417	65.95	965.2	0.06101	0.4764	0.05665	385	400	490

* By isotope dilution, in parts per million. † Decay constants: $\lambda_{238} = 1.54 \times 10^{-10}$ yr^{-1}; $\lambda_{235} = 9.72 \times 10^{-10}$ yr^{-1}. U^{238} : $U^{235} = 137.7$.

with the concordia curve (*2*), 1075 ± 25 million years and 345 ± 20 million years, respectively. The geological significance of these "events," however, is not completely determined by the available information.

We suggest two alternative interpretations. The first is that sediments of the Chuacús Series were derived from a source terrain whose primary (composite?) age is 1075 million years, and were metamorphosed and intruded by the Rabinal-type granites during a brief interval about 345 million years ago. If so, it follows that metamorphism resulted in widespread partial loss of lead from the gneiss zircons but was not severe enough to obliterate their primary age.

The following arguments support this interpretation: (i) textural and chemical similarities between some of the granites and gneisses (*1*) suggest that their origin is associated in time; (ii) the existence of weakly metamorphosed sediments lithologically similar to the Santa Rosa Formation suggests a late Paleozoic period of metamorphism; and (iii) limited Rb-Sr data published by Pushkar (*3*) tend to confirm a late Paleozoic event of major proportions. Pushkar's sample McB-G-195 is identical to our sample 2 of the gneiss and his sample McB-G-261, from the Matanzas stock, is equivalent to our Rabinal granite sample. Using an assumed initial $Sr^{87}:Sr^{86}$ ratio of 0.704 and a Rb^{87} half-life of 1.39×10^{-11} yr^{-1}, we calculate apparent ages of 395 and 270 million years for these two samples, respectively. These results, however, must be regarded as no more than suggestive.

The alternative interpretation is that the Chuacús Series was originally metamorphosed 1075 million years ago, so severely that the zircons in the gneisses lost any trace of a significantly earlier crustal history. The Rabinal-type granites were emplaced 345 million years ago, accompanied by widespread thermal effects that caused partial loss of lead in the gneiss zircons.

Evidence for this interpretation is indirect. Radiometric ages in the general range of 1000 million years have been obtained by K-Ar, Rb-Sr, and Pb-α methods on pegmatites intruding gneisses in Oaxaca, Mexico (*4*), and the Chuacús Series may possibly represent an eastward extension of the "Oaxacan Orogeny." Furthermore, the complete recrystallization of the gneisses, and the overgrowths on the zircons, suggest that the principal metamorphic episode, if much later than the primary age of the zircons, should have resulted in extreme discordance, perhaps analogous to that observed in the Catalina gneiss of Arizona (*5*). According to this point of view the observed discordance in the gneiss zircons is more nearly compatible with a secondary thermal event not associated with major metamorphic recrystallization.

Although both interpretations conclude that the Rabinal and related granites were intruded about 345 million years ago, the apparent ages given by Pb^{207}-Pb^{206} analysis for the zircon fractions from the Rabinal granite are 490 to 505 million years, which ordinarily would be considered minimum ages for this rock. Part of the discrepancy may result from the larger uncertainty associated with the common lead correction at this young age, but a more fundamental explanation is that the Rabinal granite zircon assemblage may have acquired a small component of the older isotopic systems from the gneisses during the process of magma generation or emplacement, or both. This inherited or contaminating material may be represented in part by the "anomalous" white opaque grains in the granite zircon concentrate. A substantial portion of such grains was removed by hand-picking from the fraction labeled "HP" in Table 1. The resulting shift in isotope ratios is not greater within confidence limits than analytical errors but is in the right direction. Conceivably the older component is largely occluded in otherwise normal appearing zircon grains.

The history of the older rocks of Guatemala has been complicated by numerous secondary events, culminating in uplift and nearby volcanism in the Tertiary. These younger events are reflected by a K-Ar age of 66 million years obtained on biotite from the same rock as our gneiss sample 2 (*6*).

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