16. $^{40}Ar/^{39}Ar$ AGES FROM A PRE-MESOZOIC CRYSTALLINE BASEMENT PENETRATED AT HOLES 537 AND 538A OF THE DEEP SEA DRILLING PROJECT LEG 77, SOUTHEASTERN GULF OF MEXICO: TECTONIC IMPLICATIONS[1]

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ABSTRACT

Drilling penetrated pre-Mesozoic crystalline basement beneath abbreviated sedimentary sequences overlying fault blocks in the southeastern Gulf of Mexico. At Hole 538A, located on Catoche Knoll, a foliated, regional metamorphic association of variably mylonitic felsic gneisses and interlayered amphibolite is intruded by post-tectonic diabase dikes. Hornblende from the amphibolite displays internally discordant $^{40}Ar/^{39}Ar$ age spectra, suggesting initial post-metamorphic cooling at ~500 Ma followed by a mild thermal disturbance at ~200 Ma. Biotite from the gneiss yields a plateau age of 348 Ma, which is interpreted to result from incorporation of extraneous argon components when the biotite system was opened during the ~200 Ma thermal overprint. A whole-rich diabase sample from Hole 538A records a crystallization age of 190.4 ± 3.4 Ma.

A lower grade phyllitic metasedimentary sequence was penetrated at Hole 537, drilled ~30 km northwest of Catoche Knoll. Whole-rock phyllite samples display internally discordant $^{40}Ar/^{39}Ar$ age spectra, but plateau segments clearly document an early Paleozoic metamorphism at ~500 Ma.

The age and lithologic character of the basement terrane penetrated at Holes 537 and 538A suggest that the drilled fault blocks are underlain by attenuated fragments of continental crust of "Pan-African" affinity. This supports pre-Mesozoic tectonic reconstructions that locate Yucatan in the present Gulf recess during the amalgamation of Pangea.

INTRODUCTION

Drilling at Holes 537 and 538A of DSDP Leg 77 penetrated metamorphic rocks beneath abbreviated Mesozoic-Cenozoic sedimentary sequences that cap relatively high-standing fault blocks in the southeasternmost Gulf of Mexico (Fig. 1). Whole-rock and mineral samples have been dated by incremental-release $^{40}Ar/^{39}Ar$ techniques. These results provide significant constraints for the overall tectonic evolution of the Gulf.

METHODS

Sample Preparation

Hole 537 penetrated approximately 20 m of phyllitic metasedimentary rocks composed primarily of fine-grained white mica and quartz, and characterized by development of a penetrative cleavage. Chlorite and albite are varietal phases of the regional metamorphic assemblage. After petrographic examination, two whole-rock samples of more sericitic portions of the phyllite were crushed and sieved (537-16-1, 16–18 cm and 537-16-1, 27–31 cm). Whole-rock powders (0.15–0.18 mm) were prepared for analysis by leaching in dilute HCl for 1 hr. and thoroughly washing.

Hole 538A penetrated approximately 60 m of a regional metamorphic terrane consisting of variably mylonitic biotite, quartz, two-feldspar gneisses and interlayered amphibolite. This sequence is cut by numerous post-metamorphic diabase dikes. Many of the crystalline rocks recovered at Hole 538A appear to have been altered by low-temperature, hydrothermal(?) processes; however, enclaves of fresh material are preserved locally.

After petrographic examination, an unaltered amphibolite sample was selected for study (538A-31-2, 109–114 cm). It was fine grained and crystaloblastic. It consisted principally of plagioclase (An_{42-51}) and hornblende. Optical characteristics of the hornblende suggest it is likely pargasitic in nature. The sample was crushed and sieved, and pure hornblende concentrates were prepared from two size fractions (0.10–0.15 mm and < 0.08 mm) using heavy liquid and magnetic separatory procedures. A mylonitic gneiss sample (538A-30-1, 39–53 cm) was also crushed and sieved. It consisted largely of plagioclase porphyroclasts ($An_{26-32?}$ with deformed polysynthetic twin lamellae) in an anastomosing groundmass of dynamically recrystallized quartz ribbons and much finer-grained, dark green biotite. A pure biotite concentrate was separated from the 0.10–0.15 mm sieve fraction. An unaltered whole-rock diabase sample (538A-32-3, 45–54 cm) was also crushed and sieved. The sample was fine grained with a uniform ophitic texture. It was composed primarily of labradorite, pyroxene (augite), and opaque minerals (including magnetite, ilmenite, and sulfides). The whole-rock powder (0.15–0.18 mm) was prepared for analysis by leaching in dilute HCl for 1 hr. and thoroughly washing.

Analytical Techniques

The $^{40}Ar/^{39}Ar$ incremental-release method of dating has been described elsewhere (e.g., Dalrymple and Lanphere, 1971; Dallmeyer, 1979) and will not be reviewed here. The analytical techniques used for analysis of the Leg 77 samples are those described by Dallmeyer and Rivers (1983). Measured isotopic ratios were corrected for the effects of mass discrimination and adjusted for interfering isotopes produced during irradiation by correction factors reported for the reactor, (U.S. Geological Survey, Denver) by Dalrymple et al. (1981). Apparent $^{40}Ar/^{39}Ar$ ages were calculated from the corrected isotopic ratios using the decay constants and isotopic abundance ratios recommended by Steiger and Jäger (1977). Total uncertainties in each apparent age (quoted at two standard deviations) have been calculated following the methods outlined by Dalrymple and Lanphere (1971).

RESULTS

The $^{40}Ar/^{39}Ar$ analytical data are presented in Tables 1 and 2 and are displayed as incremental-release age spectra in Figures 2–5.

Site 537

Whole-rock phyllite samples recovered from Hole 537 display internally discordant $^{40}Ar/^{39}Ar$ age spectra with total-gas ages of 449 ± 11 and 456 ± 10 Ma. In both samples, younger apparent ages are recorded in gas fractions liberated at relatively low experimental temperatures (Fig. 2); however, generally similar ages of

[1] Buffler, R. T., Schlager, W., et al., *Init. Repts. DSDP*, 77: Washington (U.S. Govt. Printing Office).

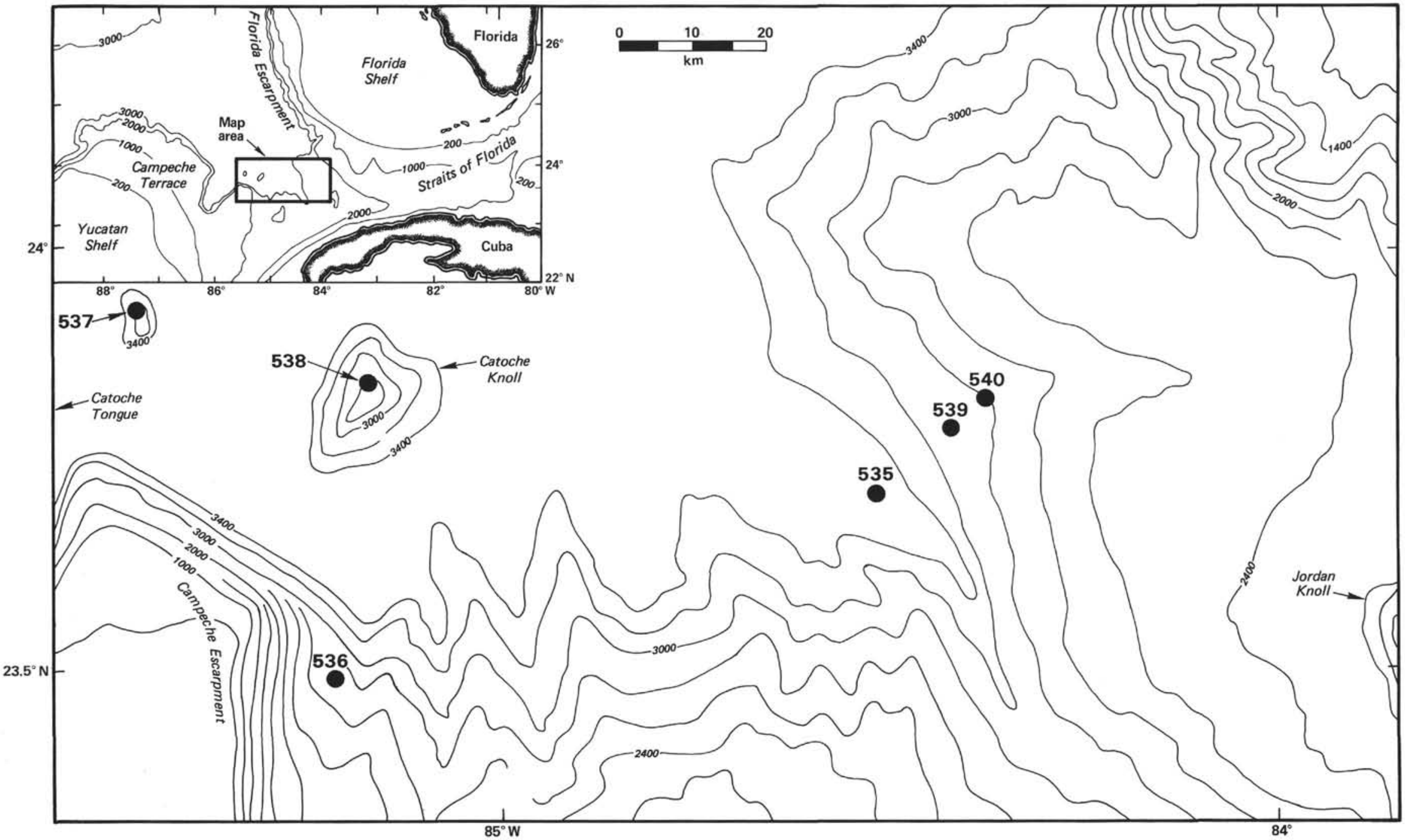

Figure 1. Location map of sites drilled during Leg 77. Bathymetric contours in m.

Table 1. $^{40}Ar/^{39}Ar$ analytical data for incremental heating experiments on whole-rock phyllite samples recovered from Hole 537 of DSDP Leg 77, southeastern Gulf of Mexico.

Release temperature (°C)	$^{40}Ar/^{39}Ar$[a]	$^{36}Ar/^{39}Ar$[a]	$^{37}Ar/^{39}Ar$[b]	^{39}Ar (% of total)	^{40}Ar nonatmos.[c] (%)	$^{36}Ar_{Ca}$ (%)	Apparent age (Ma)[d]
537-16-1, 16–18 cm[e] (J = 0.0007525)							
450	19.17	0.02257	0.072	2.00	65.20	0.09	162 ± 5
475	30.57	0.00344	0.299	25.48	96.74	2.37	363 ± 7
500	40.79	0.00207	0.153	28.09	98.51	2.00	477 ± 9
550	42.71	0.00174	0.062	26.88	98.82	0.96	508 ± 8
650	41.61	0.00472	0.234	12.29	96.68	1.35	477 ± 10
750	41.93	0.01386	0.386	4.65	90.29	0.76	452 ± 13
Fusion	96.95	0.14581	1.981	0.61	55.72	0.37	616 ± 18
Total	39.04	0.00450	0.196	100.00	96.61	1.63	449 ± 11
537-16-1, 27–31 cm (J = 0.007781)							
450	16.23	0.01596	0.049	2.78	70.93	0.08	155 ± 5
475	27.01	0.00325	0.087	19.04	96.54	0.73	333 ± 6
500	41.12	0.00082	0.026	57.89	99.40	0.85	498 ± 7
525	43.10	0.00272	0.048	6.04	98.13	0.48	511 ± 10
550	42.41	0.00753	0.200	4.43	94.75	0.72	495 ± 10
600	44.08	0.00739	0.024	2.75	95.03	0.09	509 ± 12
650	42.48	0.00216	0.027	2.39	98.49	0.34	508 ± 12
700	41.44	0.00764	0.208	2.72	94.58	0.74	480 ± 11
750	48.72	0.03993	0.351	1.50	75.82	0.24	456 ± 14
Fusion	71.67	0.14906	1.412	0.45	38.69	0.26	353 ± 19
Total	38.28	0.00376	0.063	100.00	96.87	0.73	456 ± 10
Total without 450°, 475°, 700° fusion				75.51			500 ± 8

[a] Measured.
[b] Corrected for postirradiation decay of ^{37}Ar.
[c] $^{40}Ar_{tot.} - (^{36}Ar_{atmos.})(295.5)/^{40}Ar_{tot.}$.
[d] Calculated using correction factors of Dalrymple and Lanphere (1971): error estimates (two standard deviations).
[e] Grain size analyzed.

about 500 Ma are defined by gas fractions evolved from the two samples at higher experimental temperatures. Over 75% of the gas evolved during intermediate-temperature and high-temperature heating of one of the samples (537-16-1, 27–31 cm) defines a 500 ± 8 Ma plateau.

Hole 538A

Hornblende

Both hornblende size fractions separated from an amphibolite sample recovered at Hole 538A record internally discordant age spectra with total-gas ages of 463 ± 14 Ma and 464 ± 13 Ma (Fig. 3). The pattern of discordance is similar for both fractions, with distinctly younger apparent ages of about 200 Ma defined by gas fractions evolved at low experimental temperatures, and well-defined plateaux (496 ± 8 Ma and 501 ± 9 Ma) defined by gas increments liberated at high temperatures.

Biotite

Biotite separated from a sample of basement gneiss recovered at Hole 538A displays a nearly concordant age spectrum (Fig. 4) with more than 90% of the evolved gas defining a plateau age of 348 ± 8 Ma.

Diabase Whole Rock

The whole-rock diabase sample displays a slightly discordant age spectrum in which the fusion gas increment records a distinctly older apparent age than that defined by gas evolved at lower temperatures (Fig. 5). Together, the lower temperature fractions represent more than 90% of the evolved gas, and they define a plateau age of 190.4 ± 3.4 Ma. The plateau data yield a well-defined (mean square of the weighted deviates = 1.8) $^{40}Ar/^{36}Ar$ versus $^{39}Ar/^{36}Ar$ isochron date of 190.5 ± 3.6 Ma with an ordinate intercept of 293.3 ± 3.6 (calculated after methods discussed by Roddick, 1978).

INTERPRETATION

Hole 537

The effectiveness of $^{40}Ar/^{39}Ar$ incremental-release dating of whole-rock samples of slate and phyllite from regional metamorphic terranes has been documented by Reynolds and Muecke (1978) and Dallmeyer et al. (1983). In thermally uncomplicated settings, $^{40}Ar/^{39}Ar$ age spectra are typically concordant, with plateau ages reflecting times of cooling through the relatively low temperatures required for post-metamorphic retention of argon in constituent, fine-grained white micas. In areas where a post-crystallization thermal overprint is recorded, internally discordant $^{40}Ar/^{39}Ar$ age spectra are displayed by whole-rock slate and phyllite samples. These discordant spectra are characterized by young apparent ages in low-temperature gas fractions whereas older, high-temperature plateau segments define markedly older ages related to initial post-metamorphic cooling. The Leg 77 whole-rock phyllite samples display a similar pattern of discordance, indicating that the crystalline terrane penetrated at Hole 537 underwent a complex thermal evolution. The $^{40}Ar/^{39}Ar$ data suggest that the observed metamorphic assemblage initially formed at 500 Ma, but was likely affected by a later, much lower grade geologic reheating.

Table 2. $^{40}Ar/^{39}Ar$ analytical data for incremental heating experiments on samples recovered from Hole 538A of DSDP Leg 77, southeastern Gulf of Mexico.

Release temperature (°C)	$^{40}Ar/^{39}Ar$[a]	$^{36}Ar/^{39}Ar$[a]	$^{37}Ar/^{39}Ar$[b]	^{39}Ar (% of total)	^{40}Ar nonatmos.[c] (%)	$^{36}Ar_{Ca}$ (%)	Apparent age (Ma)[d]
538A-31-2, 109–114 cm (0.10–0.15 mm[e] hornblende; J = 0.008492)							
550	24.97	0.03698	0.819	7.45	56.47	0.60	204 ± 6
600	49.33	0.10932	0.779	1.20	34.63	0.19	244 ± 24
650	25.79	0.04061	0.913	0.49	53.73	0.61	201 ± 38
700	52.28	0.12845	1.925	0.90	27.68	0.41	209 ± 41
750	43.52	0.07391	4.559	1.66	50.64	1.68	310 ± 22
800	38.12	0.03042	6.801	2.46	77.84	6.08	407 ± 14
850	38.78	0.01516	7.634	4.71	90.01	13.70	470 ± 12
900	39.82	0.01090	8.013	17.03	93.52	20.00	498 ± 9
950	39.40	0.00833	7.999	32.60	95.37	26.13	502 ± 11
Fusion	39.52	0.00944	8.310	31.49	94.62	23.98	500 ± 9
Total	38.61	0.01566	7.284	100.00	88.95	20.35	464 ± 13
Total without 550–850°, Fusion				81.12			501 ± 9
538A-31-2, 109–114 cm (<0.08 mm hornblende; J = 0.008492)							
550	23.03	0.03107	0.785	8.03	60.38	0.69	201 ± 8
750	36.64	0.01642	7.029	18.11	88.28	11.64	440 ± 11
850	38.60	0.00673	7.933	47.23	96.49	32.08	498 ± 8
900	38.28	0.00689	8.269	26.15	96.40	32.63	494 ± 9
Fusion	67.28	0.10619	8.383	0.47	54.35	2.15	490 ± 32
Total	37.05	0.01095	7.285	100.00	91.88	25.86	463 ± 14
Total without 550°, 750°, Fusion				73.38			496 ± 8
538A-30-1, 39–53 cm (0.10–0.15 mm biotite; J = 0.07825)							
475	30.70	0.01780	0.314	7.77	82.93	0.48	328 ± 7
500	27.99	0.00639	0.044	18.70	93.17	0.19	337 ± 7
525	30.03	0.00871	0.273	19.52	91.48	0.85	351 ± 8
550	32.42	0.02036	0.030	4.27	91.43	0.04	339 ± 8
600	35.50	0.03123	0.020	2.09	73.99	0.02	337 ± 10
650	28.76	0.00675	0.020	6.20	93.05	0.08	343 ± 8
700	29.66	0.01087	0.027	6.56	89.16	0.07	339 ± 8
750	31.27	0.01424	0.037	5.67	86.54	0.07	346 ± 9
825	31.35	0.01186	0.043	7.41	88.99	0.10	354 ± 8
Fusion	29.99	0.01002	0.031	21.82	90.14	0.08	346 ± 6
Total	29.92	0.01078	0.103	100.00	89.53	0.28	343 ± 9
Total without 475°, Fusion				92.23			348 ± 8
538A-32-3, 45–54 cm (0.15–0.18 mm whole-rock diabase; J = 0.008462)							
550	22.10	0.03202	7.913	32.45	60.04	6.72	192.9 ± 3.1
625	24.41	0.03963	4.009	6.96	53.32	2.75	188.9 ± 3.9
700	23.48	0.03481	2.622	13.70	57.07	2.05	194.1 ± 3.6
775	17.60	0.01647	2.680	26.24	73.54	4.43	187.8 ± 3.4
850	23.41	0.04707	38.348	14.92	53.72	22.16	187.1 ± 3.5
Fusion	89.19	0.27072	78.107	5.73	17.34	7.85	232.7 ± 6.5
Total	25.31	0.04478	14.106	100.00	59.32	7.57	192.8 ± 3.9
Total without Fusion				94.27			190.4 ± 3.4

[a] Measured.
[b] Corrected for decay of ^{37}Ar.
[c] $^{40}Ar_{tot.} - (^{36}Ar_{atmos.})(295.5)/^{40}Ar_{tot.}$.
[d] Calculated using correction factors of Dalrymple and Lanphere (1971): error estimates (two standard deviations).
[e] Grain size analyzed.

Hole 538A

Metamorphic Rocks

Metamorphic hornblende and biotite from the crystalline terrane penetrated at Hole 538A yield contrasting release spectra that reflect markedly different total-gas ages. The hornblende spectra are internally discordant, indicating that the total-gas ages have no geologic significance. The patterns of discordance (e.g., relatively younger ages recorded in low-temperature gas fractions) are identical to those displayed by hornblende from polymetamorphic terrances (Dallmeyer, 1975; Dallmeyer et al., 1981). This type of discordance has been interpreted to result from partial volume-diffusive loss of radiogenic argon during superposed thermal events (Turner, 1970). The character of the Leg 77 hornblende spectra therefore suggests a polymetamorphic history for the regional metamorphic terrane penetrated at Hole 538A, including: (1) initial post-metamorphic cooling below temperatures required for argon retention in hornblende (500 ± 25°C; Harrison and McDougall, 1980) at about 500 Ma (reflected by plateau portions of the spectra); and (2) partial diffusive loss of radiogenic argon from hornblende during a subsequent geologic reheating at 200 Ma (ages recorded in low-temperature gas fractions).

The geologic significance of the 348 Ma plateau age recorded by biotite from the metamorphic terrane is uncertain. Temperatures required for argon retention in biotite (300 ± 25°C; Jäger, 1979) are markedly lower than those required for retention in hornblende. Therefore, it is difficult to explain how the 348 Ma age could reflect initial post-metamorphic cooling of a subsequently undisturbed argon system in view of the fact that hornblende systems at Hole 538A clearly record a thermal disturbance at 200 Ma. Several workers (e.g., Dallmeyer and Rivers, 1983) have shown that radiogenic and extraneous ("excess") argon components are liberated simultaneously during incremental, $^{40}Ar/^{39}Ar$ analysis of bio-

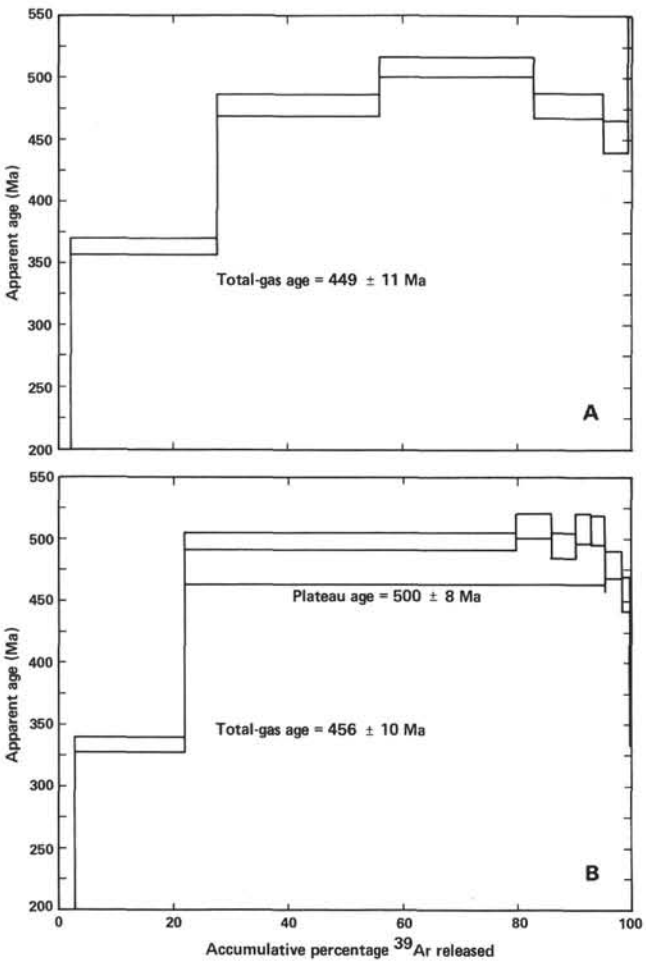

Figure 2. $^{40}Ar/^{39}Ar$ incremental-release age spectra of whole-rock phyllite samples recovered at Hole 537. A. 537-16-1, 16–18 cm; B. 537-16-1, 27–31 cm. Uncertainties in the apparent incremental ages are indicated by width of bar (2 standard deviations).

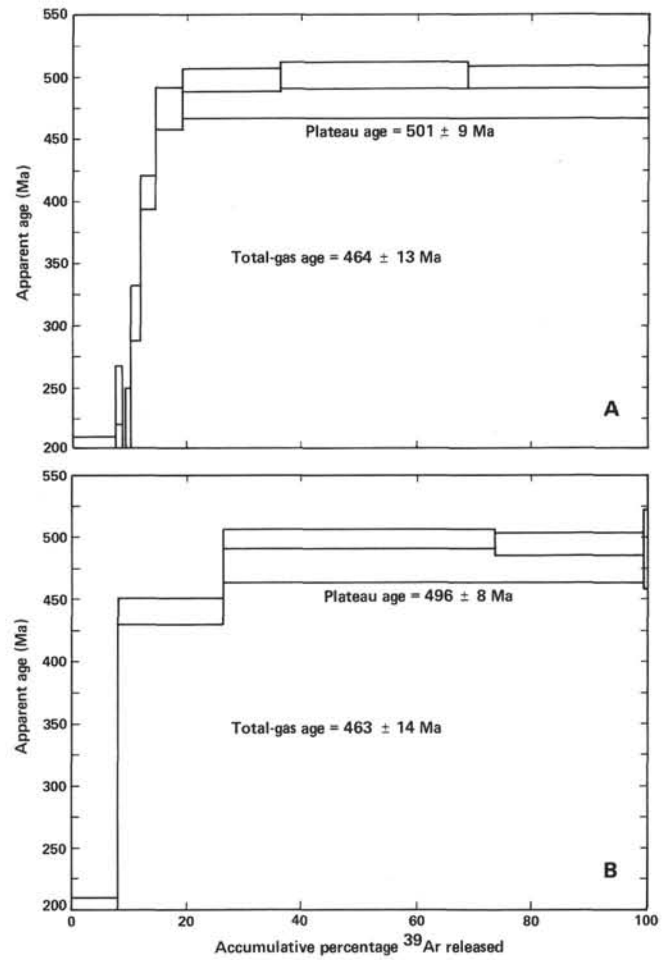

Figure 3. $^{40}Ar/^{39}Ar$ incremental-release age spectra of hornblende concentrates separated from an amphibolite sample recovered at Hole 538A (538A-31-2, 109–114 cm). A. 0.10–0.15 mm grain size. B. <0.08 mm grain size. Data plotted as in Figure 2.

tite, thereby yielding anomalously old, but well-defined plateau ages. The 348 Ma plateau defined by the Hole 538A biotite is thus more likely to reflect incorporation of extraneous argon components, when the biotite argon system was "opened" during the ~200 Ma reheating suggested by the discordant hornblende spectra.

Diabase Dike

The unaltered petrographic character of the diabase sample together with the well-defined plateau and isochron dates indicate that a crystallization age of 190.4 Ma is appropriate for the dike.

Summary

The $^{40}Ar/^{39}Ar$ results from Holes 537 and 538A are consistent and indicate that Cenozoic-Mesozoic sedimentary sections in the southeasternmost Gulf unconformably overlie a polymetamorphic terrane of variable grade. Initial metamorphism likely occurred at ~500 Ma, with markedly higher grade conditions maintained in that portion of the terrane penetrated at Hole 538A. The variations in metamorphic grade between Holes 537 and 538A may indicate that different crustal levels of the same frag-

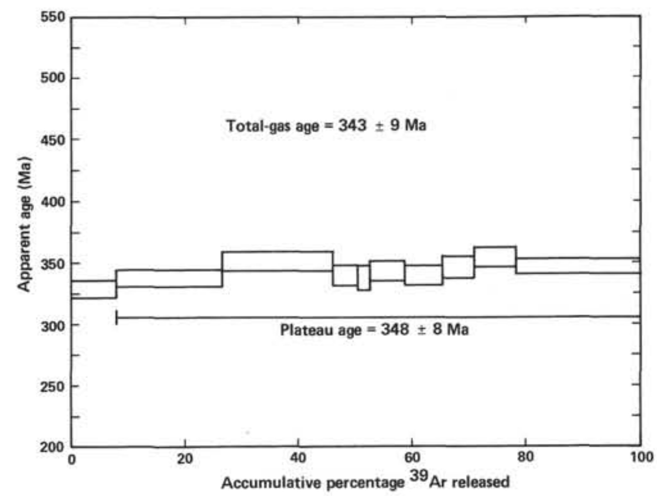

Figure 4. $^{40}Ar/^{39}Ar$ incremental-release age spectrum of a biotite concentrate separated from a mylonitic gneiss recovered at Hole 538A (538A-30-1, 39–53 cm). Data plotted as in Figure 2.

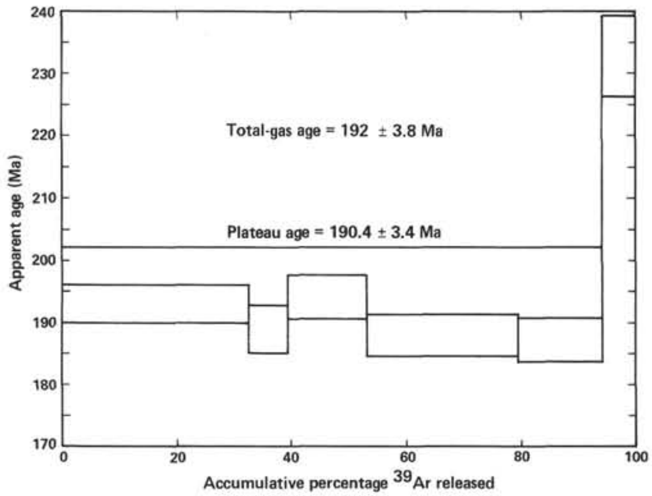

Figure 5. $^{40}Ar/^{39}Ar$ incremental-release age spectrum of a whole-rock sample of diabase recovered at Hole 538A (538A-32-3, 45–54 cm). Data plotted as in Figure 2.

mented basement complex were penetrated in the two fault blocks drilled on Leg 77. Such juxtaposition could reflect differential offset along normal faults that were active during the initial continental extension that preceded late Mesozoic formation of the Gulf.

The basement terrane at both Holes 537 and 538A record the affects of a mild geologic reheating at ~200 Ma. This most likely resulted from elevation of temperatures caused by intrusion of diabase dikes during initial late Mesozoic crustal extension.

IMPLICATIONS

The ~500 Ma dates of the hornblende and phyllite from the regional metamorphic terrane penetrated at Holes 537 and 538A are markedly older than ages reported for any other metamorphic rocks in the Caribbean, Yucatan, or exterior portions of the southern Appalachian-Ouachita system (Rodgers, 1970; Banks, 1975; King, 1975). They are, however, generally similar to dates described from so-called "Pan-African" terranes that flank cratons of older Precambrian rocks in northeastern South America and western Africa (Hurley and Rand, 1973; Dillon and Sougy, 1974; Clauer et al., 1982). In addition, available petrographic descriptions and radiometric results from subsurface crystalline basement rocks in central and northern Florida suggest that a Pan-African metamorphic terrane of variable grade may unconformably underlie a lower Paleozoic, subsurface sedimentary-volcanic sequence (Bass, 1969; Barnett, 1975; Odom and Brown, 1976; Smith, 1982; Chowns and Williams, 1983). Most recent tectonic reconstructions (e.g., Van der Voo et al., 1976; Walper et al., 1979; Dickenson and Coney, 1980; Buffler et al., 1981; Pilger, 1981; Smith, 1982; Pindell and Dewey, 1982) present a nearly closed Gulf from the late Carboniferous through the middle Mesozoic and thereby provide continuity between Pan-African terranes in western Africa, northeastern South America, and the Florida subsurface. However, there has been considerable discussion of the "precise" fit, with particular attention focused on placement of Yucatan during tectonic evolution of the Gulf. Some workers have excluded Yucatan from Gulf tectonics until after Mesozoic rifting, then introduce it from a removed western setting along sinistral transcurrent fault(s) (e.g., Walper, 1980; Pilger, 1981). Other workers have suggested an active role of Yucatan throughout amalgamation of Pangea and locate it in the present-day position of the Gulf recess (e.g., Dickenson and Coney, 1980; Pindell and Dewey, 1982; Nunn, 1982). Detailed geophysical studies in the southeastern Gulf suggest that the metamorphic terrane penetrated at Holes 537 and 538A may be traced without tectonic discontinuity under the Yucatan Shelf (Buffler et al., 1981). Therefore, the present $^{40}Ar/^{39}Ar$ results offer controls by which the alternative models presented for the tectonic history of the northern Yucatan Shelf may be evaluated.

The ~500-Ma regional metamorphism recorded in the basement rocks penetrated at Holes 537 and 538A suggests that this crystalline terrane had a pre-Carboniferous affinity with Gondwana rocks of similar age, and therefore was likely positioned in the general vicinity of the present Gulf recess (Fig. 6). This location is consistent with a penetration of Paleozoic volcanic rocks in the subsurface of mainland Yucatan which are of similar age, petrologic nature, and chemical affinity to those in the Florida subsurface (Bass and Zartmen, 1969; Ramos, 1975) and which also suggest a continuity of pre-Mesozoic lithotectonic trends between Florida and Yucatan.

Several lines of evidence appear to support active tectonic involvement of Yucatan during amalgamation of Pangea. The crystalline complex penetrated at Holes 537 and 538A is thus likely correlative with Pan-African

Figure 6. Late Devonian reconstruction showing relative positions of major continental features before final amalgamation of Pangea (adapted from Smith, 1982). * indicates the likely location of the metamorphic basement terrane penetrated at Holes 537 and 538A.

terranes in northeastern South America, western Africa, and the Florida subsurface. As such, basement rocks underlying the fault blocks drilled on Leg 77 probably represent fragments of a continental terrane that were initially attentuated and ultimately detached from counterparts now buried beneath the northern Coastal Plain during Mesozoic evolution of the Gulf of Mexico. The ~190 Ma emplacement age of the diabase dike recovered at Hole 538A is similar to that reported for undeformed mafic dikes throughout the circum-Atlantic region (Dalrymple et al., 1975; Sutter and Smith, 1979) and likely marks initial pulses of extension associated with dismemberment of Pangea. Together, the age and lithologic character of the crystalline terrane penetrated at Holes 537 and 538A are consistent with the suggestions of Buffler et al. (1981) that a large portion of the southeastern Gulf is underlain by "transitional" crust. This appears to have evolved as a result of attenuation and widespread intrusion of mafic material into originally continental material of Pan-Africa age.

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