OCEAN DRILLING PROGRAM

LEG 174B SCIENTIFIC PROSPECTUS

CORK HOLE 395A

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This Scientific Prospectus is based on pre-cruise JOIDES panel discussions. The operational plans within reflect JOIDES Planning Committee and thematic panel priorities. During the course of the cruise, actual site operations may indicate to the Co-Chief Scientists and the Operations Superintendent that it would be scientifically or operationally advantageous to amend the plan detailed in this prospectus. It should be understood that any proposed changes to the plan presented here are contingent upon approval of the Director of the Ocean Drilling Program in consultation with the Planning Committee and the Pollution Prevention and Safety Panel.

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ABSTRACT

Leg 174B will run selected logs and then install a Circulation Obviation Retrofit Kit (CORK) in Hole 395A, which penetrates over 500 m into 7-m.y.-old crust on the western flank of the Mid-Atlantic Ridge. The overall purpose of the experiments in Hole 395A is to understand hydrogeologic processes at this important reference site for young crust formed at a slow spreading rate. The logging program will include four tool runs—temperature log, flowmeter log, and two Schlumberger tool strings—focused on documenting the permeability structure in the hole and understanding the downhole flow of ocean bottom waters which has been observed since the hole was drilled in 1975. After the logging program is completed, the hole will be instrumented and sealed with a long-term CORK observatory, shutting off the long-lived downhole flow. The purpose of this CORK experiment is to allow natural hydrogeological conditions to re-establish after sealing the hole and then to monitor how the hydrologic system varies with time. Monitoring the return to the natural thermal and hydrological regime will allow us to determine if the pressure differentials which drive the downhole flow observed to date at this site are dynamically maintained due to active circulation occurring in the basement or simply an artifact of drilling.

INTRODUCTION AND BACKGROUND

Leg 174B will run a selected suite of logs in Hole 395A (Fig. 1), and then emplace a borehole seal, or Circulation Obviation Retrofit Kit (CORK) instrumented with pressure sensors and a 600-m-long, 10-thermistor cable. The purpose of the logs and CORK experiment IS to document the hydrogeology at this young crustal reference site and to test a model developed from the observations obtained since the hole was drilled over 20 years ago in 1975. The observations from Hole 395A generally support a model of lateral flow of seawater in the upper basement beneath the sediment pond in which the site is located. The logs and CORK experiment will provide essential information about the formation pressure and permeability structure, which are keys to understanding the crustal hydrogeology at the site.

Only a handful of Deep Sea Drilling Project/ Ocean Drilling Program (DSDP/ODP) holes penetrate more than 500 m into “normal” oceanic crust formed at mid-ocean ridges, and these are all, therefore, important reference holes. Among them, Holes 395A and 504B (Fig. 1) form the most important pair of reference sites for young, upper oceanic crust formed at slow and medium spreading rates, respectively. They are particularly imporant as reference sites for the hydrogeology of young oceanic crust, which has been studied with extensive downhole measurements and detailed heat-flow surveys at both sites (e.g., Fig. 2). Holes 395A and 504B are the best documented of several cases in which ocean bottom water is known to be flowing down open DSDP/ODP holes into permeable levels of upper basement. These examples suggest that young upper oceanic crust under a sediment cover is easily permeable enough to support active circulation of seawater, but we still barely understand the details of such off-axis hydrothermal circulation or its control by the pressure distribution and fine-scale permeability structure.

Site 395A is located in 7-m.y.-old crust, in an isolated sediment pond with low heat flow (Hussong et al., 1979) that might be considered somewhat typical of the structure and hydrogeological setting for thinly-sedimented crust formed at slow spreading rates. Since it was drilled in 1975-1976 (Melson, Rabinowitz, et al., 1979), Hole 395A has been revisited three times for an extensive set of downhole measurements: during DSDP Leg 78B in 1981 (Hyndman, Salisbury, et al., 1984), during ODP Leg 109 in 1986 (Bryan, Juteau, et al., 1988), and during the French wireline reentry campaign DIANAUT in 1989 (Gable et al., 1992). On each of these revisits, the first order of business was temperature logging in the hole long after it had reequilibrated from any prior disturbance by DSDP/ODP operations. Each of the three temperature logs showed strongly depressed borehole temperatures, essentially isothermal to a depth of about 300 m into basement (Becker et al., 1984; Kopietz et al., 1990; Gable et al., 1992). This indicates a strong downhole flow of ocean bottom water into the permeable upper basement, at rates of thousands of l/hr, virtually unabated over the two decades that the hole has been open (Fig. 3).

In comparison, temperatures measured during the multiple revisits to Hole 504B were initially strongly depressed to a depth of about 100 m into basement, but then rebounded nonmonotonically towards a conductive profile. This indicates that the rate of downhole flow has decayed since the hole was first drilled, and that the downhole flow is directed into a more restricted section of uppermost basement than in Hole 395A (Becker et al., 1983, 1985, 1989; Gable et al., 1989; Guerin et al., 1996). The comparison suggests that Hole 504B penetrates a more passive hydrothermal regime, whereas Hole 395A provides a man-made shunt into a more active circulation system in basement. The various observations at Site 395 generally support a model proposed by Langseth et al. (1984, 1992) for lateral circulation in the upper basement beneath the sediment pond where the site is located (Fig. 4), but we have little resolution on the details of such circulation.

A large proportion of holes drilled into young oceanic crust have proven to be drawing ocean bottom water down into permeable levels of basement (e.g., Erickson et al., 1975; Hyndman et al., 1976; Anderson and Zoback, 1982; Becker et al., 1983, 1984; Davis, Mottl, et al., 1992). Such downhole flow requires sufficient basement permeability and a differential pressure between the fluids in the borehole and the formation fluids. In general, we surmise that the necessary differential pressures may arise because of some combination of two independent effects:

(1) the differential pressure (which should not be termed an “underpressure”) between the cold, dense seawater used as drilling fluid in the borehole and the warmer formation fluids, and

(2) true, dynamically maintained underpressures due to active circulation in the basement that would occur even if the borehole were not present.

In cases of downhole flow in holes drilled into formations with high geothermal gradients, the driving force is probably dominated by the former effect (e.g., ODP Leg 139 sites in Middle Valley, Davis, Mottl, et al., 1992). For holes such as Hole 504B, both effects may be important. In holes drilled into young crust with low geothermal gradients, such as Hole 395A, the latter effect may be predominant.

SCIENTIFIC OBJECTIVES AND METHODS

By leaving Hole 395A open for over 20 years, with revisits for discrete data sampling roughly every five years, we have only learned that the downhole flow has apparently continued at a significant rate. We have no resolution as to possible variations in downhole flow rates with time (as has been documented in Hole 504B), let alone the constancy or variability of (a) the driving forces responsible for the downhole flow or (b) the formation hydrologic properties that may limit it. Furthermore, we still do not understand exactly where the downhole flow is directed in the formation, other than the general statement that it is directed into the upper 300 m or so of basement.

The Leg 174B program is intended to address these important issues by providing essential information about the permeability structure and formation pressure, which are keys to understanding the crustal hydrogeology at Site 395. Approximately five days will be spent at Hole 395A during Leg 174B. The program will begin with four logs designed to provide an estimate of the downhole flow rate in 1997 and to assess the fine-scale distribution of permeability in the hole. The hole will then be CORKed with pressure sensors and A thermistor cable, for a long-term record of the pressure and temperature variations in the sealed hole as the natural hydrologic system re-establishes itself. In more detail, the following sequence of logs and experiments will be deployed during trips of the drill string:

1. **Logs**: After initial reentry with a logging bottom hole assembly (BHA), a temperature log will be run first, followed by three logs to delineate the fine-scale permeability structure of the section penetrated by Hole 395A. These three logs include a flowmeter log, the Schlumberger combination Formation MicroScanner/Array Sonic string, and the Schlumberger Triple Combo geophysical string, to be deployed in an order to be determined at sea for greatest operational efficiency. The upper 300 m of basement is known to be quite permeable on average from the downhole flow, packer measurements, and an incomplete flowmeter experiment during the DIANAUT program (Becker et al., 1984; Hickman et al., 1984; Becker, 1990; Kopietz et al., 1990; Gable et al., 1992; Morin et al., 1992). Detailed

permeability information and structural control will be required to allow interpretation of the data to be collected from the CORK experiment long after Leg 174B in terms of active hydrogeological processes in discrete zones of the formation. This sequence of logs will require a pipe trip, plus about 36 hours logging time, for a total of 2-2.5 days on site.

2. **CORK**: Deployment of a fully configured CORK to seal the hole, instrumented with a 600-m-long, 10-thermistor cable, a pressure sensor in the sealed section, and a reference pressure sensor at seafloor depth. This installation will provide a long-term record of (a) the rebound of temperatures and pressures toward formation conditions after the emplacement of the seal, (b) possible temporal variations in temperatures due to lateral flow in discrete zones, and (c) pressure variations, which in a sealed hole would be the primary manifestation of changes in the forces that drive the natural circulation system. Approximately 1.5-2 days will be required to deploy the CORK experiment (Table 1).

Data from the CORK experiment will be collected for a still-unspecified time after Leg 174B, utilizing a submersible or remotely operated vehicle (ROV) to be supported by the National Science Foundation (NSF). The primary purpose of the CORK experiment is not necessarily to assess the equilibrium pre-drilling thermal regime (which we can estimate from detailed heat-flow surveys as in Fig. 2), but instead to monitor how the hydrologic system varies with time as natural hydrogeological conditions are re-established. Full thermal re-equilibration could require many tens or hundreds of years if it occurs only by conductive processes, but could also occur in much less time if the Langseth et al. (1984, 1992) model of active lateral circulation is correct. We are interested primarily in exploring the causes of the hydrogeological state and any possible temporal variations, with the simplest goal to determine how these are associated with and controlled by formation pressure and/or permeability structure. It is impossible to model or predict all of the possible outcomes of the experiment, but considering two possible end-member results might be instructive.

1. If the model of active lateral circulation is basically incorrect, and downhole flow is indeed simply an artifact of drilling, then sealing the hole should remove the driving force for the

downhole flow, and temperatures and pressures will slowly and smoothly trend toward values consistent with conductive, hydrostatic processes.

2. If there is some element of truth to the model of active lateral circulation in basement, with this circulation providing the driving pressure differential for the downhole flow, then sealing the hole will not change the driving force, and lateral circulation should continue even though the seal has stopped the downhole flow. Pressures in the sealed hole should approach a nonhydrostatic value in an irregular fashion that reflects variability in the natural hydrogeologic processes. Similarly, temperatures will rebound towards values consistent with the circulation system, also in an irregular fashion that reflects natural hydrogeologic variability. In addition, differences in the behavior of the temperature sensors should reflect vertical variations in the lateral flow regime due to fine-scale permeability variations. We understand so little about crustal hydrogeology that simply defining the natural time- and space-scales of such variability will be a very important result.

CONTINGENCY PROGRAM

The history of successful reentries in Hole 395A indicates that Leg 174B can expect to find the hole in good condition, open to a depth of slightly more than 600 m. If the hole depth proves to be less than 600 m, the CORK thermistor string can be shortened appropriately. In the unlikely possibility that the hole proves completely unsuitable for logging or the CORK experiment, any available time would be devoted to a contingency program in the sediments surrounding the hole. Like the primary Leg 174B program, this contingency program would focus on hydrogeological objectives, using an advanced hydraulic piston core (APC)/XCB BHA at selected locations within the sediment pond. The emphasis would be on obtaining detailed profiles of temperatures and fluid compositions down to basement at selected locations in the sediment, using multiple runs of temperature tools (Adara shoe and/or Davis-Villinger Temperature Probe [DVTP] and the downhole water sampler, temperature, and pressure probe [WSTP]).

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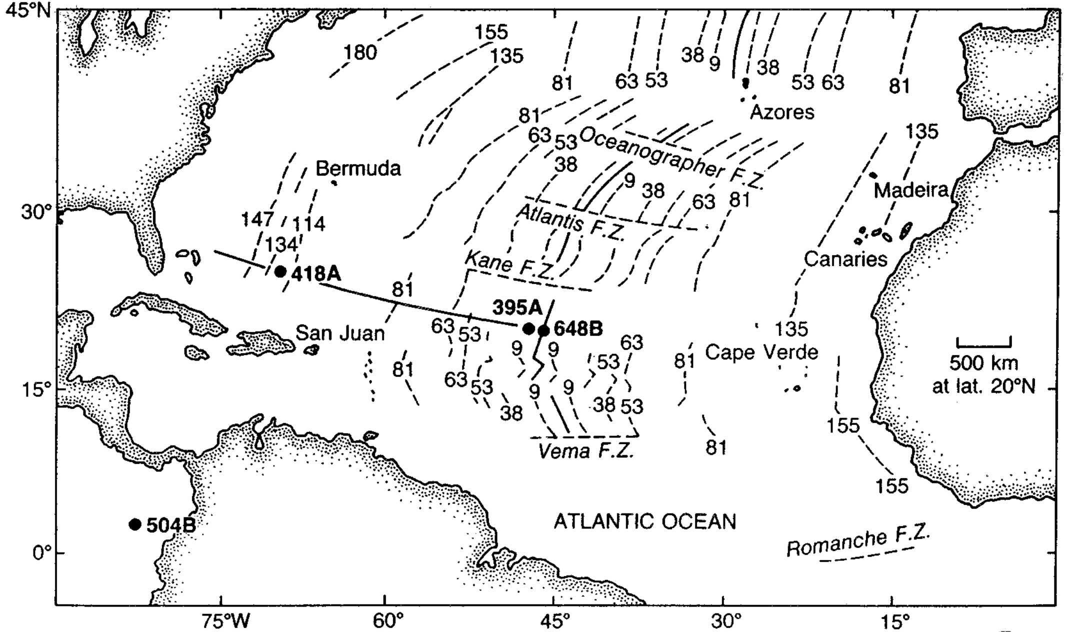
FIGURE CAPTIONS

Figure 1. Location of Holes 395A, 418A, 504B, and 648B. Dashed lines show age of crust in Ma, deduced from magnetic anomalies (after Salisbury and Hyndman, 1984).

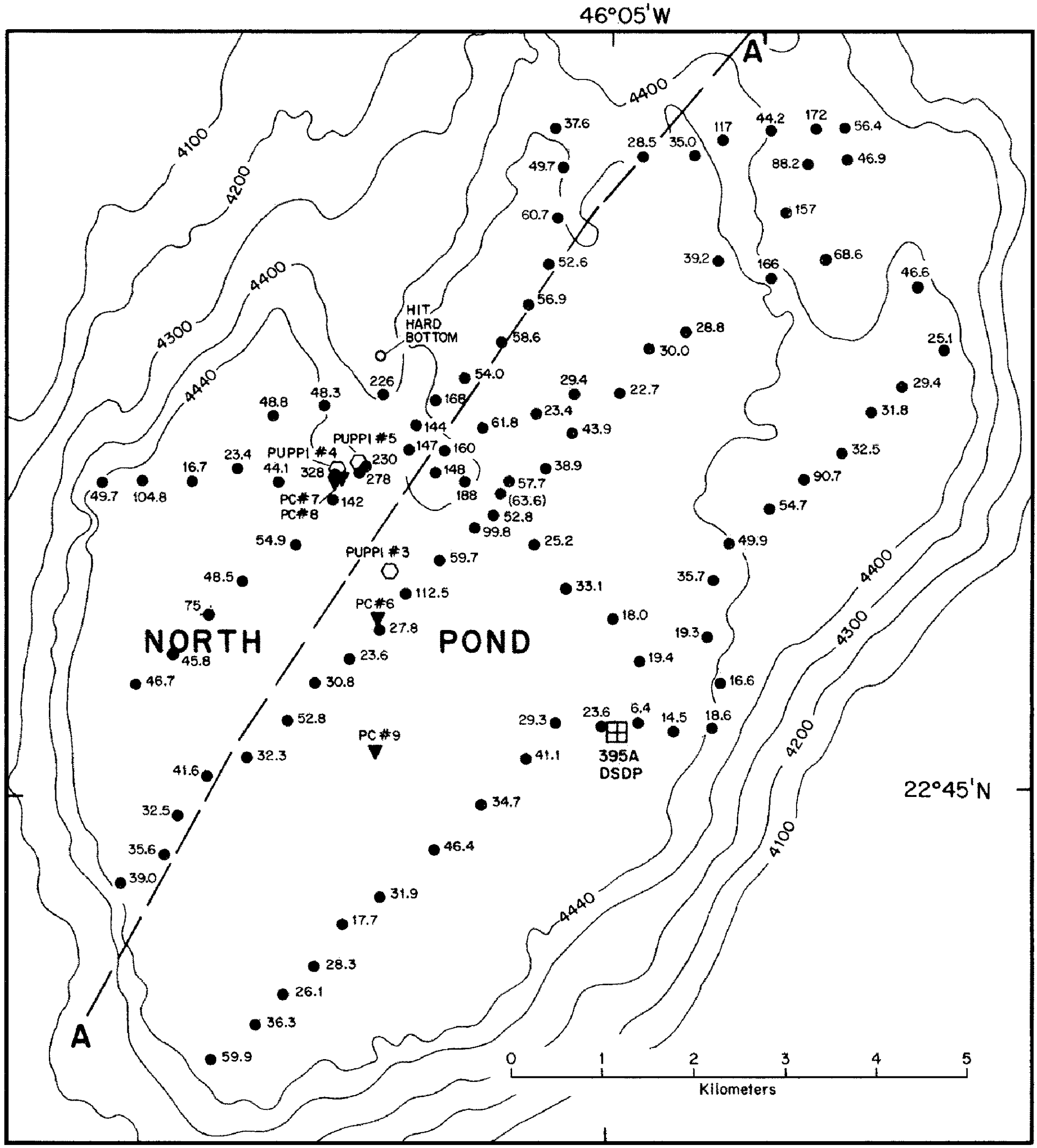
Figure 2. Location of heat-flow measurements, PUPPI deployments, and piston cores in North Pond. The heat-flow values are given next to the location of each penetration. The box in the lower right-hand corner indicates the location of Hole 395A.

Figure 3. Measured and estimated downhole flow rates in the three best documented cases: Holes 395A, 504B, and 857D. Hole 395A data are from Becker et al. (1984), Kopietz et al. (1990), and Morin et al. (1992).

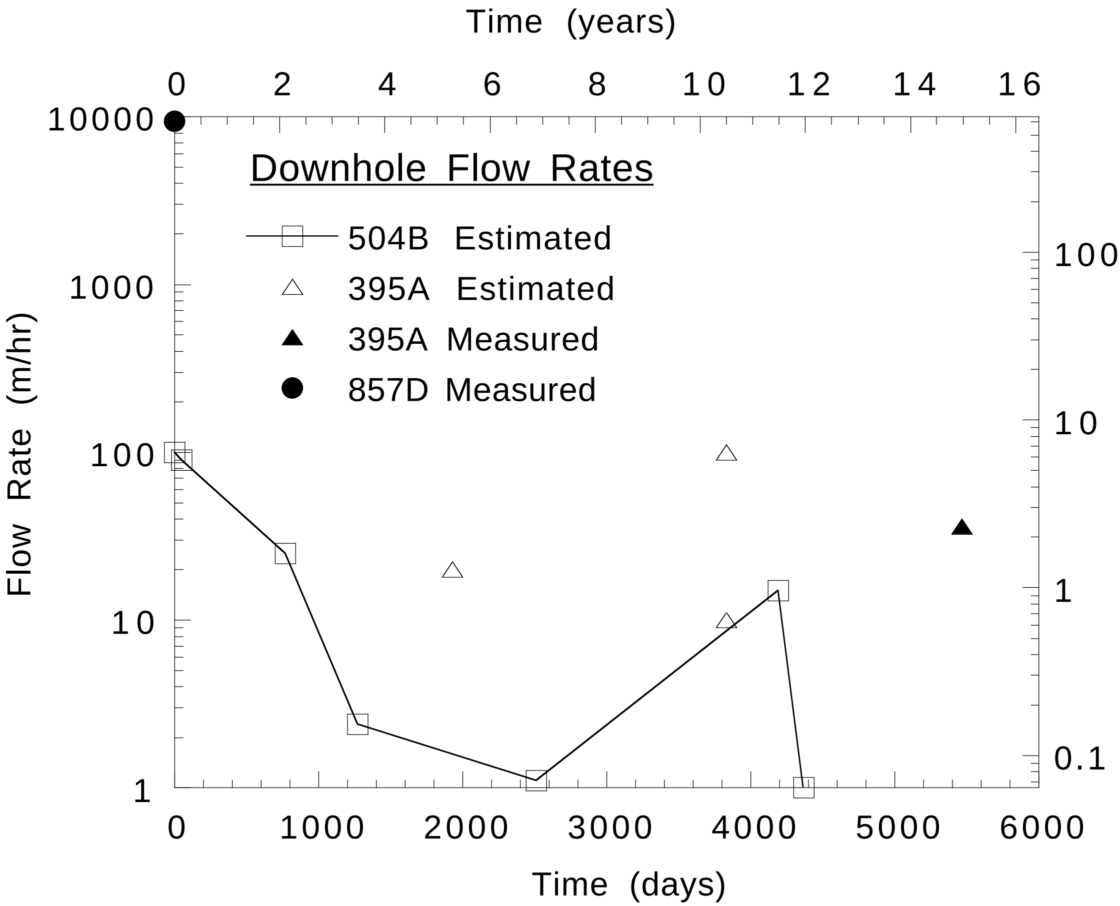
Figure 4. Schematic drawing of pore-water flow and isotherms (°C) below North Pond, assuming laminar flow at a rate of ~1 m/yr. The variation in heat flow across the pond is shown along the top of the figure.



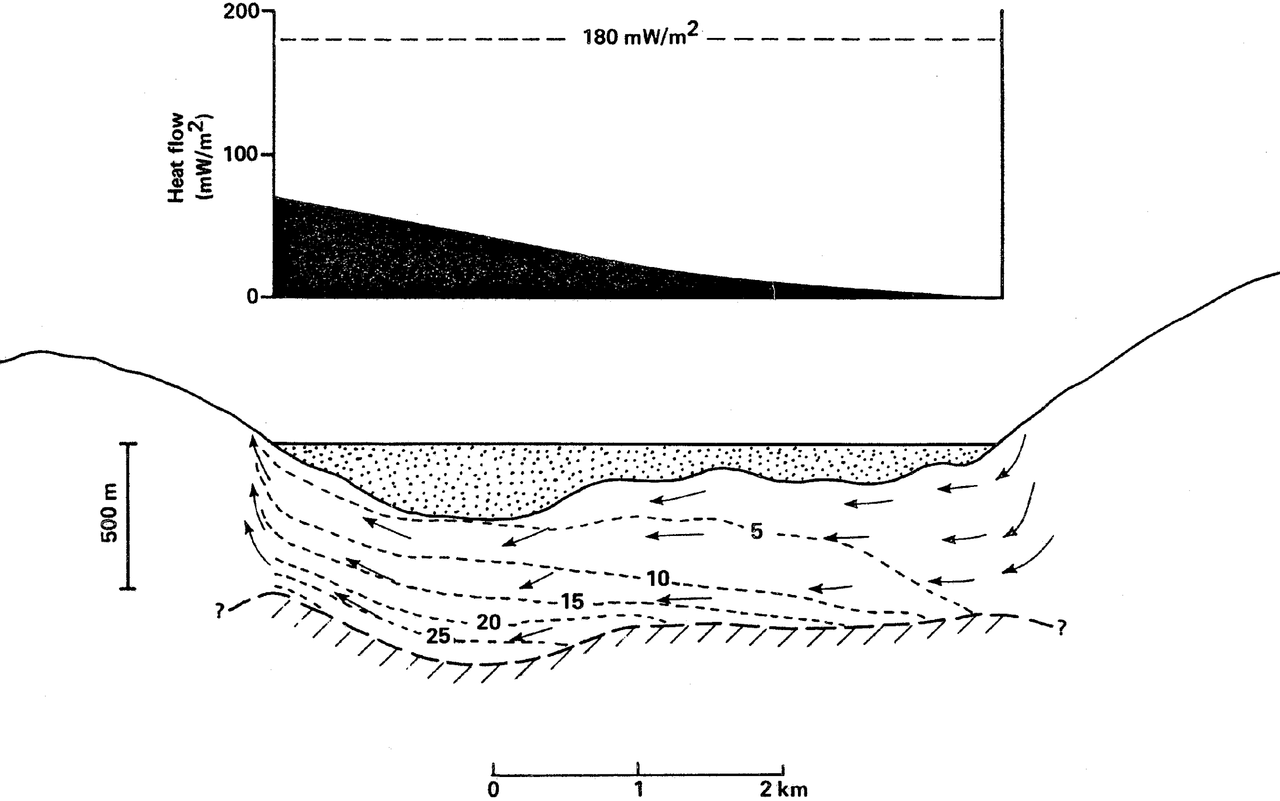
45°N
30°
15°
0°
75°W
60°
45°
30°
15°
180
155
135
81
63
53
38
9
147
114
134
Bermuda
Azores
Madeira
Canaries
Cape Verde
San Juan
Oceanographer F.Z.
Atlantis F.Z.
Kane F.Z.
Vema F.Z.
Romanche F.Z.
418A
395A
648B
504B
500 km
at lat. 20°N
ATLANTIC OCEAN



46°05'W
22°45'N
A
A'
4100
4200
4300
4400
4440
NORTH
POND
HIT HARD BOTTOM
PUPPI #3
PUPPI #4
PUPPI #5
PC#6
PC#7
PC#8
PC#9
395A
DSDP
0
1
2
3
4
5
Kilometers
37.6
28.5
35.0
117
44.2
172
56.4
49.7
88.2
46.9
60.7
157
52.6
39.2
166
68.6
46.6
56.9
28.8
58.6
30.0
25.1
226
54.0
29.4
22.7
29.4
48.8
48.3
168
23.4
31.8
144
61.8
43.9
147
160
32.5
23.4
230
16.7
44.1
328
278
148
38.9
90.7
57.7
49.7
104.8
142
188
(63.6)
54.7
52.8
99.8
54.9
25.2
49.9
59.7
48.5
35.7
33.1
112.5
75
18.0
27.8
19.3
45.8
23.6
19.4
46.7
30.8
16.6
23.6
6.4
29.3
14.5
18.6
52.8
32.3
41.1
41.6
34.7
32.5
46.4
35.6
39.0
31.9
17.7
28.3
26.1
36.3
59.9



Time (years)
0
2
4
6
8
10
12
14
16
10000
1000
100
10
1
100
10
1
0.1
Downhole Flow Rates
504B Estimated
395A Estimated
395A Measured
857D Measured
Flow Rate (m/hr)
0
1000
2000
3000
4000
5000
6000
Time (days)



200
100
0
Heat flow (mW/m2)
180 mW/m2
500 m
5
10
15
20
25
?
?
0
1
2 km

Leg 174B Prospectus

Table 1: Site Time Estimates

New York to Las Palmas, 22 July - 10 August, 1997

Site	Latitude Longitude	Water Depth (m)	Operations	Transit (10.5 kt) (days)	Operation Time (days)	Total (days)
			Transit New York to Hole 395A	7.0		7.0
Hole 395A	22° 45.325'N 46° 4.902'W	4493	Run Temperature, Flowmeter, Triple Combo & FMS/Sonic Logs, Run CORK & Instrument String		4.8	4.8
			Transit Hole 395A to Las Palmas	6.7		6.7
			Estimated Time =	**13.7**	**4.8**	**18.5**
			Available Time =	**14.0**	**5.0**	**19.0**

Site: 395

Priority: 1
Position: 22°45.35'N, 46°04.90'W
Water Depth: 4490.2 m
Sediment Thickness: 93 m
Approved Maximum Penetration: N/A
Seismic Coverage: DSDP Leg 45 seismic data; 1989 single channel seismic data; SeaBeam coverage on Site 395 from Conrad Cruise 3001

Objectives:

1. Logging program described below
2. Install CORK observatory

Drilling Program: None

Logging and Downhole: Temperature, triple combo, FMS/array sonic, flowmeter, and possible packer

Nature Of Rock Anticipated: No core anticipated

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