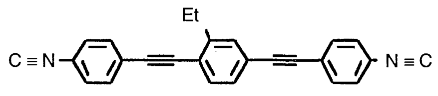
on an electron-transparent, free-standing SiO_2 film supported on a GaAs wafer (*15*). A 2.2-nm-long aryl di-isonitrile



was used to link the clusters. The measured room-temperature conductance of the unlinked array was 133 nS and of the linked network was 78 nS. After a TEM image of the LCN was obtained, the backside of the substrate was metallized and the current-voltage relationship of the LCN was measured as a function of temperature T (Fig. 5).

The low-bias conductance (Fig. 5) exhibits Coulomb charging behavior and followed the relation

$$G_0 = G_\infty e^{-E_A/k_B T} \qquad (1)$$

where G_∞ is the conductance as $T \rightarrow \infty$, E_A is an activation energy, and k_B is Boltzmann's constant. The best fit parameters to these data are $G_\infty = 1.12 \times 10^{-6}$S and $E_A = 97$ meV. The capacitance of a cluster embedded in this LCN (cluster diameter of 3.7 nm, and a gap of 1.9 nm, as estimated by TEM) was calculated with the FASTCAP program (*16*) and used to estimate the Coulomb charging energy, which should correspond to E_A for the array. This calculation yields a value of 200 meV/ε_r for E_A (ε_r, the relative dielectric constant of the organic molecules, is estimated to be 1.5 to 2). The agreement with the experimental activation energy, $E_A = 97$ meV, is quite good. The dot-to-dot resistance of this LCN is $R_D \approx (G_\infty)^{-1} = 0.9$ megohm. We estimate the maximum number of molecules linking adjacent clusters to be 32, which would yield an estimated resistance of 29 megohms per molecule. The resistance of a single 22ADI molecule is predicted to be 43 megohms from a semiempirical treatment of a molecule bridging the gap between two gold surfaces by using an extended Hückel method (*17*). The close agreement between these two estimates of molecular resistance indicates that the assumption that the clusters are linked by 22ADI is reasonable.

A general synthesis strategy for fabrication of a 2D network of metal clusters linked by organic molecules has been outlined. The power of this strategy resides in its inherent flexibility. By altering the size or composition of the clusters, the length and chemical structure of the organic molecules used as molecular interconnects, and the characteristics of the substrate, a wide range of electronic behavior can be achieved. Coulomb charging behavior has been observed in such a linked cluster network.

REFERENCES AND NOTES

1. J. R. Tucker, *J. Appl. Phys.* **71**, 4399 (1992); D. Averin and K. K. Likharev, in *Single-Charge Tunneling*, H. Grabert and M. H. Devoret, Eds. (Plenum, New York, 1992); A. N. Korotkov, R. H. Chen, K. Likharev, *J. Appl. Phys.* **78**, 2520 (1995); S. Bandyopadhyay, V. P. Roychowdhury, X. Wang, *Phys. Low-Dimensional Struct.* **8/9**, 29 (1995).
2. G. Schmid *et al.*, *Chem. Ber.* **114**, 3634 (1981).
3. G. Schön and U. Simon, *Colloid Polym. Sci.* **273**, 101 (1995); *ibid.*, p. 202.
4. R. G. Freeman *et al.*, *Science* **267**, 1629 (1995); S. Rubin, G. Bar, T. N. Yaylor, R. W. Cutts, T. A. Zawodzinski, *J. Vac. Sci. Technol. A* **14**, 1870 (1996).
5. M. Brust, M. Walker, D. Bethell, D. J. Schiffrin, R. Whyman, *J. Chem. Soc. Chem. Commun.* **1994**, 801 (1994); D. V. Leff, P. C. Ohara, J. R. Heath, W. M. Gelbart, *J. Phys. Chem.* **99**, 7036 (1995).
6. R. L. Whetten *et al.*, *Adv. Mater.* **8**, 428 (1996).
7. R. S. Bowles, J. J. Kolstad, J. M. Calo, R. P. Andres, *Surf. Sci.* **106**, 117 (1981); S. B. Park, thesis, Purdue University (1988).
8. A. N. Patil, D. Y. Paithankar, N. Otsuka, R. P. Andres, *Z. Phys. D* **26**, 135 (1993).
9. L. C. Chao and R. P. Andres, *J. Colloid Interface Sci.* **165**, 290 (1994).
10. G. E. Poirier and E. D. Pylant, *Science* **272**, 1145 (1996).
11. P. E. Laibinis, R. G. Nuzzo, G. M. Whitesides, *J. Phys. Chem.* **96**, 5097 (1992).
12. J. I. Henderson, G. M. Ferrence, S. Feng, T. Bein, C. P. Kubiak, *Inorg. Chim. Acta* **242**, 115 (1996).
13. M. Dorogi, J. Gomez, R. Osifchin, R. P. Andres, R. Reifenberger, *Phys. Rev. B* **52**, 9071 (1995); R. P. Andres *et al.*, *Science* **272**, 1323 (1996).
14. J. G. A. Dubois, E. N. G. Verheijen, J. W. Gerritsen, H. van Kempen, *Phys. Rev. B* **48**, 11260 (1993).
15. D. B. Janes *et al.*, *Superlattices Microstruct.* **18**, 275 (1995); V. R. Kolagunta *et al.*, *Proc. Electrochem. Soc.* **95-17** (Quantum Confinement), 56 (1996). An early version of this substrate was fabricated by H. Craighead at the Cornell National Nanofabrication Facility.
16. K. Nabors and J. White, *IEEE Trans. Comput. Aided Des. Integrated Circ. Syst.* **10**, 1447 (1991).
17. M. P. Samanta, W. Tian, S. Datta, J. I. Henderson, C. P. Kubiak, *Phys. Rev. B* **53**, R7626 (1996).
18. Funded in part by the Army Research Office under grant DAAL03-G-0144 and the National Science Foundation under grant NSF ECS-9117691. We thank H. Craighead, S. Datta, R. Reifenberger, and M. Samanta for helpful discussions.

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A Revised Chronology for Mississippi River Subdeltas

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Radiocarbon measurements by accelerator mass spectrometry relating to three of the four late Holocene Mississippi River subdeltas yielded consistent results and were found to differ by up to 2000 carbon-14 years from previously inferred ages. These geological data are in agreement with archaeological carbon-14 data and stratigraphic ages based on ceramic seriation and were used to develop a revised chronologic framework, which has implications for prehistoric human settlement patterns, coastal evolution and wetland loss, and sequence-stratigraphic interpretations.

The geochronology of the Mississippi delta is relevant to investigations of fluvial development in relation to deltaic evolution (*1*, *2*), coastal evolution (*3*), archaeological research (*4*, *5*), coastal wetland loss (*6*), and sequence-stratigraphic interpretations (*7*). For example, the age of subdeltas (*8*) is an important input parameter for simulation models of wetland loss, a severe environmental problem in this region. The chronology of Mississippi River subdeltas is a well-known textbook example of clastic sedimentology (*9*), and it can contribute to computer simulations of alluvial architecture (*10*) where avulsion (channel diversion) is a crucial component. Early stratigraphic studies of Holocene sediments in this region (Fig. 1) revealed a relative chronology that is still largely valid (*11*). The first ^{14}C ages were published in the early 1950s (*12*), and subsequent investigations (*13*, *14*) contributed to the development of a numerical-age chronology for Mississippi River subdeltas, which was later revised toward older ages by Frazier (*15*). His chronology has since been used for most Mississippi delta studies (*1*–*7*). However, some concerns can be raised about Frazier's sampling strategy. Many of his samples cover

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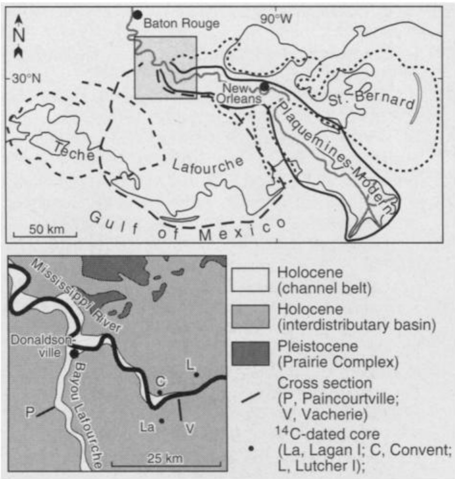


Fig. 1. Outline of the Mississippi River subdeltas [modified from (*15*)], surface geology of the study area (*1*), and the location of cross sections and ^{14}C-dated cores.

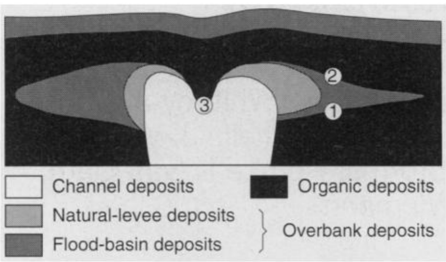


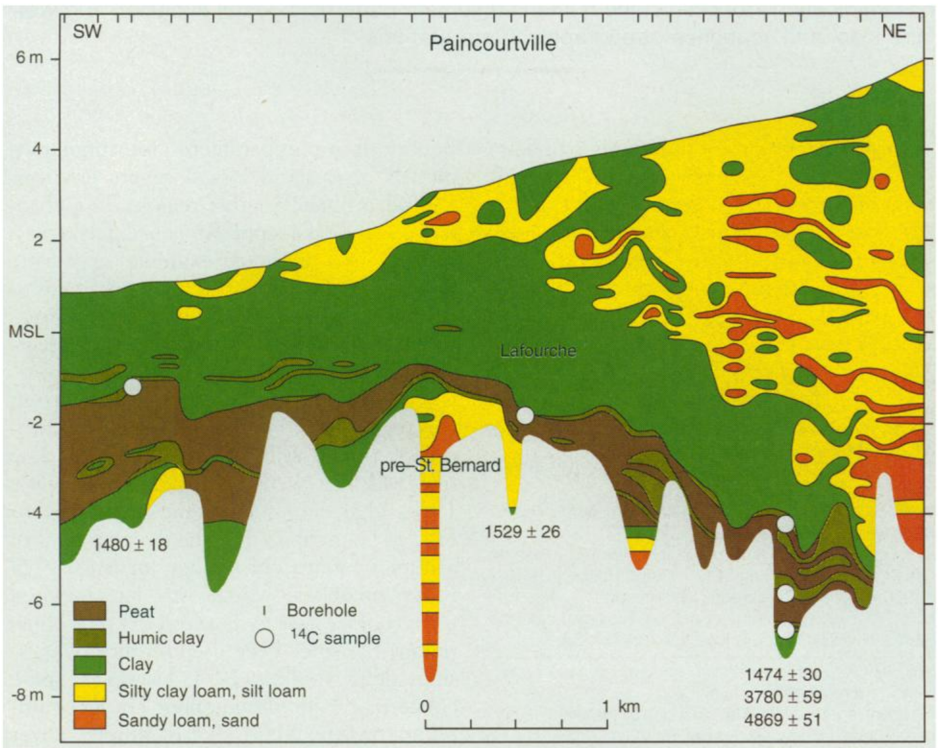
Fig. 2. Sampling strategy for dating the period of activity of distributaries (*22*). Circles with numbers refer to ^{14}C sample types.

large vertical intervals (usually close to 0.5 m) and their association with events of interest is not always clear (*16*). Modifications of Frazier's chronology have included a shift of the beginning of activity of the Lafourche subdelta (Fig. 1) from 3500 to 2500 years before present (B.P.) (*17*), whereas other revisions (*18*) shifted delta-lobe ages further back in time. Such amendments underline the present uncertainties in subdelta ages. Recent archaeological studies showed that Frazier's chronology is inconsistent with data from Native American sites (*16*, *19*). The St. Bernard and Lafourche subdeltas revealed surprisingly young ^{14}C ages for their inhabitation compared with assumed ages of the beginning of fluvial activity of 4600 and 3500 years B.P., respectively (*20*).

To address these age discrepancies, we used a different sampling strategy (*21*, *22*) in the Mississippi delta downstream of Donaldsonville, Louisiana (Fig. 1), where the trunk segments of the Plaquemines-Modern, Lafourche, and St. Bernard subdeltas are located. We focused on dating the beginning of subdelta activity by sampling the top of peat beds underneath clayey overbank deposits (*23*). The ^{14}C ages from the top of organic beds underneath overbank deposits (sample type 1) yield ages for the beginning of fluvial activity, whereas ages from the base of organic beds overlying overbank deposits (sample type 2) and ages from the base of organic residual-channel fills (sample type 3) represent the end of activity (Fig. 2). Type 1 samples provide the most consistent results (*22*). We constructed cross sections (Figs. 3 and 4) to optimize the selection of sampling sites. Other sampling sites are presented as individual cores (Fig. 5).

The cross section at Paincourtville (Fig. 3) shows part of the Bayou Lafourche channel belt and its genetically associated overbank deposits. A lateral facies change in thickness and grain size occurs away from the channel belt. A laterally continuous peat bed underlying these strata covers the narrow channel belt and fine-grained overbank deposits of a buried distributary. Presently, we lack the data to provide a definitive stratigraphic correlation and therefore refer to it as a pre–St. Bernard distributary. We ^{14}C dated the onset of activity of the Lafourche subdelta at three locations (eight measurements) and obtained consistent results (Table 1 and Fig. 3), with ages clustering around 1500 years B.P. Additional samples from the middle and basal part of the peat bed (Fig. 3) indicate that organic accumulation spanned at least 3400 ^{14}C years. We consider the basal age of ~4900 years B.P. a minimum age for the pre–St. Bernard distributary.

A cross section near Vacherie (Fig. 4) shows part of a channel belt of the Plaquemines-Modern subdelta, the St. Bernard subdelta, or possibly both. The related overbank deposits consist of two stacked units, as indicated by oxidized and consolidated sediments buried by a younger bed. We interpret these strata as belonging to the St.



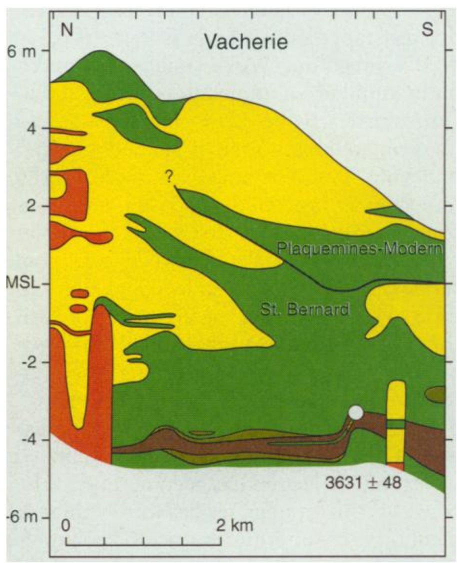


Fig. 3 (left). Cross section of deposits at Paincourtville. The ^{14}C ages are weighted means for multiple samples. MSL, mean sea level. **Fig. 4 (above).** Cross section of deposits at Vacherie. Same color legend as in Fig. 3.

Bernard and the Plaquemines-Modern subdeltas, respectively. This confirms previous inferences (*14*, *24*, *25*) that this reach of the Mississippi River was occupied during St. Bernard time and subsequently reactivated (*26*). Carbon-14 ages from the top of the underlying peat bed (Fig. 4), and at two sites north of the river (Fig. 5, Convent I and Lutcher I) indicate an age of ~3600 years B.P. (four measurements). A thinner overbank deposit underlies this organic bed and presumably belongs to another pre–St. Bernard distributary. A thin peat bed locally separates the overbank deposits of the St. Bernard and Plaquemines-Modern subdeltas. The top of this bed provided ^{14}C ages of 1200 to 1400 years B.P. (Fig. 5, Lagan I), similar to an earlier measurement (1325 ± 105 years B.P.) of an identical transition in the same area (*24*).

The distribution of dated archaeological sites in the eastern Mississippi delta (*27*) is shown in Fig. 6. The oldest human occupation was attributed to the Late Archaic period and is in the upstream part of the St. Bernard subdelta (*28*). Archaeologically derived ^{14}C data and stratigraphic ages based on ceramic seriation indicate that sites become progressively younger eastward (*29*–*31*), with initial occupation of the easternmost St. Bernard subdelta occurring during the Marksville period (*5*, *29*). The earliest inhabitation of the Lafourche subdelta dates to the very end of the Baytown period (*32*), whereas inhabitation of sites near the mouth of Bayou Lafourche dates to the end of the Coles Creek period. The earliest ^{14}C age for human settlement in this area is 980 ± 60 years B.P. (*33*). Initial occupation of the Plaquemines-Modern subdelta occurred during the late Baytown or early Coles Creek period. A buried site along a crevasse channel southwest of New Orleans has a ^{14}C age for initial occupation of 1350 ± 60 years B.P. (*30*).

The ^{14}C measurements for the beginning of activity of the St. Bernard, Lafourche, and Plaquemines-Modern subdeltas yield weighted mean ages of 3569 ± 24, 1491 ± 13, and 1322 ± 22 years B.P., respectively, and provide maximum ages for all downstream distributaries belonging to these subdeltas. Calibration to calendar years (*34*) yields 95% confidence age ranges of 1960 to 1832 B.C. (St. Bernard), 566 to 608 A.D. (Lafourche), and 664 to 744 A.D. (Plaquemines-Modern), in agreement with existing archaeological data. The delta lobes evidently were rapidly occupied after their formation (*33*, *35*). Apparently the formation of the Lafourche and Plaquemines-Modern subdeltas started almost simultaneously. Similar phenomena have been observed in the Rhine-Meuse delta, The Netherlands (*36*).

Our results show that the chronology of Mississippi River subdeltas needs reevaluation. When our data are compared with previous chronological work (Table 2), McFarlan's (*14*) and Saucier's (*24*) results are more consistent with our findings than those of Frazier (*15*). This is not surprising, because these earlier chronologies were based on ^{14}C ages of organic materials underneath natural levees. We believe that our results constitute an initial framework for a revised ^{14}C chronology for the Mississippi delta.

Table 1. List of ^{14}C ages. The UtC number is the laboratory number. UTM, universal transverse mercator.

UtC number	^{14}C age (years B.P.)	$\delta^{13}C$ (per mil)	UTM coordinates and surface elevation above mean sea level (m)	Depth below surface (cm)	Sample name*	Material†
3871	1469 ± 35	−27.2	3319.240N, 686.920E, 4.7	891–893	P I-1a	1 Tdt
3872	1486 ± 55	−25.0	3319.240N, 686.920E, 4.7	891–893	P I-1b	1 Tdc
3873	3780 ± 59	−27.7	3319.240N, 686.920E, 4.7	1045–1047	P I-2	10 Sr
3874	4869 ± 51	−28.4	3319.240N, 686.920E, 4.7	1125–1128	P I-3	5 Cs
3875	1483 ± 36	−25.6	3318.560N, 685.700E, 3.5	530–532	P II-1a	1 Tdt
3876	1578 ± 37	−23.5	3318.560N, 685.700E, 3.5	530–532	P II-1b	1 Tdc
3877	1503 ± 31	−26.8	3317.660N, 683.820E, 1.0	216–220	P III-1a	1 Tdt
3878	1462 ± 33	−24.5	3317.660N, 683.820E, 1.0	216–220	P III-1b	1 Tdt
3879	1438 ± 37	−24.7	3317.660N, 683.820E, 1.0	216–220	P III-1c	1 Tdc
3880	1524 ± 43	−25.1	3317.660N, 683.820E, 1.0	216–220	P III-1d	1 Tdc
3881	3523 ± 38	−27.4	3326.940N, 720.500E, 1.8	468–470	L I-1a	1 Ch
3882	3664 ± 73	−27.2	3326.940N, 720.500E, 1.8	468–470	L I-1b	4 Ch
3883	4917 ± 57	−27.9	3326.940N, 720.500E, 1.8	672–675	L I-2	7 Sr
3884	3541 ± 46	−28.3	3322.840N, 711.960E, 3.3	552–554	C I-1	8 Sr
3885	3631 ± 48	−27.4	3317.720N, 716.720E, 2.8	608–610	V I-1	8 Sr
4456	1400 ± 60	−24.9	3316.380N, 712.360E, 1.9	157–159	La I-1a	1 Tdc
4457	1380 ± 31	−25.8	3316.380N, 712.360E, 1.9	157–159	La I-1b	6 Ch
4458	1197 ± 39	−32.0	3316.380N, 712.360E, 1.9	157–159	La I-1c	11 U

*P, Paincourtville; L, Lutcher; C, Convent; V, Vacherie; and La, Lagan. †Tdt (or Tdc), *Taxodium distichum* twig (cone); Sr, *Scirpus* cf. *robustus* nut; Cs, *Carex* sp. nut; Ch, charcoal fragment; and U, unidentified nut.

Table 2. Beginning of activity of Mississippi River subdeltas according to various authors [McFarlan (*14*), Frazier (*15*), and Saucier (*24*)]. SB, St. Bernard; LF, Lafourche; and PM, Plaquemines-Modern.

Author	Begininng of activity for subdelta (^{14}C years B.P.)		
	SB	LF	PM
McFarlan	2750–2200	~1500	~1200
Frazier	~4600	~3500	~1000
Saucier	~4000	—	~1200
This study	3569 ± 24	1491 ± 13	1322 ± 22

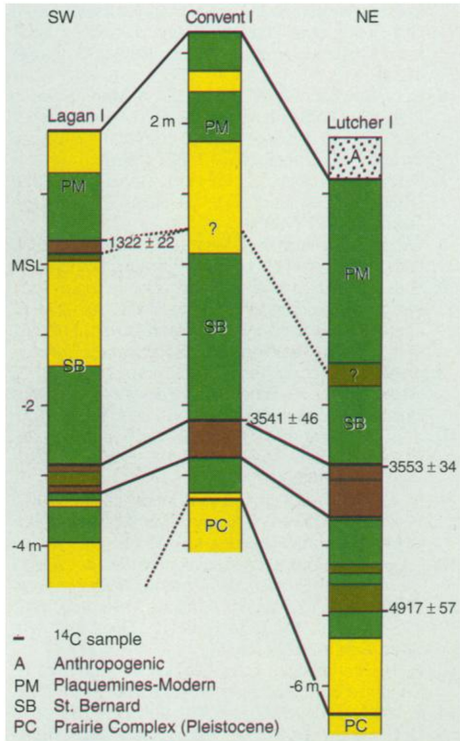


Fig. 5. Cores Lagan I, Convent I, and Lutcher I. Same color legend as in Fig. 3. The ^{14}C ages are weighted means for multiple samples.

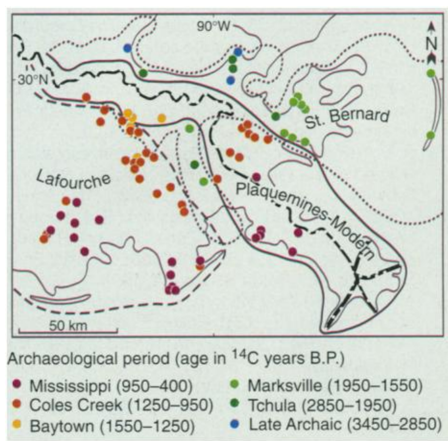


Fig. 6. The distribution and age of archaeological sites in the eastern Mississippi delta (*27*).

REFERENCES AND NOTES

1. W. J. Autin, S. F. Burns, B. J. Miller, R. T. Saucier, J. I. Snead, in *Quaternary Nonglacial Geology: Conterminous U.S.*, R. B. Morrison, Ed. (Geological Society of America, Boulder, CO, 1991), pp. 547–582.
2. R. T. Saucier, *Geomorphology and Quaternary Geologic History of the Lower Mississippi Valley* (Mississippi River Commission, Vicksburg, MS, 1994).
3. S. Penland, J. R. Suter, R. Boyd, *Mar. Geol.* **63**, 197 (1985); E. C. Kosters, *J. Sediment. Petrol.* **59**, 98 (1989).
4. J. H. Altschul, *The Houma-Terrebonne Archaeological Project* (New World Research, Fort Walton, FL, 1978); S. M. Gagliano, R. A. Weinstein, E. K. Burden, K. L. Brooks, W. P. Glander, *Cultural Resources Survey of the Barataria, Segnette, and Rigaud Waterways, Jefferson Parish, Louisiana* (Coastal Environments, Inc., Baton Rouge, LA, 1979).
5. D. E. Wiseman, R. A. Weinstein, K. G. McCloskey, *Cultural Resources Survey of the Mississippi River–Gulf Outlet, Orleans and St. Bernard Parishes, Louisiana* (Coastal Environments, Inc., Baton Rouge, LA, 1979).
6. R. H. Baumann, J. W. Day Jr., C. A. Miller, *Science* **224**, 1093 (1984); L. A. Deegan, H. M. Kennedy, C. Neill, *Environ. Manage.* **8**, 519 (1984); J. H. Cowan Jr. and R. E. Turner, *ibid.* **12**, 827 (1988).
7. R. Boyd, J. Suter, S. Penland, *Geology* **17**, 926 (1989); E. C. Kosters and J. R. Suter, *J. Sediment. Petrol.* **63**, 727 (1993).
8. We prefer the term "subdelta," synonymous to "delta complex" as used by many previous authors.
9. H.-E. Reineck and I. B. Singh, *Depositional Sedimentary Environments* (Springer, Berlin, 1980); M. R. Leeder, *Sedimentology* (Allen and Unwin, London, 1982); H. G. Reading, Ed., *Sedimentary Environments and Facies* (Blackwell, Oxford, 1986); R. G. Walker and N. P. James, Eds., *Facies Models* (Geological Association of Canada, St. John's, 1992).
10. J. S. Bridge and M. R. Leeder, *Sedimentology* **26**, 617 (1979); S. D. Mackey and J. S. Bridge, *J. Sediment. Res.* **B65**, 7 (1995).
11. H. N. Fisk, *Geological Investigation of the Alluvial Valley of the Lower Mississippi River* (Mississippi River Commission, Vicksburg, MS, 1944).
12. _____, *Geological Investigation of the Atchafalaya Basin and the Problem of Mississippi River Diversion* (Waterways Experiment Station, Vicksburg, MS, 1952); _____ and E. McFarlan Jr., *Geol. Soc. Am. Spec. Pap.* **62**, 279 (1955).
13. H. R. Brannon Jr., L. H. Simons, D. Perry, A. C. Daughtry, E. McFarlan Jr., *Science* **125**, 919 (1957).
14. E. McFarlan Jr., *Geol. Soc. Am. Bull.* **72**, 129 (1961).
15. D. E. Frazier, *Gulf Coast Assoc. Geol. Soc. Trans.* **17**, 287 (1967).
16. T. R. Kidder, *Eng. Geol.*, in press.
17. S. Penland, J. R. Suter, R. A. McBride, in *Coastal Sediments '87*, N.C. Kraus, Ed. (American Society of Civil Engineers, New York, 1987), pp. 1689–1705.
18. D. R. Levin, *Gulf Coast Assoc. Geol. Soc. Trans.* **41**, 408 (1991).
19. R. A. Weinstein and S. M. Gagliano, in *The Lafourche Country: The People and the Land*, P. D. Uzee, Ed. (Univ. of Southwestern Louisiana, Lafayette, LA, 1985), pp. 122–149; R. A. Weinstein and D. B. Kelley, *Report No. COELMN/PD-89/06* (Coastal Environments, Inc., Baton Rouge, LA, 1992).
20. P. V. Heinrich, in *Cultural Resources Investigations Related to the West Belle Pass Headland Restoration Project, Lafourche Parish, Louisiana*, R. A. Weinstein, Ed. (Coastal Environments, Inc., Baton Rouge, LA, 1994), pp. 5–22; S. L. Perrault and C. E. Pearson, *Report No. COELMN/PD-94/06* (Coastal Environments, Inc., Baton Rouge, LA, 1994).
21. A. Verbraeck, *Toelichting bij de Geologische Kaart van Nederland 1:50.000, Blad Gorinchem (Gorkum) Oost (38 O)* (Rijks Geologische Dienst, Haarlem, The Netherlands, 1970); H. J. A. Berendsen, *Utr. Geograf. Stud.* **25**, 1 (1982).
22. T. E. Törnqvist and G. J. van Dijk, *Boreas* **22**, 129 (1993).
23. We selected botanical macrofossils from these samples by sieving over a 500-μm screen, to avoid contamination that usually occurs in bulk peats [T. E. Törnqvist, A. F. M. de Jong, W. A. Oosterbaan, K. van der Borg, *Radiocarbon* **34**, 566 (1992)], and then dated them by accelerator mass spectrometry [K. van der Borg, C. Alderliesten, C. M. Houston, A. F. M. de Jong, N. A. van Zwol, *Nucl. Instrum. Methods Phys. Res.* **B29**, 143 (1987)] (Table 1). Identification of macrofossils included microscopic examination of wood to ensure that we used twigs and no roots.
24. R. T. Saucier, *Recent Geomorphic History of the Pontchartrain Basin* (Louisiana State Univ. Press, Baton Rouge, LA, 1963).
25. C. R. Kolb and J. R. Van Lopik, in *Deltas in Their Geologic Framework*, M. L. Shirley, Ed. (Houston Geological Society, Houston, TX, 1966), pp. 17–61.
26. Note that the Cocodrie subdelta in (*24*) is now considered part of the St. Bernard subdelta.
27. Compilation of this map is based on published data [(*4, 5, 19, 20, 28–33*); R. A. Weinstein, E. K. Burden, K. L. Brooks, S. M. Gagliano, *Cultural Resource Survey of the Proposed Relocation Route of U.S. 90 (LA 3052), Ascension, St. Mary, and Terrebonne Parishes, Louisiana* (Coastal Environments, Inc., Baton Rouge, LA, 1978)] and examination of site record forms on file with the Louisiana Division of Archaeology, Baton Rouge. Only the initial occupation sequence is shown, and we only used sites with an undisputable relation with the geological context.
28. S. M. Gagliano and R. T. Saucier, *Am. Antiq.* **28**, 320 (1963); C. Hays, *1995 Annual Report for Management Units IV and V* (Louisiana Division of Archaeology, Baton Rouge, LA, 1995); J. T. Kuttruff, M. S. Standifer, C. Kuttruff, S. C. Tucker, *Southeast. Archaeol.* **14**, 69 (1995).
29. W. G. McIntire, *Prehistoric Indian Settlements of the Changing Mississippi River Delta* (Louisiana State Univ. Press, Baton Rouge, LA, 1958).
30. K. R. Jones, H. A. Franks, T. R. Kidder, J. K. Yakubik, B. Maygarden, *Report No. COELMN/PD-93/08* (Earth Search, Inc., New Orleans, LA, 1993).
31. T. R. Kidder, *Report No. COELMN/PD-95/03* (Earth Search, Inc., New Orleans, LA, 1995).
32. D. G. Hunter, C. E. Pearson, S. K. Reeves, *An Archaeological Survey of Golden Ranch Plantation, Lafourche Parish, Louisiana* (Coastal Environments, Inc., Baton Rouge, LA, 1988); C. E. Pearson, B. L. Guevin, S. K. Reeves, *A Tongue of Land Near La Fourche: The Archaeology and History of Golden Ranch Plantation, Lafourche Parish, Louisiana* (Coastal Environments, Inc., Baton Rouge, LA, 1989).
33. R. A. Weinstein, *Report No. COELMN/PD-94/04* (Coastal Environments, Inc., Baton Rouge, LA, 1994).
34. The calibration method we used follows that described by J. van der Plicht, *Radiocarbon* **35**, 231 (1993), and T. E. Törnqvist and M. F. P. Bierkens, *ibid.* **36**, 11 (1994).
35. S. M. Gagliano, in *Perspectives on Gulf Coast Prehistory*, D. D. Davis, Ed. (Univ. of Florida Press, Gainesville, FL, 1984), pp. 1–40.
36. T. E. Törnqvist, *Geology* **22**, 711 (1994).

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RNA Tertiary Structure Mediation by Adenosine Platforms

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The crystal structure of a group I intron domain reveals an unexpected motif that mediates both intra- and intermolecular interactions. At three separate locations in the 160-nucleotide domain, adjacent adenosines in the sequence lie side-by-side and form a pseudo–base pair within a helix. This adenosine platform opens the minor groove for base stacking or base pairing with nucleotides from a noncontiguous RNA strand. The platform motif has a distinctive chemical modification signature that may enable its detection in other structured RNAs. The ability of this motif to facilitate higher order folding provides one explanation for the abundance of adenosine residues in internal loops of many RNAs.

Ribozymes and large RNA components of spliceosomes and ribosomes fold into complex three-dimensional architectures. To form these biologically active structures, helical regions must pack together specifically. Comparative sequence analysis (*1*, *2*), biochemical experiments (*2–5*), and modeling based on intermolecular contacts in crystals of small RNAs (*6*) have identified some elements responsible for long-range tertiary interactions in large RNAs, but their molecular details are largely unknown. The crystal structure of the 160-nucleotide P4-P6 domain of the *Tetrahymena thermophila* self-splicing intron (*7*) has revealed several new types of long-range contacts, including three examples of the adenosine platform motif described below.

The secondary structure of the P4-P6 domain, like that of many other large RNAs, contains base-paired regions interspersed with internal loops (Fig. 1A). As in other RNAs, many of the loops contain a

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