same budgets as for Arctic and Antarctic research and logistics.

There are non-fiscal threats as well. A natural gas pipeline, if it's built, would mean more people, more traffic, more way stations, and more gravel excavation. One of Shaver's sites is right next to an old gravel pit that, if reactivated, could destroy the site either directly or by increasing silt and other runoff sufficiently to invalidate longitudinal studies.

To counter these possible problems and more, Barnes and his colleagues at the University of Alaska are beginning to seek support from federal and state officials for a 44.5-hectare research park that would protect the study plots against potential intrusions. The U.S. Bureau of Land Management leases 10.8 hectares to the University of Alaska Institute of Arctic Biology as the station's grounds and has zoned the 31,000 hectares around Toolik Lake as a Research Natural Area. Expanding the size of the protected zone to include the upper Kuparak River watershed, a site of some long-term studies, would safeguard research without impeding oil and natural gas development, says Barnes.

It would also protect Toolik's future and avoid, in Gholz's words, NSF's having made "a huge investment that's thrown out." Toolik deserves special attention, Bingham and others would argue, because of its ability to monitor a key component of global climate change. "Arctic ecosystems are some of the most endangered habitats and organisms on earth," she says. **–ELIZABETH PENNISI**

Archaeology

Unraveling Khipu's Secrets

Researchers move toward understanding the communicative power of the Inca's enigmatic knotted strings, which wove an empire together

In 1956, Peruvian archaeologists uncovered a vessel hidden in the floor of a high-status home in the Inca administrative center of Puruchuco, near present-day Lima, Peru. Inside, they found a kind of treasure: a set of 21 of the knotted strings called khipu. The Inca relied on sets of khipu (or quipu in Spanish) to keep records of their far-flung realm, which extended more than 5500 kilometers, the distance from Stockholm to Cairo.

The Spanish who conquered the empire discovered that it was held together by a highly efficient bureaucracy that controlled the distribution of labor, goods, and services, using streams of khipu to issue orders and record the results. So essential were khipu to the native population, according to Galen Brokaw, an expert in Andean texts at the State University of New York at Buffalo, that the early colonial government reluctantly approved their continued use until they could be displaced by alphabetic texts the Spaniards could understand. Today, only perhaps 600 pre-Hispanic khipu survive.

For more than a century, researchers have sought to understand how these distinctive objects were used within the empire, and whether they functioned as a unique kind of three-dimensional, textile-based "writing." On page 1065 of this issue, anthropologist Gary Urton and mathematician-weaver Carrie J. Brezine, both at Harvard University in Cambridge, Massachusetts, take a step toward answering both questions. Through a computer-aided analysis of seven of the Puruchuco khipu, Urton and Brezine have identified one way that data and instructions were passed up and down the hierarchy from local villages to the powerful central government in Qosqo (modern Cusco). In the process, they also have tentatively made the first-ever identification of a khipu "word."

Almost simultaneously, archaeologist Ruth Shady Solis of the National University of San Marcos in Lima has independently unveiled what is seemingly the oldest khipu—or, perhaps, proto-khipu—ever discovered. Found in a cache buried inside a pyramid at Caral, an ancient city north of Lima that Shady's team has been excavating since 1994 (*Science*, 7 January, p. 34), the object resembles an Inca khipu, except that the pendant strings are twisted around small sticks.

First strings. This artifact from the ancient city of Caral may be a khipu as old as 4500 years.

CREDIT: PILAR OLIVARES/REUTERS

According to Shady, it is more than 3000 years older than the oldest previously known khipu, which date from the 9th century C.E. If so, then khipu, though younger than the world's first writing systems of Sumerian cuneiform and Egyptian hieroglyphics, arose in the third millennium B.C.E. and are among humankind's oldest means of communication.

The Caral artifact's apparent great age of 4000 to 4500 years "indirectly strengthens the case" that the khipu were "more than numeric," notes Daniel H. Sandweiss of the University of Maine in Orono. Ancient writing methods such as cuneiform evolved over many centuries from accounting records, as scribes invented symbols to identify what was being counted. "If what Ruth has found really is a khipu ancestor," Sandweiss says, "then khipu would be following the pattern of other writing systems."

Inca khipu consist of a main cord from which dangle as many as a thousand smaller strings, the latter of which contain clusters of knots. In the 1920s, Leland Locke, an amateur scientist, argued that khipu were simply lists of numbers, with individual knots representing digits and groups of knots on a strand representing successive powers of 10. (Blank spaces function as zeroes.) Locke's rules held true for many khipu, and his view of them as mnemonic devices largely held sway until the 1970s, when the Cornell University husband-wife team of Robert and Marcia Ascher overhauled his work, assembling a detailed khipu database (http://instruct1.cit.cornell.edu/research/quipu-ascher/). They argued that khipu were more akin to writing—and indeed that about 20% of surviving khipu do not fit Locke's rules.

If khipu were a form of writing or proto-writing, they were unlike any other. Scribes "read" the khipu by running their fingers along the strings, sometimes while manipulating small black and white stones—in striking contrast to other cultures' ways of recording symbols, which involve printing or incising

marks on flat surfaces. "The Spaniards were bewildered by them," Urton says. "Four hundred years later, we aren't much better off."

The Aschers sparked a new push to decode khipu. Supported by a National Science Foundation grant and a MacArthur Prize, Urton and Brezine in 2002 began assembling a more sophisticated khipu database that permitted complex searches (http://khipukamayuq.fas.harvard.edu/). Among the first khipu they entered was the set unearthed at Puruchuco. According to anthropologist Carol Mackey of California State University, Northridge, these khipu were found in the home of a *khipukamayuq*, an elite scribe who created and read the khipu that recorded the flow of goods, labor, and taxes within the empire. Mackey noted that two of the khipu were almost identical—an observation that tallied with the Inca writer Guaman Poma's 1609 claim that *khipukamayuq* made multiple copies of each khipu so that "no deception could be practiced by either the Indian tribute payers or the official collectors."

Brezine realized that the pattern of string colors on the two matching khipu also "was very similar—you had sequences of four strings, each with [the same] repeated pattern of four string colors." Brezine then asked the database to identify khipu with a "similar kind of arrangement of four string colors in repeating sets." By interfacing the values in the Harvard khipu database with the popular software Mathematica, Urton says, "she was able to ask, 'Is there any instance of these strings whose sum is found on another khipu?' "

The answer was yes. Brezine's data-sifting revealed a hierarchical pattern involving seven of the 21 khipus. The hierarchy consists of three levels, each with two khipu. (Urton and Brezine removed one of the level 2 khipu, which has disappeared from the Puruchuco museum, from their analysis). Khipu on each level have identical or nearly identical number values and string colors—"the checks-and-balances aspect" of khipu accounting. And the values on lower-rank khipu add up to the values on subsections of higher-rank khipu. Thus, Urton and Brezine argue, the seven khipu represent either demands, probably from the provincial governor, for labor or goods, which lower-level functionaries broke down into components, or reports of tribute from the bottom being aggregated on their way up the ladder. Either way, Urton says, "you see how information might have been funneled upward and dispersed downward"—an essential task in controlling the large, diverse, and populous empire.

Notably, some of the cords in the level 2 khipu are only approximate sums of the corresponding cords in level 1. But the top level khipu is much more precise, with only 2 inexact totals. That suggests to Urton that "some data-manipulation was going on." The *khipukamayuq* may have been matching real figures for labor taxes on the bottom to ideal requests from the top, for example.

Line by line. A set of khipu found together (one from the set, *above)* may help in understanding khipu such as this 1200-year-old one (*top*).

CREDITS (TOP TO BOTTOM): W. CONKLIN; G. URTON

The khipu on the two top levels have introductory segments of three figure-eight knots on three strings. To Urton and Brezine, the knots on these khipu, which presumably would have circulated out of their place of origin and perhaps as far as the capital, most likely served to identify their place of origin, the palace at the place now called Puruchuco. If so, then the introductory segments give its name—the first-ever precisely deciphered "word" in khipu "writing."

"The identification seems logical to me, though we are being cautious about it," Urton says. Aware that the decoding of both Mayan and Egyptian hieroglyphics began by identifying place names, he believes that "if khipu can be deciphered, this is the kind of approach that will do it."

Urton has previously argued (*Science*, 13 June 2003, p. 1650) that khipu were a kind of binary code, with the 0s and 1s being the either-or choices faced by khipu-makers (right or left direction for knots, spin, and ply, for example). With other researchers, Brokaw has criticized this binary theory, because, he says, "there is no way to reconcile it with the decimal code in which the khipu [also] clearly participate," and because he believes it is not supported by ethnographic data. But Brokaw calls the current work "fascinating," noting that it does not directly depend on the earlier binary theory.

The increased belief that the khipu were a complex means of communication is coupled with growing recognition of the extraordinary role of textiles in the precolonial Andes. "Textiles are important to every society," says William J. Conklin, an architect and archaeologist who is a research associate at the Textile Museum in Washington, D.C. "But their role in Andean societies as carriers of meaning and power is different from anything else that I know." Conklin notes, for example, that very early textiles from Huaca Prieta, a north coast site dated to about 1500 B.C.E., were apparently not used for clothing. The "incredible fact," in Conklin's view, is that "weaving was invented for what we might call 'conceptual art'—to communicate meaning—and only afterward was it used for clothing."

Khipu, Conklin says, were part of this tradition, as possibly shown by the Caral proto-khipu. Consisting of a ladderlike assemblage of 12 cotton strings, some knotted, that are wrapped around sticks, the object was found in a sealed room within one of the large pyramids at Caral earlier this year. Along with the other objects in the cache—including pristine baskets, mysterious spheres of fiber, and what looks like netting—the apparent khipu will be displayed at a Caral exhibit in Lima's Museo de la Nación until 31 August. Shady reports that her group "soon" will submit for publication the results from a "study of the context and the material within the cache." Sandweiss cautions that the huge temporal gap between the Caral object and the earliest firmly dated khipu—one carbon-dated by Conklin to between 779 and 981 C.E.—is "puzzling." Clearly, he says, "there is a great deal more to be learned here."

–CHARLES C. MANN