Remote Sensing (II): Brazil Explores Its Amazon Wilderness

Belem. Five years ago, the Amazon Basin was a largely unknown wilderness—the largest in the world, covering 5 million square kilometers and nearly 60 percent of Brazil. Today it is still a wilderness, although the Brazilian government is stepping up its development efforts, but it is no longer unknown. The agent of this transformation is an unprecedented exploration effort known as Project Radam (for *Rad*ar *Am*azon). Radam has combined a sophisticated remote sensing technique with systematic investigations on the ground to produce a staggering amount of information, including the first accurate maps for much of this huge area, geological and mineral surveys, soil and timber analyses, and estimates of agricultural potential. Perhaps most striking, Radam scientists have proposed regional land use patterns for the Amazon Basin designed to protect ecologically fragile or unique regions and to permit the planning of future development in a more rational way than has previously been possible.

Radam's productivity is based on a unique coupling of U.S. technology and Brazilian ingenuity and industry in its use. The technology is an airborne radar mapping scheme developed in the United States but first applied on a large scale in Brazil. Radar mapping is rapid and relatively inexpensive, partly because it is not dependent on weather conditions or restricted to daytime use; a single aircraft guided by a network of navigational radio transmitters can cover as much as 500,000 square kilometers a day. The technique used in Radam was developed by Goodyear Aerospace (see accompanying article) and is known as "side-look" radar because the beam is directed to one side of the aircraft flight path and strikes the ground at an angle; the reflected signal, recorded on film, yields information about the topography of the surface as well as patterns characteristic of particular soils and flora.

The ground effort involves logistical miracles by the Brazilian Air Force and no little courage on the part of the Radam investigators. Supply planes leave Belem as often as several times a day, headed for base camps at small landing strips in remote parts of the Amazon Basin. From there, helicopters ferry crews out to sites chosen to be representative of particular regions on the basis of the radar images. Men with chain saws strapped to their backs are lowered into what is often impenetrable jungle to cut a landing pad (Fig. 1). Other crews follow, taking soil and rock samples, studying the local biota, assessing the agricultural and mineral potential. Still others push up small tributaries in canoes or river boats to gather similar information. In the course of 5 years, hundreds of base camps have been occupied and abandoned; more than 3000 sites have been explored by helicopter, and many more by river boat. The crews risk snakebite, disease, and sometimes hostile Indians; 45 people have died in plane crashes, boat accidents, and from disease. But few have quit. Apparently the lure of the unknown, of what one Radam scientist calls "the adventure of knowing you are the first person to set foot on this place," is strong.

The information gleaned from these forays and from laboratory analyses of

Fig. 1. (Top) A helicopter landing pad carved out of the jungle to bring in Radam survey teams. [Source: Project Radam] Fig. 2. (Bottom) Part of the Trans-Amazon Highway cut through a part of the basin that has extremely poor, fragile soil. Note that the unpaved portion of the cleared land has turned to barren sand. [Source: Project Radam]

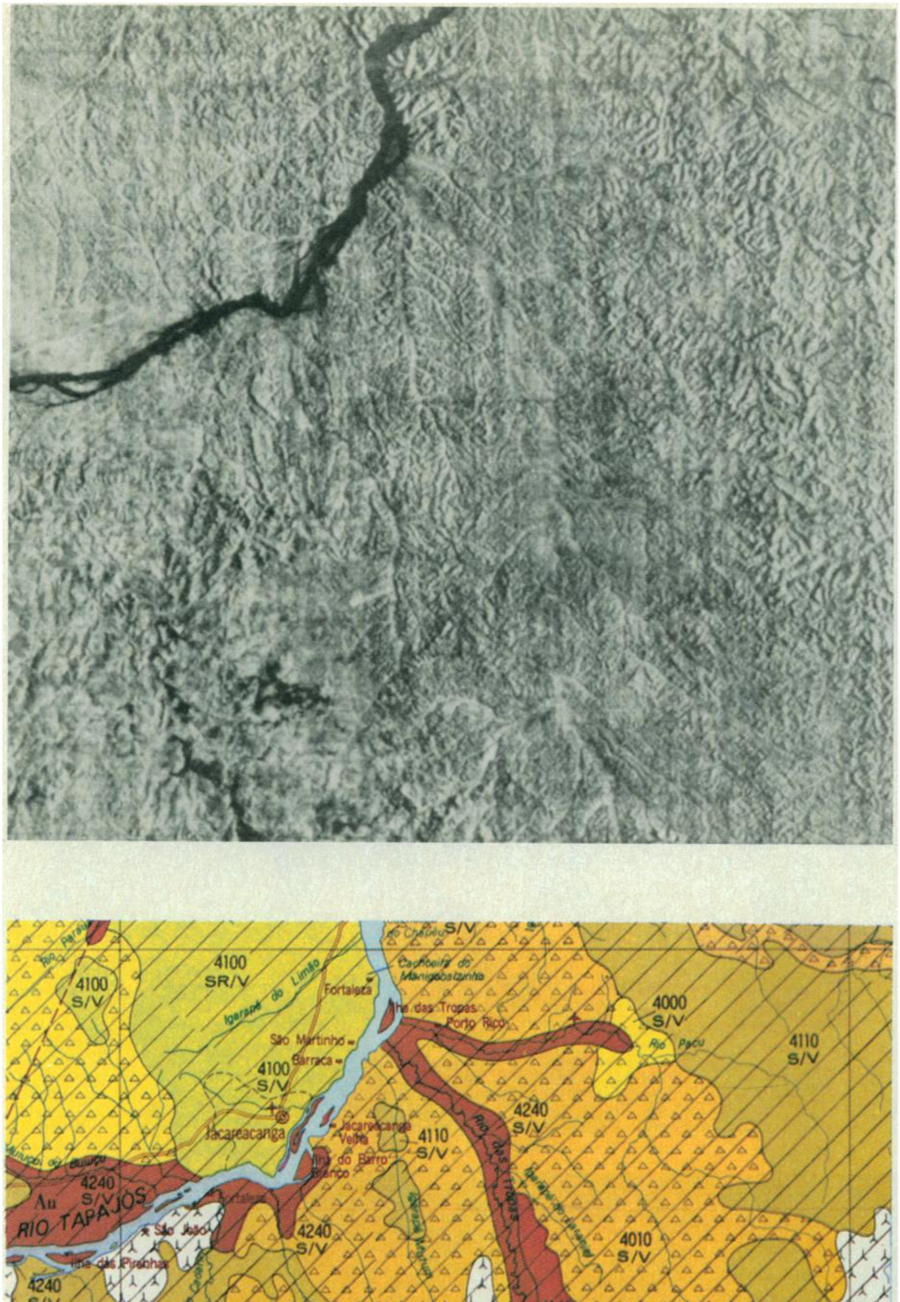

Fig. 3. (Top) Radar image of a portion of the south-central Amazon Basin approximately 16,000 square kilometers in area. The Rio Tapajos, an Amazon tributary, can be seen flowing northward. Note the topographic detail that the radar technique provides. (Bottom) Proposed land use zoning of the same region. The map indicates the Radam assessment of land use potential by a four-digit number in each map unit; the digits indicate on a scale of 0 to 4 the potential for lumbering, agriculture, extractive products, and cattle raising (natural pasture), respectively. White map units are ecologically fragile areas protected in theory by Brazilian law or proposed as preserves or special use areas. Promising mineral deposits are also indicated. [Source: Project Radam]

the returned samples is brought to Radam's cramped headquarters here in Belem for interpretation and synthesis. The early results so impressed the Brazilian government that what was initially a small experimental mapping effort was expanded to include the entire Amazon Basin and, last year, expanded again to include the rest of Brazil as well. Other government agencies have become regular customers for Radam's output, as have hundreds of mineral companies and private investors eyeing land purchases. The Radam results have also shown the ineptitude of some earlier development projects in the Amazon region (Fig. 2). Roads planned over routes that turned out to be largely under water 6 months of the year have not been uncommon, nor have land-clearing projects for agriculture in regions that turned out to have unstable or practically nonexistent soils.

So poorly known were some parts of the region that Radam discovered a major new tributary of the Amazon, a river hundreds of kilometers long. Mountain ranges indicated on old maps turned out to be far from their supposed locations, and a region marked out as a national forest reserve turned out to be an open savannah. Earlier soil and vegetation maps tended to suggest that the Amazon Basin is covered by a relatively homogeneous rain forest, but Radam data show that the forest is by no means homogeneous and that the soils beneath it are diverse, ranging from sand or laterite (iron-bearing) soils to rich topsoils a meter or more in depth. The geology is equally diverse—as much as 1 million square kilometers of the underlying formations appear to be volcanic, a fact that is forcing reevaluation of ideas about the early history of the South American landmass—but appears to be predominately of two types, geologically recent (Tertiary) sediments and ancient (Precambrian) rock. Of great economic importance to Brazil, Radam has discovered or greatly extended earlier discoveries of bauxite, iron ore, tin, rare earths, and other minerals.

The information gathered by Radam is made available in a series of maps accompanied by a thick book of supporting data for each section of the country—18 volumes in all for the whole Amazon Basin. In addition to the radar images themselves, six interpretive maps are published: geology, geomorphology, soils, vegetation, agricultural potential, and proposed land use categories, all on the same (radar-based) grid at a scale of 1 to 1 million. Otto Bittencourt Netto, technical director of Radam, says "these maps give us for the first time a feeling for the regional patterns" of this immense area.

These patterns include, for example, variations in the type of forest cover with soil types and local climate. Not all of the Amazon is covered with dense rain forest; natural grasslands or savannahs occur, and Radam botanists now distinguish open forests in which palm trees occur nearly as frequently as the huge hardwood trees that predominate in denser areas. They have identified more than 400 species of trees and estimate the value of the standing crop of the species with known uses to be in excess of $1 trillion. (Exploitation of hardwood species in a big way is not now contemplated, however, because the trees would sink in water and are so huge, often 60 meters high, that anything other than river transport would be difficult.) The idea of a rain forest itself may be somewhat misleading, Radam investigators say, because only three regions of the Amazon Basin have year-round rainfall. Other areas experience dry seasons 2 to 5 months in length.

Soil patterns are equally surprising. Although much of the soil is poor in nutrients, pockets of good soil exist. Radam scientists found one large area in the westernmost reaches of the Amazon that contains 100,000 square kilometers of thick, fertile soil capable, they say, of supporting intensive agriculture. Netto estimates that at least 2 percent of the Amazon Basin consists of good soil, and he points out that the radar images recently led to the discovery of large deposits of limestone which, if added to neutralize the acidic soils of many plateau areas, could make them productive as well. In large areas, however, the soils will not support use at all, turning to sand or (in laterite areas) to rock when the covering vegetation is cleared.

The land use map is, in a sense, the summation of the information on the other six, but includes as well the results of sociological surveys of any existing inhabitants of the region. They were asked what crops grow well, what institutions and infrastructure (landing strips, schools, and so on) already exist in the region, and the state of the local economy. The map attempts to single out the most promising areas and activities for development, points out restrictions posed by soil or vegetation, and proposes regions for preservation. Specifically considered are any known mineral indications and the potential for lumbering, raising cattle, and agriculture.

A typical example is a 290,000 square kilometer region in the south-central Amazon Basin, straddling the boundary between the states of Amazonas and Para. The Rio Tapajos runs through the region, which is heavily forested. The Radam maps (Fig. 3) indicate that lumbering is, in fact, nearly the only activity that ought to be contemplated, although there are also indications of gold, tin, and several other minerals scattered throughout the region. The soils, however, are too poor to support intensive agriculture, and the existing vegetation is not appropriate for cattle ranching. In a few places, however, especially along river beds, there appears to be a substantial potential for extractive products such as palm oil. A number of areas are marked as unexploitable by law, because the slopes are at angles greater than 45°, or as needing special protection because of their fragility. The proportion of the area covered by the map that falls into each category is summarized on a separate legend.

All these maps, with the exception of the radar images, are made essentially by hand. That is particularly remarkable because the scientific staff of Radam totals about 150, and these same people perform the fieldwork. The operation has been a lean one in other ways as well. The total cost of the effort, which is funded by Radam's parent agency, the Departamento Naciónal da Producão Mineral of the Ministry of Mines and Energy, has been about $40 million for the first 5 years. Radam has also had what seems to be a remarkable degree of autonomy in developing its own sampling and interpretive techniques and deciding what information should be published, and in what form.

Radam is highly regarded in Brazil, as well it might be. More to the point, the information it is providing is being actively sought and used by government planners who have responsibility for development activities in the Amazon Basin. Even the proposed land use designations seem not to have become controversial, and there are indications that they are being adopted by other agencies. In any case, it is clear that Radam has provided the means for what one Brazilian describes as "a rare opportunity—the chance to plan a continent's development before it happens."

—ALLEN L. HAMMOND

Remote Sensing (III): The Tools Continue to Improve

Remote sensing extends the human perspective not only by offering airborne and satellite platforms from which to look at the earth but also by making possible new and more quantitative methods of gathering information. The aerial camera, for example, has been supplemented by multispectral scanners that record information in digital rather than photographic form. Improvements in methods of processing remote sensing data are extending these tools even more. Two recent examples are an experimental technique for superposing Landsat and side-look radar images, thus combining in a single image information from two complementary approaches normally used in isolation from each other, and the development of new methods of exploiting the information content of digital Landsat data to produce enhanced images.

Microwave radar is less well known as a remote sensing tool than, for example, Landsat, but it is finding increasing use—part of a trend toward applying new portions of the electromagnetic spectrum that also includes the infrared radiometers on weather satellites. Radar remote sensing systems were developed in the United States for intelligence purposes and have since been declassified, and several are commercially available. The version developed jointly by Goodyear Aerospace and Aero Service seems to have been most successful and has been used commercially to survey more than 12 million kilometers on four continents in the past 5 years.

The system transmits microwave pulses at a wavelength (0.03 meter) that is relatively insensitive to weather conditions. The reflected signal is processed electronically, displayed on a cathode ray tube, and recorded on film, pulse by pulse; Doppler variations in signal frequency created by the motion of the plane appear as varying densities in the film emulsion, creating a phase history—in effect, a kind of hologram—of the radar image. This technique synthesizes information from several pulses and can thus distinguish features as close as 10 meters, even from a high-flying aircraft—a resolution otherwise unobtainable without an antenna too large to carry on an aircraft. The image itself is reconstituted, in the final processing