Men Who Measure the Earth

Surveyors from 18 New World Nations Invade Trackless Jungles and Climb Snow Peaks to Map Latin America

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With Illustrations by National Geographic Photographer John E. Fletcher

ON a windy mountain 15,590 feet up in the Peruvian Andes, I huddled next to a campfire and waited for the sun to set. As the shadows stretched longer, the air turned bitter cold. The few drops of water in my canteen cup froze solid; my feet felt as if they were going to do the same thing.

To the east a bank of gray clouds mounted ominously, but to my relief they stayed high, so they would not interfere with the operation I was about to observe. Within an hour numb-fingered engineers on the mountain where I sat—and on four surrounding snow-caps—would begin a series of scientific observations to measure the earth.

Perhaps you thought, as I once did, that geographers already knew the earth's shape and dimensions. And so they do, in a general way. They know it is more or less round—a spheroid, or near-sphere—and flattened at the poles, with a middle-age bulge around the Equator. But precisely how flattened, how big a bulge, and how nearly spherical—even the experts don't know.

They are eager to find out. In this age of guided missiles, the *exact* distance from, say, Tallahassee to Timbuktu may suddenly become crucially important. And as of now there is no way to calculate this distance except to know the size and shape of the earth's surface between the two cities.

Night Lights on Snowy Peaks

Presently NATIONAL GEOGRAPHIC photographer Jack Fletcher, barely recognizable in a bright wool *chullo,* an Indian mountain hat, joined me at the fire's edge. With cold-clumsy fingers he worked to insert film in his camera.

"I just made a bad mistake," he said.

"What was that?" I asked.

"I moved."

Even mild exercise is exhausting three miles up. After six hours of it, we were both feeling symptoms of *soroche*, mountain sickness, caused by too little oxygen in the air. My head and jaws ached alarmingly, and my neck was so stiff I could not look over my shoulder. The mere thought of eating was nauseating.

As we sat by the fire and swapped symptoms, a shout rang out behind us.

"Here come the lights!"

The sun had finally set, and the brown mountains turned purple and black. Suddenly, on top of a snow peak six miles west and 2,000 feet above us, a pinprick of light glowed like a fallen star. Behind me, to the east, another light blinked on; then a third and a fourth.

A Girdle for the Earth

This was what we had come to see. These specks of light, actually powerful battery-run signal lights shining incongruously from peak to peak in a mountain wasteland, were instruments to map a still largely uncharted continent and, in the process, to fit a new girdle to the planet earth (page 336).

The hard work in making maps is not done at a drawing board. It is done by geodetic surveyors—specially trained engineers who cross and recross the country through deserts, mountains, and jungles.

As they go, they establish thousands of control points at which latitudes, longitudes, and elevations are determined. The word "geodetic" means that measurements are adjusted to allow for the curved shape of the earth, which geographers call the geoid.

Fletcher and I were here to report and picture one of the biggest geodetic and mapping programs ever undertaken anywhere, the first attempt in history to map a continent as a whole rather than piecemeal. It is an all-American project, being carried forward jointly by the United States and 17 Latin American nations.* Coordinating the work is

* Bolivia, Brazil, Chile, Colombia, Costa Rica, Cuba, Dominican Republic, Ecuador, El Salvador, Guatemala, Haiti, Honduras, Mexico, Nicaragua, Panama, Peru, Venezuela, working according to specifications adopted by the Pan American Institute of Geography and History.

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Shivering Surveyor in the High Andes . . .

Mapping the still largely uncharted continent of South America, U. S. and Latin American engineers and soldiers are swarming up 18,000-foot peaks, camping in jungles, and exploring the Amazon's headwaters.

Eighteen countries, including the United States, are working on the program, which is coordinated by the Inter-American Geodetic Survey (or IAGS), a mapping agency of the U. S. Army.

Before maps can be made, geodetic surveyors must crisscross each country, putting in basic controls identified by bronze disks painstakingly established as to latitude, longitude, and elevation, and firmly fixed in concrete or stone. All parts of

← Colored Lights Guide Engineers

When a survey leads through a city, engineers set up their instruments on the highest building available. To distinguish their station lights from street lamps and neon signs, they may use prearranged groupings of colors. Red, white, and blue signals flash at sunset on this clock tower in Diriamba, Nicaragua.

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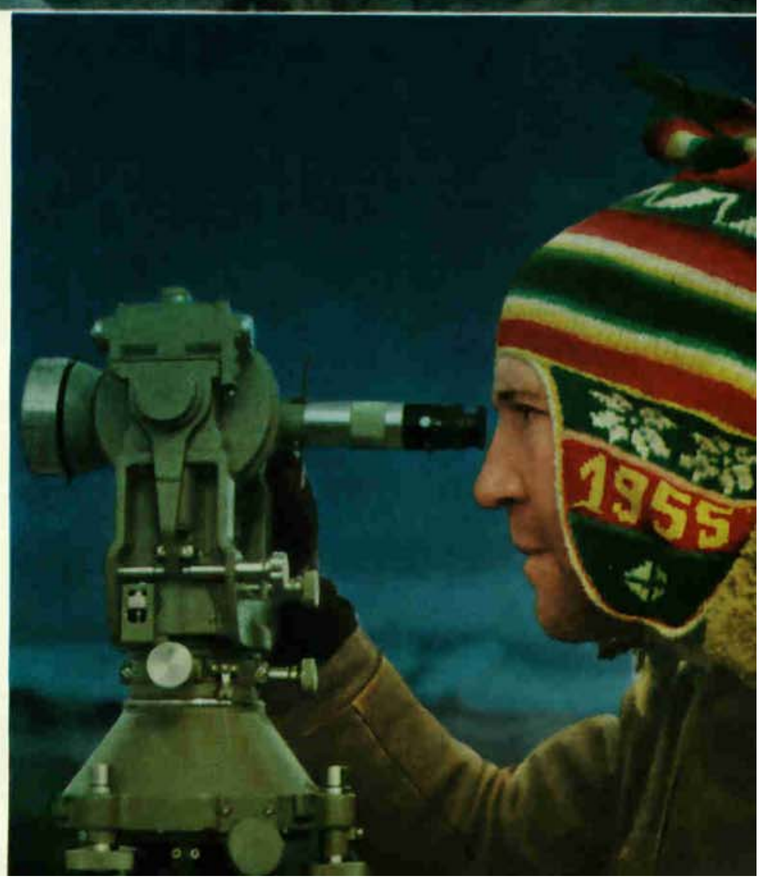
. . . Peers at a Signal Light 6 Miles Away

the map are drawn in reference to these control points.

Surveyors accurately determine distances of hundreds of miles by triangulation, a process by which two of a triangle's sides are calculated from measured angles and a known base line (page 357). They form such triangles by setting up lights on mountain peaks. Normally they work at night, when warm air currents subside.

Here at dusk engineer Norman Fassett sights his theodolite on a light atop 17,085-foot Mount Sorpresani, near Tarata, Peru. He himself works at 15,590 feet. His signal light (20 feet away) provides a target for an observer on Sorpresani.



Indian-style Cap Warms Ears →

Mr. Fassett's $2,100 theodolite combines a high-power telescope and a microscope mounted on a swivel. When the telescope is sighted on a distant light, the microscope reads degrees, minutes, and seconds from two illuminated glass circles in the base.

the Inter-American Geodetic Survey (IAGS), an agency of the U. S. Army Corps of Engineers. It is known throughout Latin America as *Servicio Geodésico Interamericano*.

At its headquarters in Fort Clayton, Panama Canal Zone, Col. Robert R. Robertson, the affable and energetic Army engineer who directs IAGS (opposite), told me how it first came into being.

"During World War II," he said, "we learned the hard way that adequate maps just didn't exist for most parts of the globe. Even in the United States, only 37 percent of the land is covered by really accurate topographic maps.

"When the war ended, the President started a long-range plan to promote map making, with United States technical help, in friendly countries all over the world. The Army, Navy, and State Department were directed to cooperate. The Army named its Latin American program MAPPLAN. The IAGS is MAPPLAN in operation."

Case of the Missing Mountains

"Many of the existing maps of Latin America," Colonel Robertson told me, "were compiled from whatever information was available—aeronautical charts, rough sketches by explorers and prospectors, missionaries' charts, and sometimes just guesswork.

"Right here in Panama there's a mountain range 125 miles long, with peaks up to 5,000 feet, that did not show at all on previous maps. Rivers are sometimes 40 miles out of place.

"Some results of our work, incidentally, have shown up already in the National Geographic Society's new map of Eastern South America. Your own cartographers can tell you how many mountains they had to raise and how many Brazilian rivers they had to relocate when they compiled it."

Navigation problems raised by supersonic flight, as well as by an increase in long-range night flying, gave new urgency to the other part of IAGS's assignment: finding data to determine the size and shape of the earth. These data will come from a continuous overland measurement running all the way from Alaska to southern Chile.

IAGS, Colonel Robertson stressed, is no giveaway program. The bulk of the actual work is done by the 17 collaborating countries themselves. In terms of dollars, for example, these countries annually spend over three times as much as the IAGS. In terms of personnel the ratio is even more impressive: about 660 United States workers as compared to more than 4,000 Latin Americans.

The United States engineers, pilots, cartographers, and other assorted technicians have made up a kind of slogan from the initials of their outfit. IAGS, they say, means "I'm Always Going Somewhere." And so they are. A man just back from hacking his way through stifling jungle, may, the following month, find himself encamped on a frozen mountaintop or paddling down the Amazon in a dugout canoe.

For two months last year I lived and worked with these men, slept in mosquito-infested jungle bases, sweated on horseback under a broiling tropical sun, paddled in leaking *cayucos,* and skimmed over hundreds of miles of thick green forest in small one-engine planes and helicopters. It is no soft life.

Yet this is high-precision work they are doing, with fragile scientific instruments costing thousands of dollars apiece. Just the names of the tools are enough to bewilder a layman: the theodolite, the pendulum astrolabe, the chronograph, gravimeter, geodimeter, and the magnetometer, to name a few.

The instruments are delicate, but not the men who use them. Consider Earl Meador, for example, who was struck by lightning in the line of duty. In Venezuela I met Earl, a quiet-spoken young engineer from Kentucky.

"I was working on a mountain about 13,000

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Map Makers Plan a Massive Task: → the Charting of a Continent

Inter-American Geodetic Survey was established in 1946 after World War II had revealed the scarcity of adequate maps for most parts of the world, including South and Central America.

Using the most modern scientific methods, the survey has set up a control system extending from Atlantic to Pacific and from Mexico to southern Chile, and containing thousands of points at which latitude, longitude, and elevation have been determined. Aerial photography, another stage in map making, is now under way.

Finished maps, on a scale of 1 to 250,000, will be produced by Army Map Service in Washington, D. C., and by map-making agencies in the 17 cooperating countries.

Here Maj. Gen. Lionel C. McGarr (left), who commands U. S. Army forces in the Caribbean area, confers with Col. Robert R. Robertson, Director of IAGS, at Fort Clayton, Panama Canal Zone, the headquarters of IAGS. National Geographic maps cover the work table. The IAGS emblem, woven in flowers, marks the survey's anniversary.


SERVICIO GEODESICO
INTERAMERICANO
SOUTH AMERICA

Engineers in Managua, Nicaragua, Tread Gingerly on a Flower Bed

To IAGS surveyors, the new National Stadium is a picture point; that is, it is identifiable in an aerial photograph. Before cartographers can use the picture for mapping, several such points must be located as to latitude, longitude, and elevation.

These surveyors sight on a calibrated rod near the stadium entrance. Their instrument, called a Wild reduction tacheometer, can measure the distance to the rod as well as its relative elevation and horizontal position. Statue honors Nicaragua's President Anastasio Somoza.

feet up, near Huancayo, Peru," he told me. "We were setting up a theodolite about 4 p. m. It was cold, and I was wearing a fur-lined parka. That's what saved me, I guess.

"It began to snow and sleet, and I heard some thunder. Then a bolt of lightning flashed down and hit me on the back of the head. I couldn't see it because it knocked me out cold. But another man up there with me said that lightning ran right down the back of the parka and into the ground.

"It made me feel pretty bad. I couldn't even work that night."

Earl Meador was one of the lucky ones. He lived to tell about it. Others have been killed by lightning; still others have died in plane crashes, drowned, frozen, been menaced by jaguars, or struck by deadly tropical diseases.

This is not to say that IAGS has an unduly high mortality rate. It has not. Strict safety regulations govern all its operations, and they are observed. But the nature of the work is hard and hazardous.

Monuments on Mountaintops

The trademark of the geodetic engineer is a bronze disk about 3½ inches in diameter. If you have hiked or camped in the mountains or along the seacoast in the United States, you have probably seen them, set in solid rock or concrete. In the United States they are often stamped with the name of the U. S. Coast and Geodetic Survey, and the warning: "$250 fine or imprisonment for disturbing this mark. . . ." In Latin America the IAGS disks are similar, but the legend is in Spanish.

There are tens of thousands of these monuments in Latin America. In cities, you may find one in the cornerstone of the governor's palace, or in the base of Bolívar's statue in the park. They lie buried under snow in the Chilean Andes and hidden (but never lost) in thickets of the Amazon jungle.

There's a story about a party of mountain climbers who arrived in a Central American city and announced with some fanfare that they were going to scale for the first time a near-by 11,000-foot peak, regarded as difficult and risky. After a send-off by the mayor, the mountaineers set out. They made it to the top, too, but there the fanfare fizzled out. Embedded in rock on the summit they found a *"Servicio Geodésico"* disk. It seems an IAGS engineer had climbed the peak two years earlier, planted a monument, made his observations, and climbed down again without bothering to tell the local papers.

A dot marks the center of each disk. The job of the geodetic surveyor is to plant the disks immovably, and then to determine the precise location of the dot—its latitude and longitude, or elevation above sea level, or both. Like the numbered dots on a child's drawing puzzle, these disks, placed along mountain ranges, valleys, rivers, and roads, form the framework around which a map will eventually be drawn.

The geodetic surveyor must go where his compass leads, regardless of hardship or danger. Sometimes he must turn explorer, push-

ing his way through unknown terrain. For jobs like this, the IAGS employs specialists.

In Nicaragua I met one of the specialists. Frank Herbst is a bushman, and looks the part (page 346). He stands well over six feet; his face is weather-beaten from years of living without benefit of wall or roof. He is an expert with pistol, rifle, and shotgun.

Trek Across a Continent

Once, when he found himself at loose ends in Cochabamba, Bolivia, Herbst decided he would rather be in Georgetown, British Guiana. He set out on foot, switching to cayuco when he could—a trip of over 1,700 miles across part of the high Andes and through the Amazon jungle of Brazil.

"It took me about four months," he admitted, "but I was in no hurry."

When there is particularly rough country to be surveyed, Herbst goes through first, armed with revolver, machete, and high-powered rifle, to find the best route for the geodetic engineers as they establish control points.

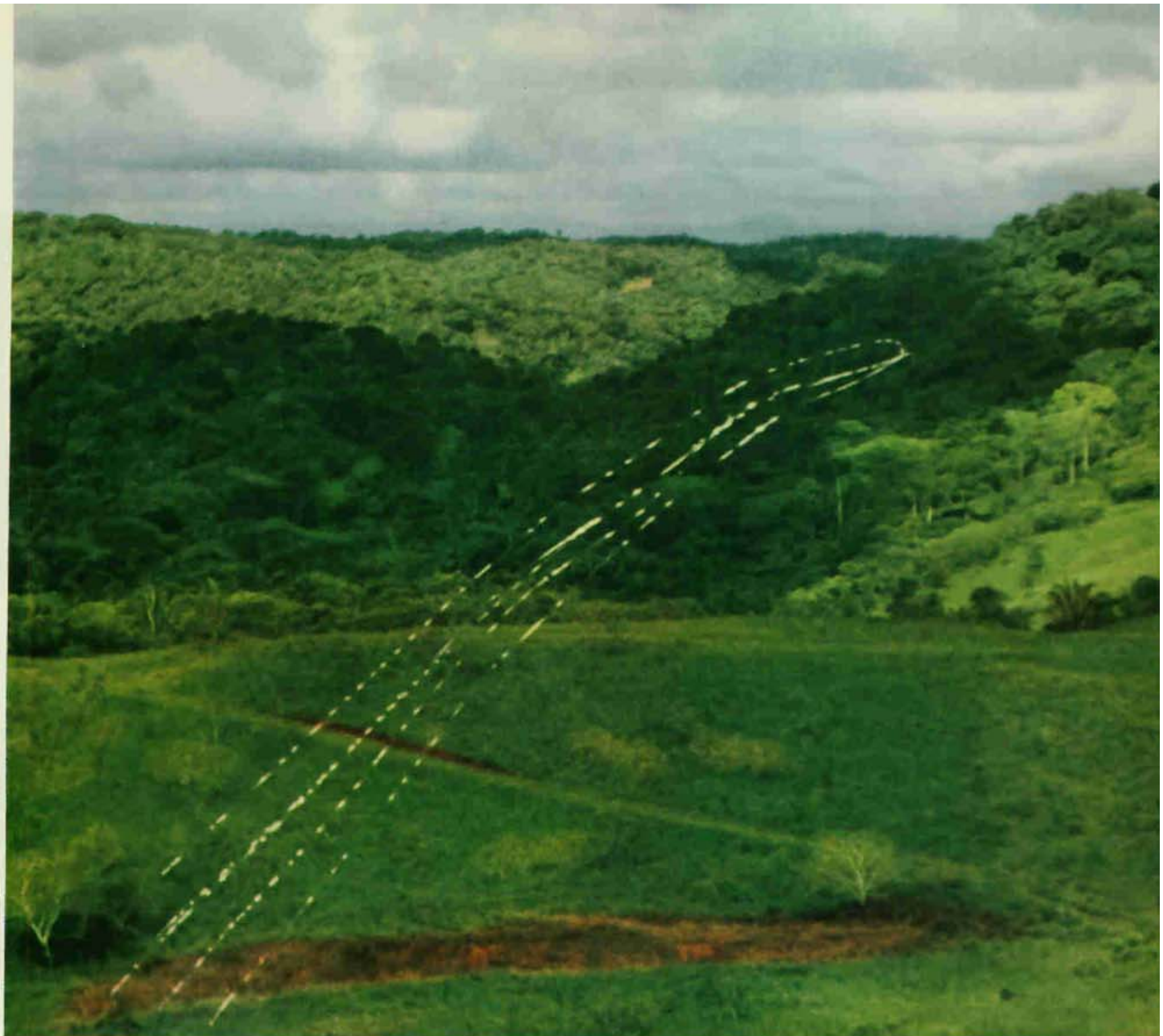
I met Herbst in Puerto Cabezas, a small lumbering town on the Mosquito Coast of the Caribbean (map, page 344). His task was to reconnoiter the wild coastal area from Puerto Cabezas north to the Honduran border.

When I arrived, Herbst had already flown along the coast in a small two-seater L-19, one of 45 U. S. Army aircraft authorized to IAGS (page 342). One of his objects was to pick out stations—high points of land visible from one to the next—on which the engineers later would set up their instruments.

"Now I have to reconnoiter each station on foot," Herbst said. "I go to the first one tomorrow. Why don't you come along?"

We left the next morning at 6:30, Maurice Tewinkel, an IAGS engineer, Herbst, and I. In a rented truck we lurched and bounced the first 10 miles across a dirt track to Crukira, a Mosquito Indian village north of Puerto Cabezas. There, to cross a wide lagoon, we rented a *pipante,* a dugout canoe. We paid five cordobas (about 70¢) for it. It turned out to be less of a bargain than we thought. A huge leak in the bow almost swamped us before we reached the other side.


41435
U.S. ARMY



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Plane Drops Glittering Foil to Mark a Survey Station

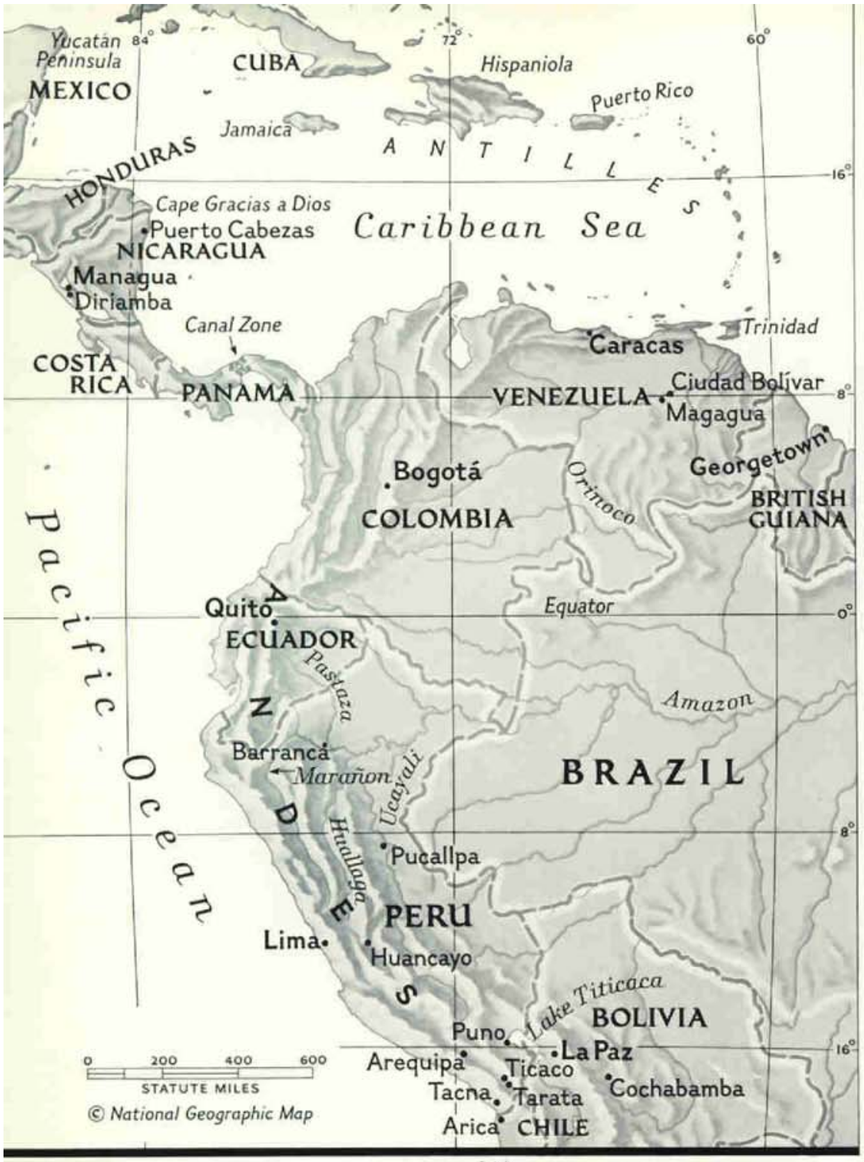
Light planes of the U. S. Army enable IAGS surveyors to spot the easiest routes through rough terrain and pick the best sites for stations.

Helicopters, transporting men and gear, save days of hacking through jungle. Airlifts of food obviate tedious pack trips.

This L-19, having dropped a streamer of foil to mark a station in Panama, speeds on to find another site.

←Page 342: When the plane has finished reconnaissance, a helicopter flies in an engineer to begin ground operations. This man is being lowered by a sling to save the 'copter's rotors from damage in brush.

→After landing amid the identifying foil, the engineer pinpoints his position on an aerial photograph so that other surveyors can find it.



Latin America Survey Paves the Way for Progress

Oil, minerals, lumber, water power, and fertile virgin soil lie untapped in the 17 countries collaborating with IAGS. Their development cries for detailed maps to guide the men who someday will build the roads, railroads, pipelines, dams, and airfields.

The maps are coming. In Venezuela's oil-soaked flatlands, along Nicaragua's lonely Mosquito Coast, and around Lake Titicaca's lofty shores the author watched United States and Latin American engineers working side by side to produce the basic data. These men must establish some 91,000 miles of first-order triangulation and 195,000 miles of level lines. Flying crews must take hundreds of thousands of high-altitude photographs.

By the end of 1955 the job was about one-fourth done.

Not far away we found two Indians with four horses—small animals, but sturdy enough. Here Frank struck another bargain. Why walk when we could ride? The two Indians announced they would come along, too. That made five of us, with only four horses. When we mounted our steeds, one Indian remained afoot, twirling a length of heavy rope.

I soon learned why. No amount of tongue-clucking or goading on my part had any effect on my animal. The Indian's job was to trudge behind us swinging his rope. When he caught up with a horse, the rope hit its rump with a "thwack!"—and the horse would trot briskly 18 or 20 steps. Then it would decelerate until the Indian got within thumping distance again.

At this jerky pace we rode for about four hours, first through jungle, and then, more comfortably, on the smooth beach of the bright blue Caribbean. At last we turned inland again onto a sandy plain, and there Frank stopped.

"Look," he said, pointing at a low hill about a mile ahead.

On the hilltop I could see something glistening in the tropical sunlight (page 343).

"That's our station," said Frank. "That shiny stuff is aluminum foil. I dropped it from the plane yesterday. It makes the station easier to locate."

On the hilltop Frank's main job was "verifying intervisibility"—making sure that this was the highest of several near-by hills, with a clear line of sight to the next station. Then, with a compass and a rough sketch map, he read and jotted down azimuths—compass directions—from our hilltop to the two other stations farther up the coast.

Finally he wrote down notes which would later be expanded into a station description, a report on the location and appearance of the hill and how to reach it, for use by the engineers who would follow.

The men who follow Herbst with lights and theodolites, bags of cement, and bronze disks will determine the distance from hill to hill, fixing the latitude and longitude of each station. They will compute distances, just as surveyors have done all the way from Alaska to Chile, by triangulation.

"Triangulation," an engineer told me, "is half trigonometry and half endurance." Its principle is this: If you know the length of one side of any triangle and can measure the size of its angles, you may then, by an easy equation, determine the length of the other two sides.*

To start with, then, a line must be measured by hand, with a tape—the known side of the first triangle. After that, triangulation can go forward on its own, with each new triangle sharing a known side from the last.

Indians Collect Shiny Disks

Measuring a starting line, called a base line, must be done with extreme precision, since any error at this stage will affect all the other triangles (page 356). At each end of the line one of the familiar disks is set in concrete. And since primitive Indians sometimes like to collect shiny bronze disks, another concrete marker is usually buried three feet below the top one—a reserve marker in case the surface one disappears.

The base line finished, triangulation is ready to begin. The engineers themselves form the corners of the triangle, one side of which, of course, is the base line itself. Their measuring instrument is the theodolite, which combines a telescope and an angle-measuring device marked with degrees, minutes, and seconds (page 337).

Each man sights his theodolite on the other two—or, more accurately, on their lights—since precise triangulation is nearly always done at night. Each carefully measures the angle between the two lights he sees; to be sure he's right he measures it not once but 32 times. Then all three engineers, communicating by two-way radio or by blinking their lights in code, "close" the triangle—that is, add their figures to be sure they're right.

After that, of course, they are able to determine the length of all three sides. Using any one of these as the known side, they form a new triangle and repeat the whole process. Each new triangulation carries the measurement forward from 10 miles, in flat terrain, to 50 miles or more in mountainous country.

To watch a triangulation party at work, Jack Fletcher and I flew to Tacna in southern Peru, and drove northeast from there to the little Indian village of Tarata.

Here, working from a base camp 11,000 feet up, a crew of Peruvian cartographers and engineers were just attacking one of the toughest triangulation jobs, or "arcs," ever run anywhere. Working with them were three IAGS men, Norman Fassett, Tom McShane, and César Díaz.

"This arc will run from Tacna right over the Andes to Lake Titicaca," project engineer Fassett explained to me. "The average elevation of the stations we'll occupy will be more than 15,000 feet, higher than any point in the United States.

"Tomorrow the first party will take off for a station on top of Mount Pisacane, 17,524 feet high. It will take at least a day just to get up there; then they've got to tunnel through 11 feet of snow to get down to rock so they'll have a firm base for the station. The men will have tents, of course, to help break the wind, and small gasoline stoves."

Why did they choose such rugged peaks? Peruvian Army Lt. Fritz Du Bois's explanation was succinct:

"We can't see through them," he said, "so we've got to get up where we can see over them."

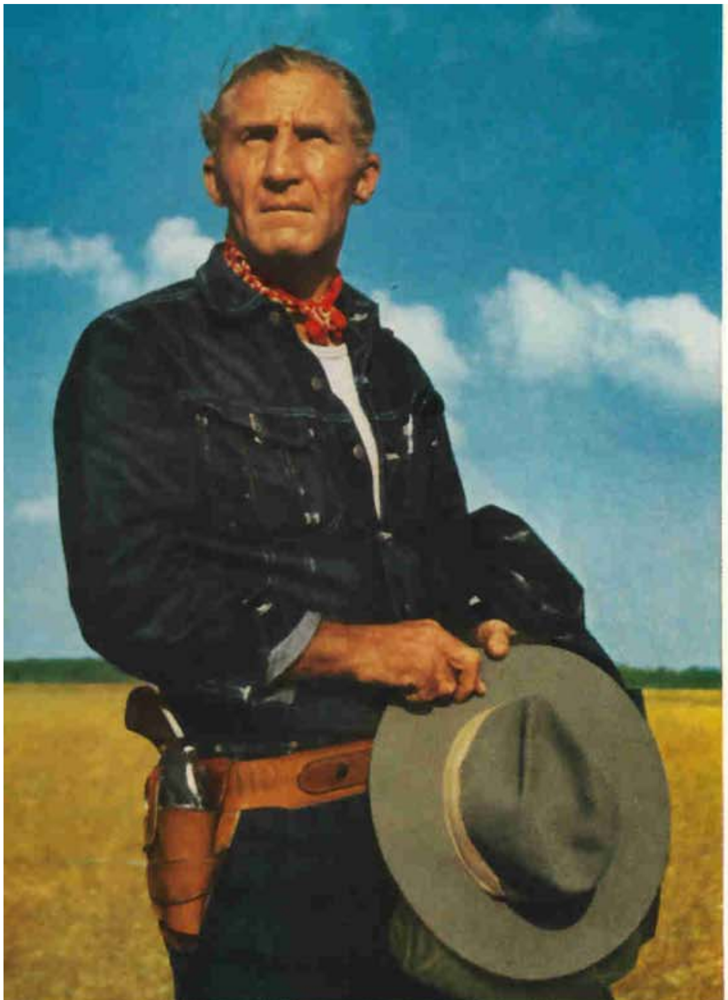
"We'll have one relatively easy station in this operation," Fassett added. "It's a supplemental station to bring the geodetic control down near the road that runs from Tacna to Puno. You could watch the whole operation from there, if you'd like. It's only 15,590 feet—not bad at all."

Eighty Days on a Mountaintop

The next day Fassett, McShane, Fletcher, and I set out for the intersection station—a round-topped hill on a lofty plateau ringed by loftier snow peaks. On our way we passed a herd of a dozen vicuñas, red-brown and slender legged, grazing in the coarse clump grass. As we approached, they fled single file up the mountainside.

As promised, the station was easy to get to. The hard part was staying there. This was where Jack and I got our taste of soroche. I, too, made the mistake of moving too strenuously. Rashly, I volunteered to help Fassett nail together an instrument stand, precut of two-by-four lumber, for his theodolite. Ten minutes of driving nails at 15,590 feet leaves your head aching and your ears ringing.

* See "Charting a World at War," by William H. Nicholas, National Geographic Magazine, November, 1944.



Jungle Trouble Shooter Carries Pistol on Hip

IAGS engineers in Latin America must extend surveys through country known to few except Indians. They face malarial mosquitoes, snakes, jaguars, and head-hunters.

When the going looks toughest, the IAGS is likely to tap Frank Herbst, onetime gold and diamond prospector, to blaze a trail. A former professional soldier in Europe and Africa, he has taught survival techniques to U. S. Marines. Born in Czechoslovakia, he speaks six languages fluently.

Mr. Herbst disappears into the bush with only a few pounds of provisions, relying on rifle or shotgun to bag game. He reappears with a rough map for the geodetic engineers who follow him.

↓ U. S. Airman Tries to Explain Shoran to Puerto Rican Girls

Measuring distances too wide for theodolites, the U. S. Air Force uses shoran, a radar device.

To tie the Antilles into maps of North and South America, radar beams are bounced from a high-flying plane to two ground stations and back to the plane again. From the elapsed time, measured in microseconds, mathematicians compute distances between ground stations.

Kodachrome by David S. Boyer, National Geographic Staff (below)

"Ideally," Fassett said, "the men on station up there should be able to finish their work and get off station in three days. Trouble is, there are so many things to go wrong."

"For instance?" I asked.

"Weather is the worst problem. In an IAGS project I worked on in Mexico, we had to sit on some stations six weeks before it got clear enough to see from one to the other. I know men who have spent 80 days on a mountain waiting for rain and fog to lift."

When this happens, new problems arise. Men on remote stations may run out of food or water after a few weeks. Frequently, triangulation parties take along shotguns or rifles to keep the camp in fresh meat.

Night Visitors—Human and Otherwise

Engineers have survived on berries, leaves, and roots while waiting for a plane to drop food. Water is even more of a problem. Unless there are parachutes, it bursts from ordinary containers when dropped from an aircraft. One headquarters chief had a bright idea: He scrounged some blocks of ice from a near-by city and dropped them to a field party, who simply gathered the ice and melted it down for drinking.

Weather and supplies are not the only hazards. In Costa Rica, a triangulation party chief, sleeping in a tent with four companions, woke up in the dead of night to hear someone—or something—scratching and snuffling near his bed. Suspecting that it was not one of his tentmates, he pulled a .38 revolver from under his pillow and said softly:

"Who's there?"

He received only a snarl for an answer, so he aimed the gun at a dark patch on the floor and started shooting. When the tumult died and somebody lit a lantern, they found their night visitor stretched dead on the floor—a jaguar six feet long.

Other nocturnal visitors have included Indians, who occasionally set fire to surveyors' tents. The Indians sometimes resist survey teams simply because they don't understand what the strangers are doing with their shiny instruments and flashing night lights. So awed were men of one primitive tribe in Colombia by the first appearance of an IAGS helicopter, which they mistook for a huge grasshopper, that they revised their calendar from that date. For them, 1955 was the "sixth year of the grasshopper" (page 348).

The old-timers, engineers who have been in the business for two or three decades, will tell you, with a faint undertone of nostalgia, that surveying has "gone soft."

"In the old days," said engineer Maurice Tewinkel, who isn't as old as this makes him sound, "if you had to go into the bush you went on foot, or at best on horseback. If you got lost or ran out of food, you were on your own. Now, with radios and jeeps and helicopters and airdrops, it's getting easier every year."

To support its operations, IAGS is authorized 25 light airplanes and 20 helicopters. It also has some 500 assorted trucks and jeeps, and 40-odd boats.

Most modern innovation, however, is Able Charlie Item, a 17-station shortwave-radio network which keeps IAGS projects in all collaborating countries in constant touch with headquarters and each other. (Able, Charlie, and Item are code words for the network's call letters, ACI.) Besides the 17 main transmitters, powerful enough for intercontinental talk, field parties carry shorter range portable two-way radios and walkie-talkies.

Yet despite all the modern machines, the air and ground support, and a growing network of roads, there are areas in South America where conventional triangulation is impracticable because it would be too slow and too costly.

Where the Amazon Rises

The most extensive such area is the vast region of swamp and jungle where the Amazon River rises, including parts of Brazil, Bolivia, Peru, Colombia, Ecuador, and Venezuela. In this almost impenetrable land tribes of Indians roam untouched by civilization, hunting game and each other with blowguns, spears, and arrows.

"The truth is," one cartographer remarked to me, "there's not much in there to map."

But I found men who disagreed. In the depths of this jungle, sailing down the swirling Marañon River in a small boat one day, I came on what I thought at first must be a mirage. On a bend in the river stood a white mansion, mounted on barges made fast to shore. Inside was a living room fitted with chrome-and-plastic furniture, comfortable bedrooms, hot and cold showers, fans and water coolers, and even a laundry room with automatic washers and dryers.

This was the mobile base camp of Texas Petroleum Company prospecting a 2½-million-

Venezuelan Children → Mob a "Grasshopper"

Within a 180-mile-wide circle near Ciudad Bolívar, the Venezuelan Government and IAGS are spending $1,000,000 on a project to find out, as one observer put it, "which way is down." Scientists are studying the force of gravity at thousands of sites around the center of the circle—the "datum point." Object: to eliminate the error in geodetic surveying caused by anomalies—the fact that irregularities in the earth's crust deflect gravity.

This fixed point may help establish positions all over South America.

Accustomed to airplanes, Indian villagers still get a thrill out of helicopters, which they sometimes call grasshoppers. This landing disrupted life in Magagua (population about 90).

← Peruvian Pupils Recite a Spanish Lesson

Following a survey team through the little-known headwaters of the Amazon River, the author came upon a rustic school in the Indian village of Barranca. Walled in by dense tropical forest, Barranca is a handful of thatched houses on the banks of the Marañon River.

Peru has compulsory free education for children from 7 to 16, but only in recent years has its school system reached into remote Indian settlements. Tribes still deeper in the jungle have no written language at all.

Plaque beneath the bell in corner reveals that this is public school No. 1529.

Four South American heroes look down on the class: Simón Bolívar (left), who freed much of South America, including Peru, from Spanish rule; Adm. Miguel Grau, who led Peru's Navy in the war against Chile; Gen. José de San Martín, Argentine soldier who fought Spanish rule; and Col. Francisco Bolognesi, who died in the Battle of Arica against Chile.

Señora Fernanda V. de Morales holds the pointer to the blackboard. Toddler in foreground visited the classroom to see what school was like.

acre concession granted to it by the Peruvian Government. Herbert Edwards, the engineer in charge, showed me the maps they were using. The concession was outlined in bold straight lines, but the rest of the topography was so vague that, as one of the oilmen said, "You're never quite sure where you are."

To men like these, and others eager to develop the resources of this rich, untapped land, maps are all-important and urgently needed. Roads, railroads, oil pipelines, even adequate air transport, all require maps.

Rivers Are Only Landmarks

The data for mapping the headwaters of the Amazon are now coming, slowly and toilsomely, out of the jungle. The men producing the facts have jobs even lonelier than the triangulation men on their mountaintops.

An IAGS man named David Phillips, we were told, was camping in the jungle on the Pastaza River, which flows into the Marañon from Ecuador (map, page 344). His surveying operation was of a type we had not yet seen. "Astro work," the engineers call it.

Choosing sites some 15 miles apart along the major rivers, which are about the only landmarks in this flat, green sea of trees, Phillips was putting in monuments and determining their position by astronomy. The instrument he used was a pendulum astrolabe, a V-shaped telescope which looks into the sky at a fixed 60° angle.

No commercial airline would fly us into this remote country. In Lima, Peru, we appealed to Maj. Gen. Guillermo Suero, of the Peruvian Air Force, for help or advice. A reader of the NATIONAL GEOGRAPHIC MAGAZINE, he listened sympathetically.

"Try *Linguística,*" he advised us. "They'll fly you in."

Fine. But who or what was Linguística?

Linguística, I learned, is a popular name for the Summer Institute of Linguistics, an earnest group of young men and women from the United States who are studying Amazonia's primitive Indian languages and teaching the tribes to read and write. A majority of the teachers are women. To teach a tribe to read, they must move into the jungle with the Indians and live with them for as long as seven years.

At its jungle headquarters near Pucallpa, Peru, the Institute maintains several pontoon-equipped planes. When a teaching party, normally two women but sometimes a married couple, are ready to go to work, one of the planes flies them as close as possible to the place where their tribe lives. After they leave the plane, the teachers are on their own. Equipment includes a small food supply, machetes, and a portable two-way radio.

It is tedious work, learning the language word by word, compiling a simple dictionary, and then showing the Indians that "pictures can talk." At present 25 tribal languages are being studied in Peru.

A commercial airline flew us over the Andes to Pucallpa, trading post on the edge of Amazonia. From there a battered and brakeless taxi drove us over a mud road to Yarina Cocha (Palm Lake), the Linguística headquarters.

This turned out to be a charming lakeside village with rambler-style houses, picture windows, and gardens bright with flowers.

"We cleared all this land by hand," Dr. W. Cameron Townsend, the Institute's director, told me. "With axes and machetes, it has taken us years, though of course a bulldozer could have done the job in a few weeks."

"But who supports all this?" I asked.

"The Peruvian Government gave us land," he explained. "Money comes from individual contributors in the United States and from churches. We're not really a religious organization, but we do introduce the Indians to Christianity by translating parts of the Bible into their languages. Our young people get their training in linguistics at the Universities of Oklahoma and North Dakota."

Mapping by the Stars

The next morning we flew from Yarina Cocha in one of Linguística's planes, a one-engine Norseman. As we climbed, I could see the Ucayali River winding off to the north. The river would guide us and serve as a landing field in any emergency. Linguística pilots try to avoid long flights over riverless stretches of jungle.

We had to make one such hop, however, from the Ucayali to the Huallaga River, which flows into the Marañon. It was on this wooded stretch of about 75 miles that our solitary engine coughed and suddenly died. For a few tense seconds we floated in silence broken only by the rush of air past the wings.

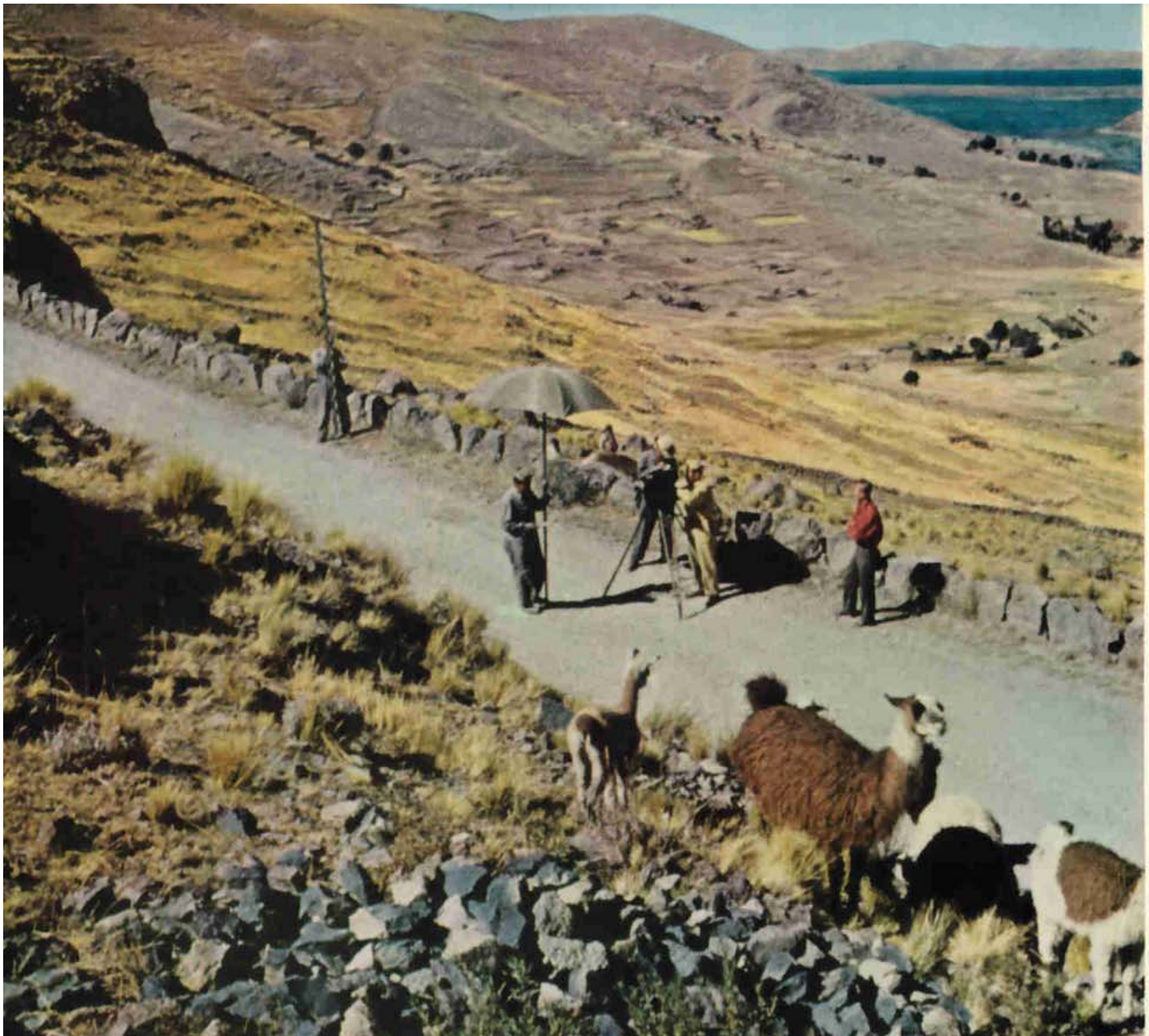
Then the engine roared again and the pilot apologized: "Belly tank ran dry. Sorry."

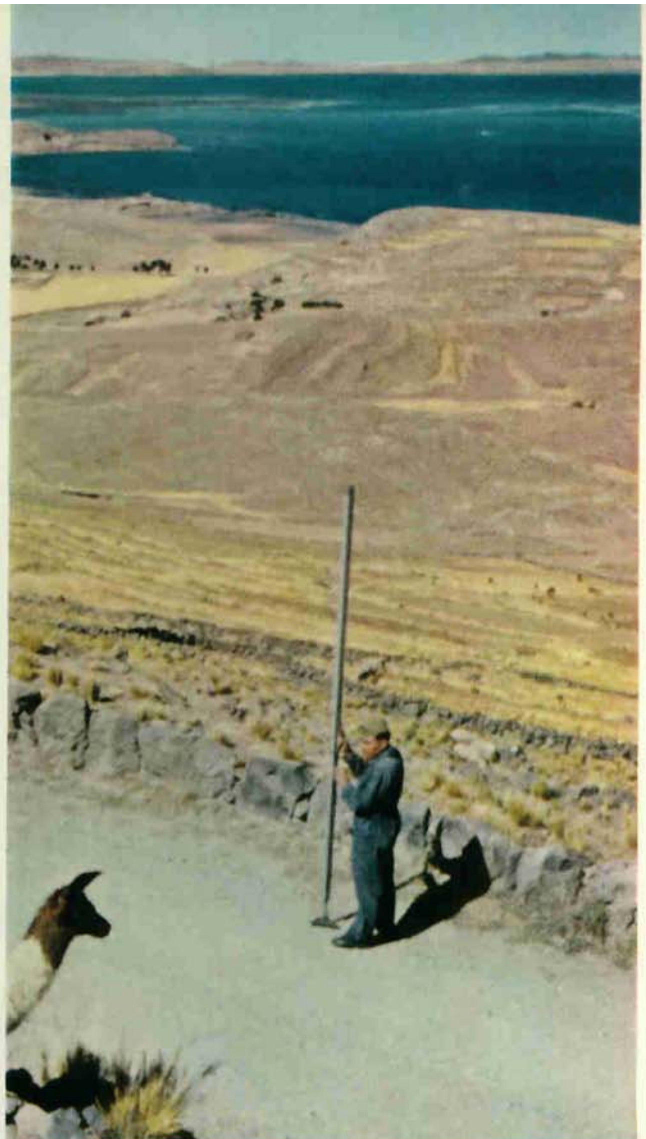
(Continued on page 359)

↑ **Peruvian Survey Squad Starts Up a 17,200-foot Snow Peak in the Andes**

While surveying from peak to peak, United States and Peruvian engineers and soldiers camp at sites up to 18,000 feet without benefit of oxygen. Tents, gasoline stoves, and layers of clothing protect them against wind and cold. Here Peruvian Army Lt. Fritz Du Bois, who studied geodesy with the United States Coast and Geodetic Survey, leads the way up Nevado Ticaco, northeast of Tacna.

↓ Indian women in always-fashionable felt derbies offer potatoes and tuberous *ocas* for sale in Puno, on Lake Titicaca (page 353). "Irish" potatoes originated in the Andes.





Inquisitive Llamas Watch Surveyors Run a Level Line past Lake Titicaca

To find elevations above sea level, IAGS sends in crews armed with 10½-foot rulers called precise leveling rods. Hiking from sea coast to the heights, the men measure the land rise as they go.

Measurements are made by standing two leveling rods upright about 100 yards apart and placing a rotating telescope between them. When the telescope is precisely leveled, the observer reads the figures, first on one rod, then on the other. Subtracting the smaller figure from the larger, he determines the difference in elevation.

Rear rod and telescope then leapfrog forward, repeating the process. A bronze disk set in concrete marks elevations about once every mile.

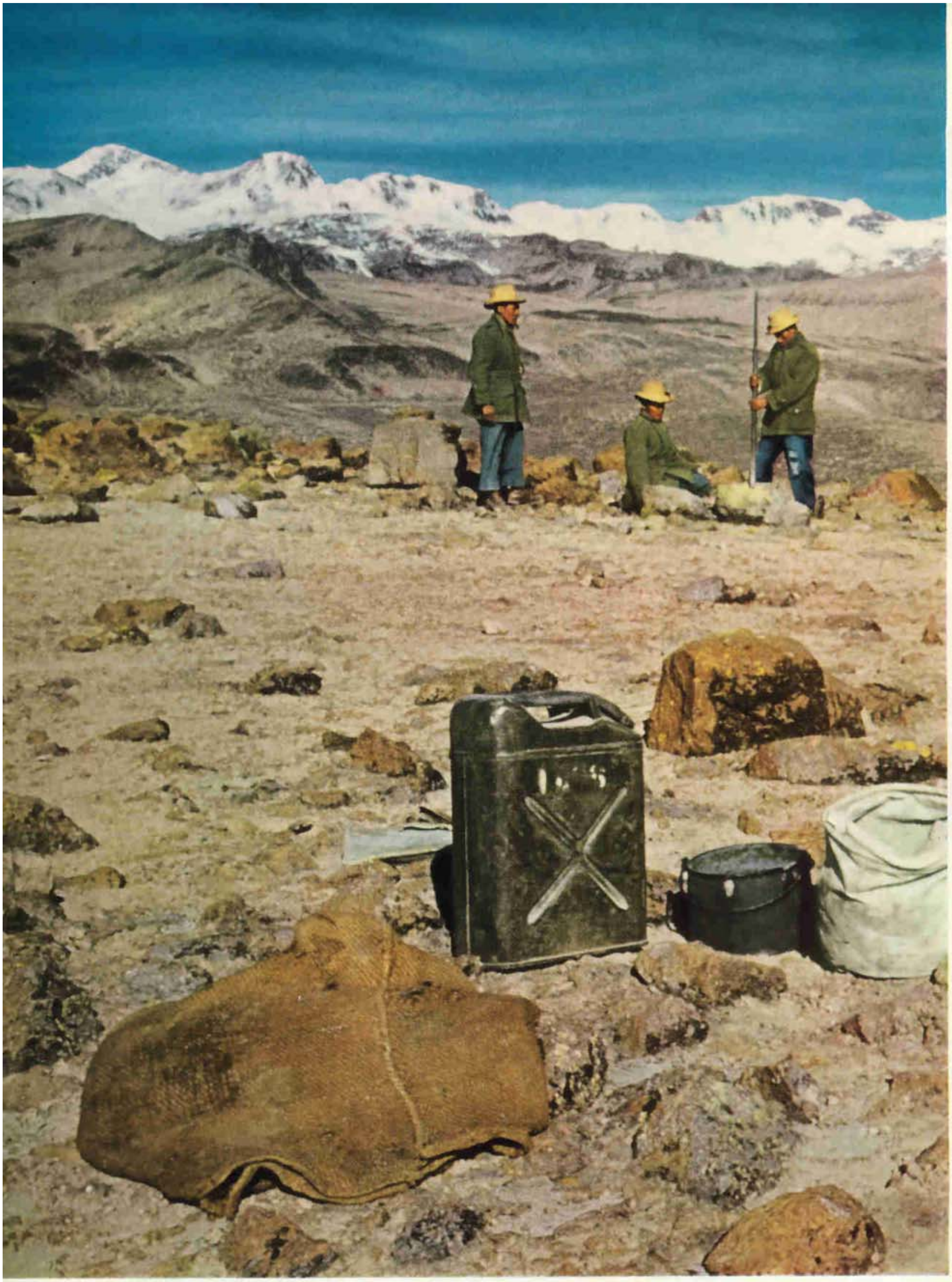
This level party works near Puno, Peru. An umbrella shields the telescope from direct sunlight lest heat affect the delicate leveling mechanism.

Titicaca, at 12,506 feet, is the highest body of water of its size in the world.

Page 352, lower: Farmers' wives line up near Ticaco, in southern Peru, to apply for irrigation water. Spoonlike silver pins secure their shawls.

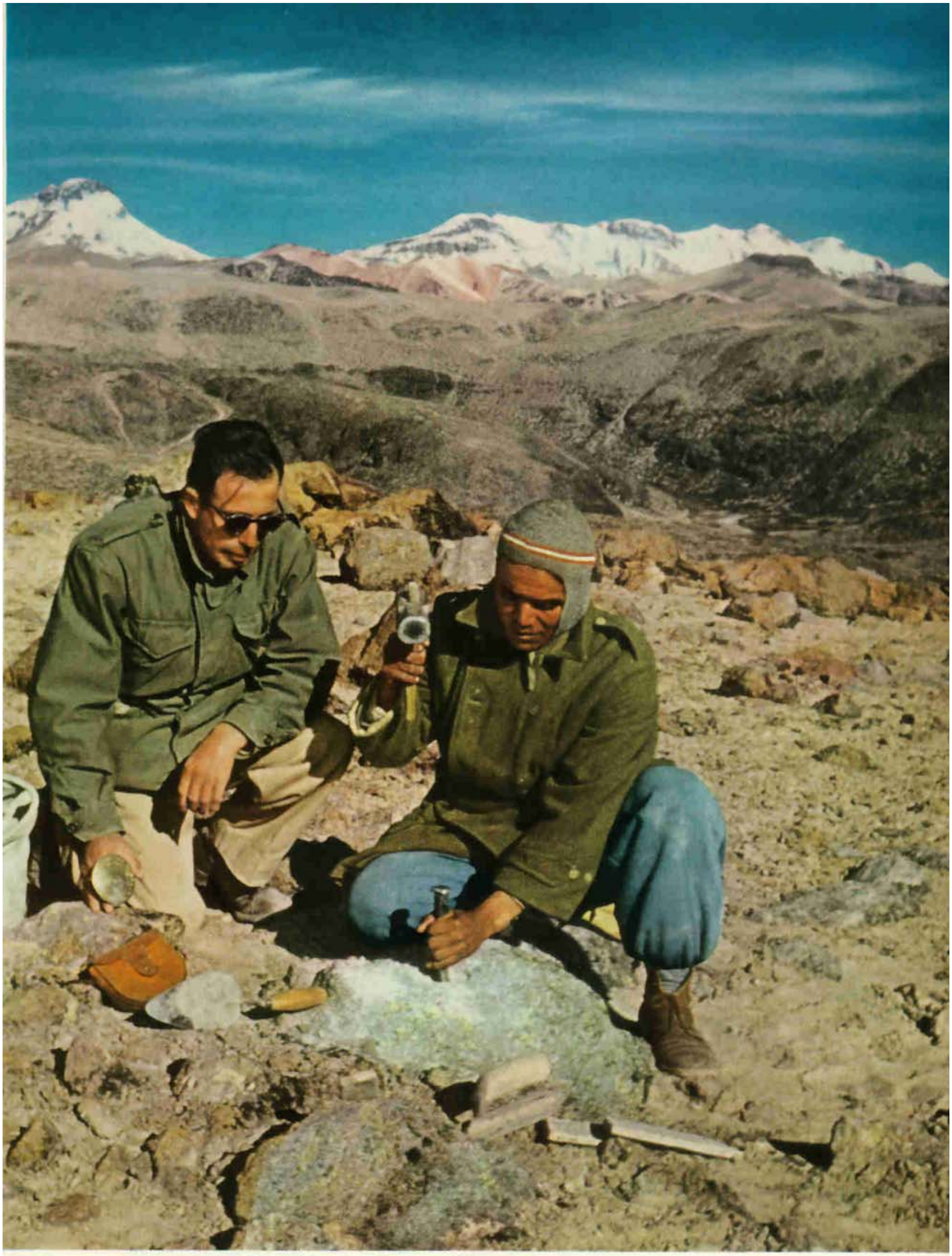
↓ "You Look Through Here . . ."

When the leveling group was working in Puno's Pino Park, crowds gathered to ask what was going on. Sgt. Bonifacio Rodriguez, of Peru's Instituto Geográfico Militar, endeavored to explain the operation of a Wild N-III precision level. His audience seemed more impressed by the sergeant than by the telescope.



A Crew in the High Andes Works in a Landscape as Bleak as the Moon's

Engineers call their bronze, concrete-set disks "monuments." Three disks locate this control point: the triangulation station itself (right) and two reference markers 50 feet or so away. Arrows stamped on the reference markers point to the main station to help future surveyors find it in case drifting sands hide it.



A Hole Drilled in Stone Is Prepared for the Surveyors' Bronze Marker

Crews carry cement, water, sand, and stonemason's tools as they work through the mountains a few days ahead of the triangulation party. César Díaz, a Peruvian engineer, holds the disk. Once its position has been pinpointed, it will serve as a reference to map makers, road builders, and prospectors for decades to come.


2

↓Tower Lifts Men and Rotating Light over Trees

For surveying in level woodlands, helicopters fly in parts for light steel towers. A separate inner tower extending up through the surveyor's platform holds the theodolite steady.

↑ Yards of Red Cloth Protect Measuring Tape from Winds

Starting point and final check for all triangulation is the base line. If it is wrong, months of work may have to be repeated. Engineers therefore measure base lines, usually several miles long, with excruciating care. A 50-meter tape, checked by the U. S. Bureau of Standards, is pulled to a constant tension by a stretching device at one end (lower left). Windbreak helps maintain accuracy.

These engineers begin a 7-mile measurement near Ciudad Bolivar, Venezuela. Their line will be measured twice, once from each end. The two measurements must agree within one part in 300,000.

Page 356, left: When the spring balance shows 15 kilograms (about 33 pounds) of tension, a crew member marks the starting point of a section on a strip of metal tacked to a post, one of a set of markers placed at intervals along the line.

←A technician sets up a Worden gravity meter near the Venezuelan datum point (page 348). An $8,000 instrument, it can detect variations in gravity equivalent to the adding of 1/10,000,000 gram to a one-gram weight. The machine is so delicate that if knocked over it must be sent to the manufacturer in Texas for repair. Coming back, it must be carried by hand.

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Kodachrome by Staff Photographer Willard R. Culver

Using Red and Blue Lights, a Kelsh Plotter Projects Aerial Photos in Three Dimensions

Cartographers, in a final stage of map making, trace topography from photographs to map sheets. Here two projectors throw images from overlapping pictures onto the drawing table. Colored lights and matching lenses in spectacles create the illusion of depth, enabling the operator to plot contours.

We found Phillips at a bend in the Pastaza, camping in a wood-and-grass hut with six representatives of Peru's *Instituto Geográfico Militar*. After we had introduced ourselves, I gave him some mail I had picked up for him at headquarters in Lima.

"Thanks," he said. "This is the first mail I've had in a month. But come and eat some lunch. We were just ready to start."

He led the way to the hut. As we entered, I saw a table against one wall piled with figure-covered papers.

"Computations for our latest set of observations," Phillips explained. "It takes four or five days of paper work to determine each position after we're through observing."

As we ate lunch—rice and chicken with gravy—Phillips gave me a quick outline of the project and how he operates.

Work begins after sunset on clear nights. A shortwave radio picks up a time signal from the U. S. Bureau of Standards in Washington, D. C., 3,500 miles away. Its steady ticking of seconds is a weird sound in the jungle night. Phillips, having consulted a bulky astronomical manual, aims the blunt nose of his 80-power astrolabe at the path of a known star. He waits, as the clock ticks, until the star appears in his lens. Then he records the exact second it crosses the center of the lens, marked by cross hairs.

On a single night Phillips may "shoot" as many as 96 stars. From these data—the known path of each star, the time it crossed his lens, the direction his astrolabe was pointing—he can compute his position.

Hundreds of such positions at river bends and junctions and settlements will form the network of control on which a map of Amazonia will someday be based.

Tide Gauges Measure Sea Level

If you should walk around the coast of South America, you would find, every few hundred miles along the beach, a shack with an odd-looking machine clicking away inside. If you waited a day or two, you would notice a man enter, jot down some figures, wind the springs that run the instrument, and leave.

This is a tide gauge, a device which records on tape the daily rise and fall of the sea. Data from 80 such tide gauges are collected at IAGS headquarters to determine the mean sea level along both coasts.

Before a country can be mapped, hundreds or thousands of points in it must be measured for height above sea level, or, as the engineers say, vertical control must be established. This is not only because the map itself is expected to list elevations of mountains, cities, and passes. Aerial photography, on which modern cartographers depend heavily, can't be used for mapping unless there are at least three points in each photograph whose elevations are known.

This is because an airplane, flying over bumpy air currents, wobbles and tilts the camera. Aerial pictures are always distorted. Cartographers need three known elevations to compensate for the tilt in copying from photograph to map (opposite).

Working inland from the tide gauges, "level parties" move on foot, measuring land elevations as they go (page 353). They do it by the rather simple method of standing two rulerlike rods on end 100 yards or so apart, and observing how much higher the front rod is than the rear one. Having done this, and recorded the difference, they move the rear rod around to the front and do it again—and again and again—covering several miles a day.

Snapshots at 36,000 Feet

In the old days—up until a few decades ago—after horizontal and vertical controls were established, map makers took to field and hillside and sketched in landscape, relating key features to the control points. Nowadays the airplane speeds things up.

In Arequipa, Peru, a white and sunlit city with a bracing mountain climate, I met an aerial photographic team of six: two men, three cameras, and a P-38. They were working for Hycon Aerial Surveys, a United States firm with headquarters in Pasadena, California. Under contract with the U. S. Army Map Service, Hycon is collaborating with IAGS to photograph parts of Peru, Chile, Colombia, Bolivia, and Ecuador.

The human members of the team were pilot Sam Smith, from Minneapolis, reserve major in the U. S. Marine Corps, and Gilbert Mendoza, of Los Angeles, the photographer-navigator. Their P-38, a type used as a fighter and reconnaissance plane during World War II, is rated at 400 miles per hour (page 360). In its belly are set three aerial cameras, one pointing straight down, the other two oblique left and right. Their job is to fly back and forth across the area to be mapped, following parallel lines about five miles apart, snapping pictures every 15 or 20 seconds.

"What's your biggest problem on the job?" I asked the team.

"Clouds," said Smith.

"Cold," said Mendoza.

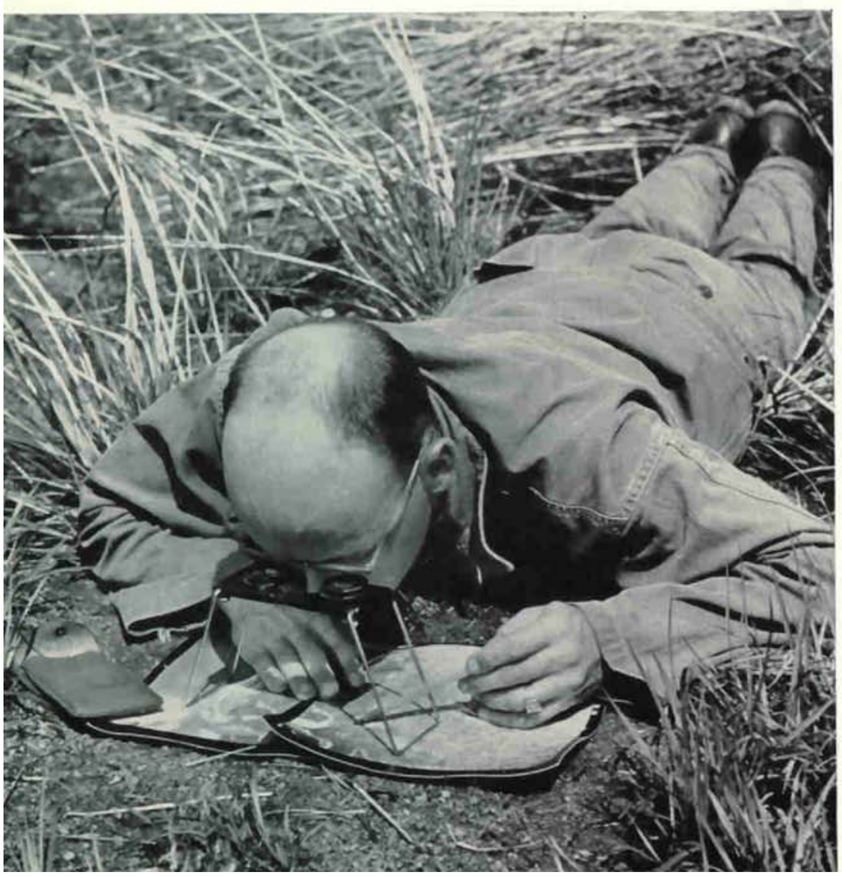
It all depends on where you sit. At 36,000 feet, outside temperatures fall to 50 or 60 degrees below zero Fahrenheit. The plane's heaters can't keep up with prolonged temperatures that low. Smith, in the pilot's plastic bubble, basks in sunlight and stays warm; Mendoza lies below and shivers.

As for clouds: "If there's even a little puff below you," Smith said, "and it shows in the photograph, they'll reject it. When it's really cloudy we can't work at all.

"And, of course," he added as an afterthought, "when we don't work we don't get paid."

How to Tell a Ball Park from an Airport

After the pictures are developed they are shipped back to the field for "picture-point control." The 3½-inch disks which mark basic controls are, of course, invisible in a photograph taken at 36,000 feet. So other survey teams must now extend this control, by more triangulation and leveling, to locate objects that show in the pictures: houses, road junctions, fence corners, even large trees. These are picture points (page 340). When the surveyors have fixed the latitude, longi-



Aerial Photographers Plot a Day's Work for Their P-38

Based in Arequipa, Peru, pilot Sam Smith (opposite page, left) and photo-navigator Gilbert Mendoza were assigned to photograph southern Peru and parts of Bolivia and Chile from 36,000 feet.

In flight, Smith follows parallel east-west lines drawn on a map at intervals of some five miles. Mendoza sets his cameras so that the area shown in each photograph overlaps that in the last one by 56 percent.

Film magazine on table holds enough to cover about 600 linear miles—roughly three hours' work from takeoff to landing.

←Using a pocket stereoscope, IAGS surveyor Scott MacCalden places two overlapping aerial photographs together to get a three-dimensional view of an area he is mapping.

tude, and elevation of a picture point, they prick a pinhole in the photograph and write the data on the back.

Survey teams also identify topography which may not be clear in the photograph. A line across a field, for example, might be a road or a canal; a clearing may be a ball park or an airport. All must be shown with proper symbols on the final map.

IAGS, as its name makes clear, is not a map-producing agency but a geodetic survey. It transmits its volumes of data, horizontal, vertical, and astronomical, along with thousands of photographs, to the Army Map Service in Washington, D. C. Here the raw material will be turned into finished maps. The same data, of course, also go to the mapping agencies in the cooperating countries.

Finding the Earth's True Shape

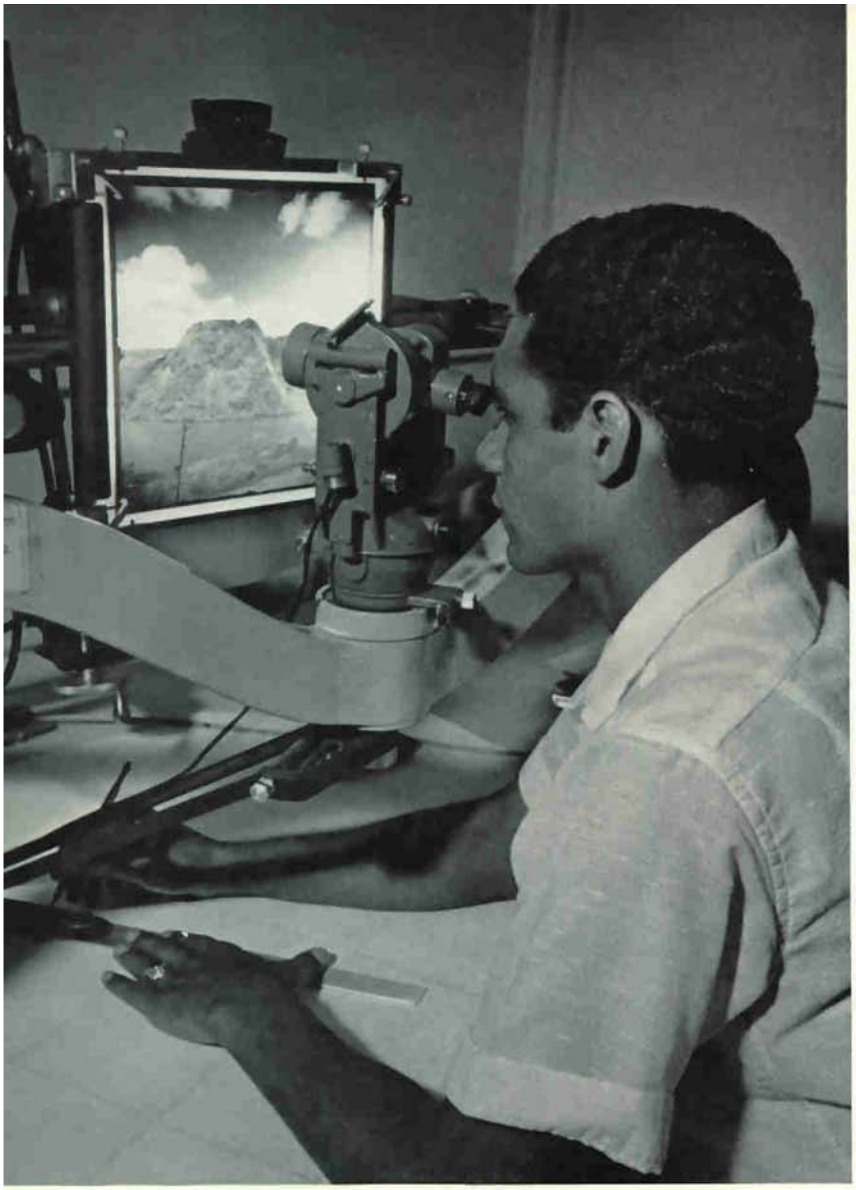
In conjunction with other surveys the IAGS triangulation has created along the west coastline of North, Central, and South America the longest measured line in the world. It will run from Point Barrow, northernmost tip of Alaska, to the southern end of Chile, a distance of more than 11,000 miles.

This long arc of triangulation will eventually lock the maps of North and South America into a unified whole. But it will also serve another purpose: It will provide scientists with valuable new data for determining the shape of the earth.

Approximately every 150 miles along this line, geodesists have set up astronomical observation points called Laplace stations (after Pierre Simon Laplace, a French mathematician). They set their instruments, normally, atop triangulation stations whose positions are already established.

At each Laplace station, latitude and longitude are redetermined by astronomy, using instruments far more precise than Dave Phillips's jungle astrolabe. After they have been checked and rechecked, the resulting figures are compared with those found earlier by triangulation.

The two sets of figures never agree. The astronomical position always comes out farther north or south, farther east or west, some-



An IAGS Student Practices Surveying on a Photograph

To help Latin Americans make accurate maps of their own countries, IAGS maintains a cartographic school in the Panama Canal Zone. Here in the last three years 227 students from 17 countries have learned subjects like geodetic surveying, astronomy, photogrammetry, drafting, and map reproduction.

Apprentice cartographers practice on all sorts of instruments. Student Angel Luján of Peru uses a Wilson photoalidade to measure angles between points in the photograph exactly as if he were on the spot where the camera stood.

times by thousands of feet. This apparent error is not the fault of the engineer or his instruments, but of the earth itself. Before he looks at the stars, the surveyor carefully levels his instrument so that he will know at just what angle it is pointing into the sky. His leveling, of course, is always done in reference to the ground beneath his feet and to the pull of gravity.

Any irregularity in the earth's surface at or near his Laplace station makes itself known as what scientists call a "gravity anomaly," which means simply that the direction of gravity's pull at that spot is deflected from the vertical. This, of course, spoils the surveyor's aim with his telescope and causes an error in his calculations when he determines his latitude and longitude.

The amount and direction of this error are what the geodesists need to know in order to figure out the shape of the earth. Working backward, they can calculate just what kind of a kink or bulge in the geoid must have caused it. And using data from hundreds of Laplace stations in a line stretching nearly from pole to pole, they will end up with an accurate picture of the earth's over-all curvature.

"An important thing to remember about the IAGS," Colonel Robertson told me, after I had seen its work going on in five countries, "is that we are not mapping Latin America. We're helping the Latin Americans to do it themselves. It's their program. We offer suggestions, we lend equipment and give technical advice. The rest is up to them.

"You get our engineers working with Chilean or Colombian or Guatemalan or any other Latin American engineers and they become friends. They stick together on a project for months or years and really get to know each other. Our men learn Spanish, the others learn English. They get to like each other and, even more important, they come to respect each other.

"Imagine this going on in 17 countries, on half a dozen or more projects in each country, year after year. You can see what a terrific thing it is for furthering inter-American relations."