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SATELLITE AND AIRBORNE REMOTE SENSING ANALYSIS FOR THE DETECTION OF ANCIENT FOOTPATHS IN COSTA RICA

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RESUMEN

En la región de Arenal, en el norte de Costa Rica, se utilizó datos de sensores remotos aéreos y satelitales para detectar una red de senderos prehistóricos. Usando datos de varias fuentes, desde fotografía en blanco y negro a imágenes satelitales de alta resolución y técnicas de procesamiento de imágenes, se aislaron rasgos lineales que se verificaron por medio de investigaciones de campo y excavaciones. A partir del fechamiento de capas volcánicas de tefra asociadas a los senderos, hemos descubierto que estos existieron durante las fases Arenal (500 a.C. a 600 d.C.) y Silencio (600 a 1300 d.C.). Esta información proporciona una nueva visión de como los habitantes antiguos se movilizaron y comunicaron sobre el paisaje prehistórico. Aunque estos senderos se preservaron por más de dos milenios, hoy están amenazados por los acelerados cambios en la cobertura y uso de la tierra. Con los sensores remotos hemos mapeado estos rasgos antes de que sean destruidos.

ABSTRACT

Satellite and airborne remotely sensed data were used to detect an ancient prehistoric footpath network in the Arenal region of northern Costa Rica. Using various data sources ranging from black-and-white photography to high-resolution satellite imagery, image processing techniques were used to isolate linear features that were verified through field survey and excavation as being ancient footpaths. By dating the volcanic tephra layers associated with the footpaths we have discovered that they existed during two phases: the Arenal phase (500 BC to AD 600) and the Silencio phase (AD 600 to 1300). This information is providing new insight into how the ancient inhabitants moved and communicated upon their prehistoric landscape. Although these footpaths were preserved for over two millennia they are threatened today by accelerating landcover and land use changes. Through the use of remote sensing we are mapping these features before they are destroyed.

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Archeological landscapes around the world are being destroyed at an alarming rate to a complex of land cover/land use changes including deforestation, urban expan-, and agricultural development. By analyzing high-resolution satellite imagery and al photography, we have mapped an ancient footpath network in Costa Rica on a dscape that is undergoing rapid land cover/land use changes. This ancient footpath work is providing insight into the economic, social, political, and ritual functions of ancient inhabitants. Through the use of remote sensing, we have located the nains of ancient footpaths, and through the use of historic satellite imagery and ae- photography, we have located the position of footpath segments that have been stroyed.

The ancient footpaths that we have discovered in the Tilaran-Arenal area once med with human activity as the inhabitants moved across their environment. ough the people themselves are gone, they have left us the traces of their activities at are embedded upon the contemporary landscape. From the legacy of their ancient th network we can rediscover their social integration and how they interacted with eir local and regional environment, including surrounding settlements. Footpaths cord past means of transportation, communication, exchange, and corridors for ri-al activity. They establish the relationships between both cultural and natural fea-ires. By mapping a culture's movements in space and time, we can better understand e daily movements of its people as well as its evolutionary development.

Our footpath study fits into the context of Landscape archeology. Landscape arche-logy is a branch of modern ecology that deals with the relationships between human eings and their open and built-up landscapes. Satellite imagery can provide an nformative backdrop for archeological landscape studies, particularly those where the rcheological landscape information is poorly understood or difficult to acquire. The erial vantage point lays out archeological sites and their setting and leads to the rea-ization that everything observable in an ancient landscape has meaning and intercon-nection. The attention of archeologists can be directed to features, such as ancient ootpaths, which were previously unnoticed on the ground but whose significance could be appreciated when viewed from above. Through the use of remote sensing, Global Positioning System (GPS) and Geographic Information System (GIS) technology, the landscapes of current and past cultures can be better understood and virtually re-presented.

BACKGROUND

Based upon the positive results of a conference in 1983 (Sever & Wiseman), the National Aeronautics and Space Administration (NASA) and the National Science Foundation joined forces to investigate the utility of remote sensing for archeological investigations. The project that was selected to illustrate this new area of research was under the direction of Payson Sheets, University of Colorado, who was investigating the effects of volcanic eruptions upon simple, egalitarian societies in northwestern Costa Rica (Sheets & McKee, 1994). As a result, NASA sent its remote sensing research air-craft to Costa Rica on three occasions in the mid-1980's to obtain high resolution remote sensing imagery. The overflights provided diverse data sets consisting of color photography, color-infrared photography, thermal infrared multispectral scanner (TIMS) imagery, light detecting and ranging (LIDAR) data, and L-band, four polarization radar data. The data were acquired over a 2-by-4 kilometer study area. These data sets considerably enhanced the 9-by-9 inch black and white aerial photos which Sheets had purchased from the local Instituto Geografico.

An unexpected outcome of the data analysis was the detection of linear features in the color-infrared photography (Fig. 1) and to a lesser degree the digital TIMS imagery.

These features turned out to be ancient footpaths that connected villages and cemeter-ies and were verified through ground survey and subsequent excavation. The excavat-ed trenches and profiles revealed that the ancient inhabitants followed the same pre-cise route in/out of the cemetery, forming a small shallow depression that eventually eroded into a long, broad trench. Researchers believe that the repetitive use was based on a religious belief that entering and exiting the cemetery represented a formalized, symbolic, ritual act.

This human-induced activity resulted in an eroded path that was buried a meter to a few meters (depending on degree of slope) below the original ground surface. The date of the footpath's use could be dated from the volcanic ash layers of the Arenal volcano, which had erupted at least ten times in the past 4,000 years. Even when the path was buried by subsequent ash layers, it was still visible on the ground as a more faint li-

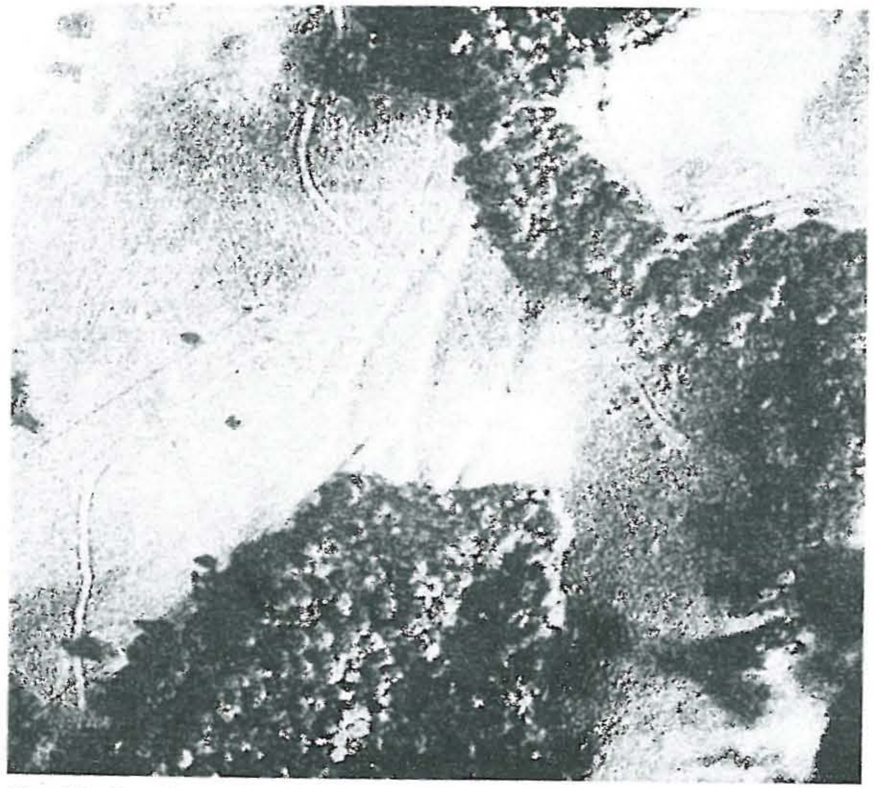

Fig. 1 *In this 1985 color-infrared air photo from a low-level NASA aircraft overflight, ancient footpaths are visible as indented lines, connecting the cemetery under the rain-forest (top of photo) and running under the pasture (center of photo) toward a spring (bot-tom of photo).*

near depression. On flat areas of little slope, the linear depression was no longer visible on the present surface. Nevertheless, the footpath showed up on the imagery due to the fact that the plant-root matrix in the ancient path was sufficiently different from the plant-root matrix on both sides of the buried path (Fig. 2).

The results of this initial investigation indicated that footpaths could be used as a window into a culture's religious, economic, political, and social organization (Sheets & Sever, 1991: 53-65). The research revealed the potential that remote sensing holds for the study of human cultures. It verified that remote sensing would radically alter archeological survey by detecting features that would normally not be seen with conventional methodologies. In addition, the research demonstrated that projects of broader regional and theoretical scope were now possible.

After tracing the footpaths to the eastern and western boundaries of the remotely sensed area in the 1980's, two decades passed before inexpensive, high-resolution satellite imagery became available to continue the study and determine where the footpaths were leading. Although the aircraft data was successfully used in the 1980's, the fact remained that aircraft data is expensive both in the data acquisition and data processing. Because the tropical forest area of Costa Rica is generally cloudy, the NASA aircraft often sat idly in San Jose awaiting clear weather, adding to the cost and delaying the mission. Georeferencing the data was also a time-consuming, expensive process, especially given the fact that GPS technology was not available at the time. In this era before laptop computers, there was no capability to do computer analysis in the field. The data was subsequently analyzed at a NASA computer laboratory and then selected images were printed and taken to the field. Determining the location of the footpaths on the ground was not done by GPS coordinates but by their relationship with other features in the data such as fence lines, streams, hilltops, roads, and tree clusters.

As a result of the dynamic development in satellite, GPS, and computer technology and software over the years, a new investigation of the footpaths began in 2002 that extended beyond the initial 2-by-4 kilometer study area of the 1980's.

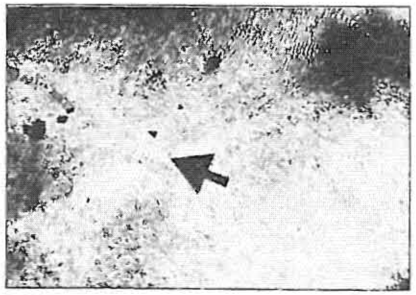

***Fig. 2** Color-infrared photo (left) with arrow pointing to the convergence of two ancient footpaths. Ground photo (right) of same location in the field, demonstrating the value of remotely sensed imagery for detection of subtle features.*

NEW DATA SETS

New data sets of IKONOS high-resolution satellite imagery and airborne MASTER data were used in the 2002 investigation. In addition, historic black and white photography and color-infrared photography were digitized and with computer analysis were once again useful in finding linear segments.

In September, 1999, IKONOS, a commercial satellite, was launched by the Space Imaging Corporation. IKONOS imagery is a significant improvement over previous satellite data used for archeological research. IKONOS provides 1 m resolution panchromatic imagery and four multispectral bands (visible and near infrared) at 4 m resolution. The satellite has a polar, circular, sun-synchronous 681Km orbit, and both sensors have an at-nadir swath width of 11 Km. Four adjacent IKONOS scenes, approximately 484 Km^2, were collected and analyzed. Features not apparent in other remotely sensed data sets (*e.g.*, Landsat TM imagery) of the area are easily visible in the IKONOS data.

For each IKONOS scene, the high-resolution panchromatic band was merged with the multispectral bands. Pan-sharpening algorithms "fuse" the high-resolution panchromatic and low-resolution multispectral imagery together to create a high-resolution color image. The resultant image preserves the original color fidelity and provides for better visualization and interpretation. Both Brovey and Principal Component transformations were used in the pan-sharpening process (ERDAS, 1999: 161-162).

Seven flight lines of MODIS/ASTER Airborne Simulator (MASTER) data were acquired in the Arenal region on March 21, 2003. The MASTER instrument has 50 channels of data extending from the visible to the thermal infrared. The instrument supports a variety of scan speeds allowing it to acquire contiguous imagery from a variety of altitudes with differing pixel sizes. Data were acquired at an altitude of 6000 ft resulting in a 5 meter spatial resolution.

Both historic black and white and color-infrared photography were digitized in order to put the information into a format that was conducive for digital analysis. Digitizing is a process of encoding geographic features in digital form as x, y coordinates. It is carried out in order to create spatial data from existing hardcopy maps and documents. In this format, information is organized into discrete units of binary data so that it can be processed and analyzed on computers. Digitizing information also makes it easier to preserve, access, and share. There is a growing trend towards digitization of histori-cally and culturally significant data in order that the information may be preserved. 1961 US Air Force black and white digitized was particularly valuable for our project since it was acquired before the 1973 earthquake that dislodged huge landslides and destroyed ancient footpaths in the eastern portion of our study area.

IMAGE ANALYSIS SOFTWARE

ERDAS Imagine (1999), RemoteView (2003), and Skyline Terra Explorer (2003) software packages were used for data analysis and visualization. These software packa-ges were loaded onto laptop computers and taken to the field. This allowed the researchers to review imagery in order to resolve questions that had occurred that day as well as determine the areas to be surveyed the next day. Linear anomalies would be marked on large-scale, laminated prints to identify pastures, streams, individual trees, fence lines and other features in order to locate the precise position of the detected anomaly. This information was supported by recording GPS positions in the imagery and navigating to those points with in-field GPS measurements (see article 3, M. Butler).

ERDAS Imagine is the industry standard for processing remotely sensed data and offers a vector module that seamlessly reads, integrates, and processes ArcInfo vector files. ERDAS Imagine also includes a powerful graphical modeling capability to develop customized models and streamline routine tasks. RemoteView (version 2.24) is the premier software application for the display, processing, and analysis of commercial (IKONOS and QUICKBIRD) remote sensing data. Designed for the most demanding image handling requirements, Remote View provides the analyst with high-speed image processing tools for time dominant tasks while meeting the most stringent image quality and control requirements. A graphical toolbar provides intuitive controls for all common imaging-processing functions. The Skyline Terra Explorer software platform enables users to see and understand 3D Geospatial data easier and faster. It allows the individual PC user to experience interactive terrain viewing by displaying highly realistic scenes from any angle or point of view and allows extremely close views of an area with excellent clarity. In addition, all the terrain information such as text, labels, graphics, photos, GPS locations, and trench profiles can be stored in the database and viewed.

RESULTS

The one-meter pan-sharpened IKONOS was particularly useful for this investigation. The data revealed numerous linear anomalies which were subsequently proven to be ancient footpaths by excavation and examination of the stratigraphy (Fig. 3). Various band combinations, contrast enhancements, sharpening, and principal component analyses were applied to the data to extract these linear and curvilinear patterns. Since the data were georeferenced, features in the imagery could be located within a two-meter accuracy on the ground.

The IKONOS imagery helped to resolve a major research objective for the summer 2002 field season which was to determine the source of volcanic stone slabs (laja) which were used to construct burial tombs in a cemetery at the beginning of the Silencio Phase (AD 600-1300). As the research team followed the western path from the cemetery located on top of the Continental Divide toward the town of Tilaran, it encountered a relatively flat, less eroded area where there was no evidence of the footpath. Land use changes from sugarcane cultivation between 1880 and 1950 and recent construction near Tilaran had modified the surface and obscured the ancient footpath. A number of linear features in the imagery turned out to be erosional drainages resulting from land use changes, historic fence lines, and a turn-of-the-century wagon road. Although several linear anomalies were investigated, the ancient path itself could not be located.

To resolve this issue we extended a vector in the IKONOS data from where the path was last confirmed and in the same direction that the path had been going. Reviewing the imagery, Sheets noted that the path was heading in the direction of four natural laja sources. With the help of Costa Rican geologist Jorge Barquero (see article 12), the research team was able to determine that the laja material was coming from the Tovar source. As a result, this confirmed that the purpose of the western path was to provide laja material for the cemetery and is supported by the fact that laja storage areas are located along the path. Although it was originally hypothesized that the path might also lead to a village on the western side, no such evidence was found. Future research will attempt to follow the path farther to the West.

The digitized photography was also very helpful in detecting footpath locations. The 1961 black and white photography was especially useful in areas that had undergone recent land cover/land use changes, and, as previously noted, in the eastern area where there were major landslides from the 1973 earthquake. The color-infrared pho-

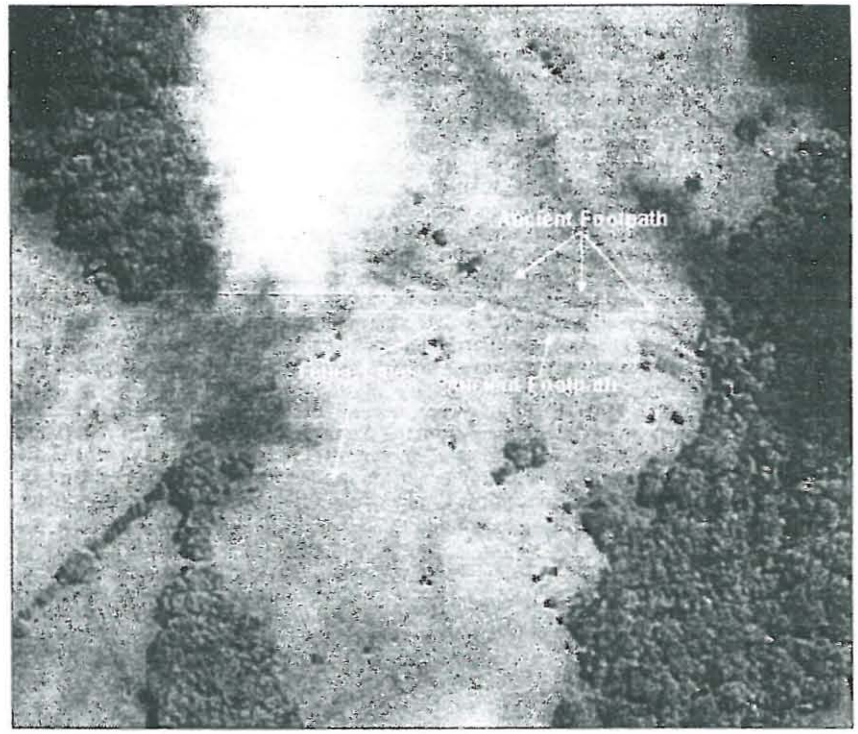

Fig. 3 *Pan-sharpened, true color IKONOS image delineating the ancient footpaths from other linear features such as modern-day fence lines.*

tography from the 1985 NASA overflights was re-examined and "spurs" were found leading away from the footpath. One of these spurs turned out to be an historic road but the other was contemporaneous with the ancient footpath.

From a combination of IKONOS and digitized photography, several linear features have been detected leading from the Silencio cemetery toward the east. While conducting foot survey in search of the 1,200 year-old footpath, the research team discovered the remnants of a footpath that was in use approximately 2000 years ago (Arenal Phase). The discovery pointed the team in the direction of a 2-by-2 kilometer area in which was found at least 12 cemeteries dating to the time of the older footpath. From image analysis and ground survey it appears that the older path is connecting one or more of the cemeteries to a village on the south shore of Lake Arenal on the eastern side of the Continental Divide. Because of the extensive landslide scars from the 1973 earthquake much of the footpath network in this area has been destroyed. However, this area will be investigated in 2004 using a combination of pre-earthquake photography from 1961, IKONOS imagery, and computer-implemented "corridor analysis" modeling techniques.

The Skyline software allowed the research team to analyze the data in a virtual mode (Fig. 4). All four adjacent IKONOS scenes were mosaicked and merged with topographic information. The locations of known footpath segments, cemetery areas, and excavated trenches were labeled and overlayed onto the data. Like flying over the area in a helicopter, the investigator can fly above the area with complete control over altitude, direction, and speed, and land at any spot on the ground with a 360 degree view of the horizon. The Skyline software provided us with many analysis tools including the ability to determine what parts of the landscape can be seen from any location (viewshed analysis), and to measure both the true and linear distance between features. Through these virtual methods, we were able to get a better understanding of the relationships between the cultural and natural features upon the landscape. The software was also useful for allowing us to become familiar with an area before beginning our ground survey. In addition, ground photos, maps, profiles, text and other scientific information can be stored in separate folders for any geographic location. For instance, if one clicks upon the position of an excavated trench, all the associated information relevant to that trench can be viewed on the screen. As a result, all of the information associated with the footpath study can be stored, preserved, and shared with others.

Unfortunately, the MASTER data were not successful for footpath detection. Although the imagery is excellent for producing clear, crisp images of the vegetation, hydrology, and human-made features, the 5 meter resolution was not as useful as the one-meter IKONOS imagery for detecting linear anomalies. It had been hoped that the large array of thermal bands, even at the 5 meter resolution, would successfully detect

Fig. 4. *IKONOS image draped over a digital elevation model showing the footpath's relationship to surrounding topography using the Skyline Terra Explorer software.*

thermal inertia variations between the footpaths and the adjacent surfaces. However, the data were collected near solar noon and it appears that the footpaths had reached thermal equilibrium with the surrounding landscape. Previous research (Sever, 1990) had indicated that in tropical forest environments the optimum time for thermal data acquisition would be within an hour of sunrise. Our study area was a small subset of the NASA MASTER mission that collected data throughout much of Costa Rica. As a result of the dynamics and logistics of acquiring aerial data over a large region, the final flight agenda prevented the data from being acquired at the optimal morning time period for our study area.

One important product of the imagery was the goodwill that it generated with the landowners and others living in the area. People were excited to see their houses, barns, and even their animals both in town and in the rural areas. In addition to showing this information on our laptop computers, we provided the landowners high-quality satellite images of their farms and ranches. They were very appreciative of these images and consequently more eager to permit us to conduct survey and excavation on their land. One hotel owner in Tilaran mounted one of the images of Tilaran in his lobby so that he could direct his customers to the restaurants and other businesses in town.

CONCLUSIONS

Footpath networks can provide an understanding of how ancient societies interacted with their environment. Just as prehistoric populations have left a permanent record in the stratigraphy of their villages and cemeteries, they have also left a record of how they negotiated across their landscape. Through the use of remote sensing we have been able to map a footpath network that can only be appreciated from a distance. Both current and historic satellite and aerial imagery have allowed us to detect features that are not apparent through traditional techniques and to test hypotheses of larger, regional scope.

The discovery and interpretation of the footpath network in the Arenal area have been facilitated by ten separate volcanic ash layers. This has aided in the preservation of the footpaths and provided an excellent record for dating the footpaths. These footpaths have survived for two millennia but are threatened today by accelerating landcover and land use changes. Future research using remote sensing and GIS technology will help us to locate these features before they are destroyed. It will also help us to determine how simple footpaths evolved into more formalized structures and complex networks such as paved roads, and the role of transportation and communication in cultural evolution.

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GLOBAL POSITIONING SYSTEM, REMOTE SENSING, GEOGRAPHIC INFORMATION SYSTEMS, AND PREHISTORIC FOOTPATHS

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RESUMEN

El Proyecto Prehistórico Arenal emplea varios tipos de datos geográficamente referenciados y los integra a un Sistema de Información Geográfica (GIS) como parte de la investigación de veredas antiguas. Entender el proceso de formación y preservación de dichas veredas ayuda a su detección en imágenes generadas por sensores remotos (Sheets & Sever, 1991). La integración de la información de campo y las imágenes en el GIS brinda, a su vez, la posibilidad de analizar y visualizar el movimiento de personas a través del paisaje antiguo. Dicha integración posibilita, además, relacionar imágenes satelitales con rasgos lineales y puntuales, y ubicarlos con la ayuda del Sistema de Posicionamiento Global (GPS). Este artículo trata sobre el uso de esos componentes tecnológicos para el mapeo y análisis espacial de configuraciones arqueológicas dentro del Proyecto Prehistórico Arenal.

ABSTRACT

The Proyecto Prehistorico Arenal is employing several types of geographically referenced data and integrating the data into a Geographic Information System (GIS) as part of its research in ancient eroded footpaths. Understanding the processes of formation and preservation of eroded footpaths enable us to detect them on remotely sensed imagery (Sheets & Sever, 1991). The integration of the field data and remotely sensed imagery into a GIS allows us to both analyze and visualize the movement of ancient peoples across an ancient landscape. The Global Positioning System, the remotely sensed data and GIS technology all allow us to overlay satellite imagery with linear and point features. All of these components are necessary for the mapping and spatial analysis of ancient footpaths, sites and other landmark features. This article discusses the different aspect of the Global Positioning System and the integration of GPS, remote sensing, and GIS as it pertains the Proyecto Prehistorico Arenal.

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