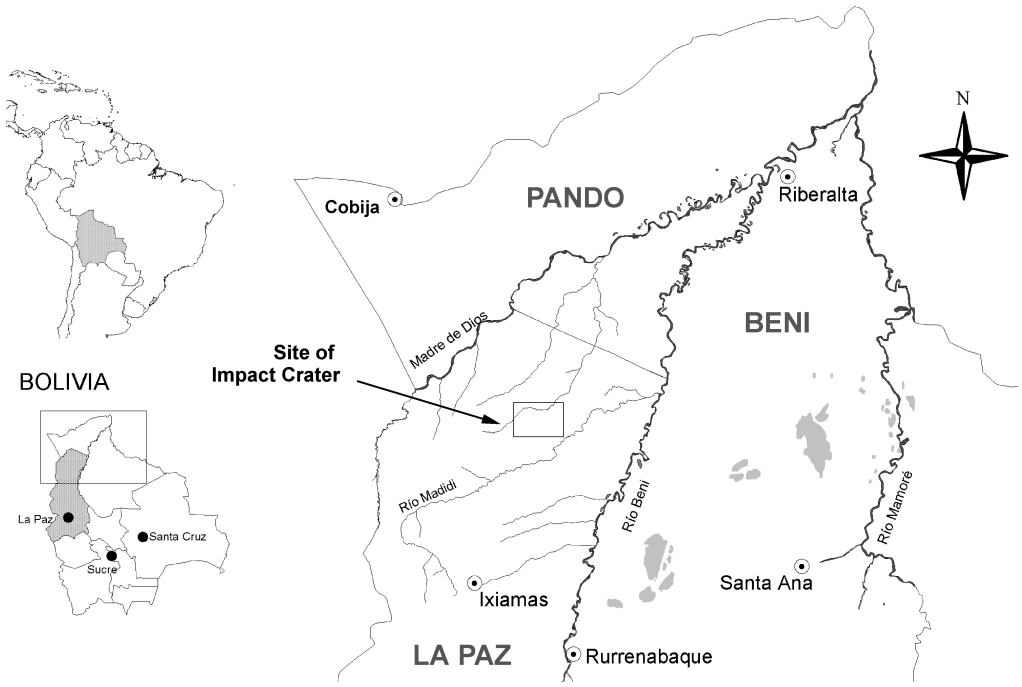
Scientists visit meteorite impact crater in the wilds of Bolivia

By T. J. Killeen

In perhaps the remotest and wildest part of the Bolivian lowlands, in an area hundreds of kilometers from the closest town, NASA scientists have identified what they believe to be the youngest complex meteorite impact crater on earth. Based on what is known about the geology of the region, they believe the meteorite slammed into the Earth sometime between 5,000 and 20,000 years ago, making it the youngest “large” impact crater on Earth. The crater is approximately 8 km across and was produced by the collision of a meteorite about 200 m in diameter. The impact released energy of approximately 500 to 1000 megatons of TNT; in comparison, a hydrogen bomb is equivalent to only one megaton, while the atomic bomb that exploded over Hiroshima, Japan released only 20 kilotons. The crater was originally identified in the mid-1980s with satellite imagery, but a previous attempt to visit the site in 1987 was unsuccessful due to the remoteness of the locality.



Figures 1. A map showing the position of the Araona Impact Crater.

The goal of the second expedition was to verify the existence of the crater (scientists are 95% confident that it is) and to gather data from the site on the nature of the meteorite that caused it. The expedition was organized by Tim

Killeen, formerly with the Missouri Botanical Garden, and Compton Tucker, a specialist in remote sensing technology with NASA's Goddard Space Flight Center. Both Tucker and Killeen have been working in Bolivia for the past several years mapping vegetation types, as part of an effort to understand the processes that lead to the development of different habitats. Accompanying them was Peter Wazelewski, a specialist in meteorite impact craters, who was interested in visiting the only (potential) crater known to exist in alluvial sediments. All other craters are found in hard rock formations, since craters formed by meteroite impacts in unconsolidated sediments are erased quickly by erosion and sedimentation.

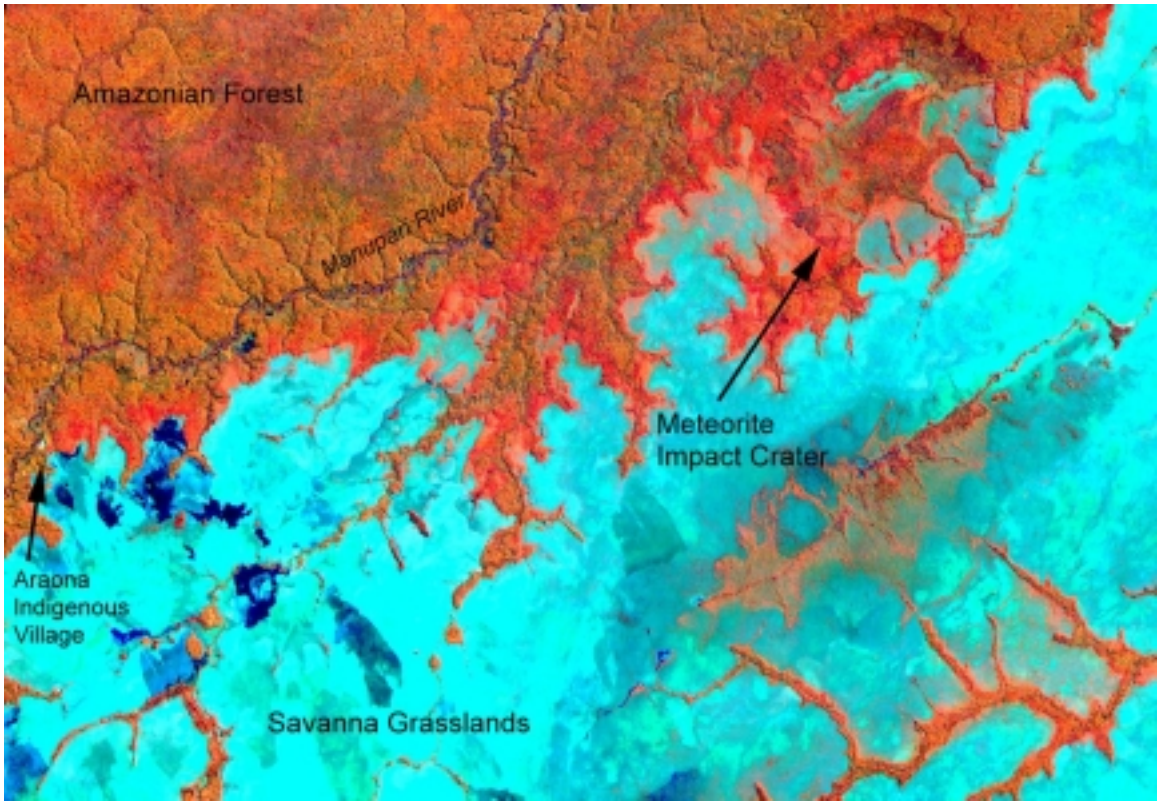


Figure 2. A false-color composite of a Landsat TM satellite image showing the impact crater (red colors are forest vegetation, blues are savanna grasslands). Soil samples (open circles) were taken along a trail (irregular line in the upper right hand quadrant), between "old growth" Amazonian forest dominated by *Bertholetia exclesior* (Brazil nut), across transitional forest types dominated by *Phenakospermum guianensis* (Patujú), and extending into the savanna vegetation in the center of the crater. A proxy soil pit in open treeless grassland was taken at the end of the airstrip at the Araona village (lower left quadrant.

The expedition reached the crater impact site after traveling by jet airliner, small airplane, motor boat, dugout canoe, and finally by cutting a 15 km long trail through the forest. Field data gathered during the expedition supports the hypothesis that the circular feature is a meteorite impact crater. The rings visible

on the satellite image correspond to slight ridges not more than 2 m in elevation, but sufficiently higher to support upland forest vegetation, while the interior of the crater is either inundated savanna or flooded forest. However, only sophisticated methods using seismology and magnetometry can definitively prove the existence of a meteorite or meteorite fragments buried beneath hundreds of meters of alluvial deposits.

NASA scientists were accompanied by biologists from the Missouri Botanical Garden, The Field Museum of Natural History, and the Noel Kempff Mercado Natural History Museum in Santa Cruz, Bolivia. The area is especially interesting to them because it is in a region unspoiled by modern man and has never been visited by biologists. The only community within a 200 km radius of the crater is a small village of about 40 people of the Araona indigenous group, which is situated just 30 km upstream on the Río Manupari (see Figure 1 and 2). The biological specimens collected have been incorporated into the growing collections from northern Bolivia (see table 1 for list of bird species collected or observed).

Table 1. List Bird species observed or collected the Rio Manupare Region

Taxa	Habitat
TINAMIFORMES, TINAMIDAE	
Tinamus major	ft
Tinamus tao	fh
Crypturellus cinereus	ft,fh
Crypturellus parvirostris	cd,cf,cp
Crypturellus soui	fh,ft,fe
Crypturellus undulatus	
Crypturellus undulatus	fh,ft
CICONIIFORMES, ARDEIDAE	
Tigrisoma lineatum	ri,rm,sm
Nycticorax pileatus	rm
Ardeola ibis	rm,cf
Ardeola ibis	rm,cf
Butorides striatus	rm, ma
Egretta alba	rm, ma
Ardea cocoi	rm,sm
CICONIIFORMES, THRESKIORNITHIDAE	
Mesembrinibis cayennensis	cf,rm,ma
ANSERIFORMES, ANATIDAE	
Cairina moschata	rm,ma
FALCONIFORMES, CATHARTIDAE	
Cathartes aura	u
Cathartes melambrotus	fh
Coragyps atratus	fh,ft,fd,cd,sg
Sarcoramphus papa	fh
FALCONIFORMES, ACCIPITRIDAE	
Elanoides forficatus	fh,ft,fd
Ictinia plumbea	fh,fd,fe
Geranospiza caerulescens	ft
Leucopternis kuhli	fh
Buteo magnirostris	u
Spizaetus ornatus	fh
FALCONIFORMES, FALCONIDAE	
Herpetotheres cachinnans	fe,cf,cp
Micrastur ruficollis	fh,fi
Falco rufigularis	fh.fe
GALLINIFORMES, CRACIDAE	
Penelope jacquacu	fh,ft
Aburria pipile	fh
Crax (mitu) tuberosa	fh
GALLINIFORMES, PHASIANIDAE	
Odontophorus stellatus	fh
GRUIFORMES, RALLIDAE	
Aramides cajanea	ft,rm
GRUIFORMES, HELIORNITHIDAE	
Heliornis fulica	rm,ma
GRUIFORMES, EURYPYGIDAE	
Eurypyga helias	rm,sm
CHARADRIIFORMES, CHARADRIIDAE	
Vanellus chilensis	cf,rm
CHARADRIIFORMES, SCOLOPACIDAE	
Bartramia longicauda	fe,cd,cp
Tringa solitaria	cf,rm
Actitis macularia	rm
CHARADRIIFORMES, COLUMBIDAE	
Columba cayennensis	fg,fe,cf,cp
Columba plumbea	fh
Columba subvinacea	fh,ft
Columbina picui	fe,sg
Columbina talpacoti	fe,cp,sg
Leptotila rufaxilla	fh,ft,fd,fe
Geotrygon montana	fh,ft

PSITTACIFORMES, PSITTACIDAE

Ara ararauna	fh,ft,fd,fg
Ara chloroptera	fh
Ara macao	fh.ft
Ara manilata	ft
Ara severa	fh,ft
Ara nobilis	fg
Aratinga aurea	fg,cd
Aratinga leucophthalmus	ft,fg
Pyrrhura picta	ft
Brotogeris cyanoptera	ft
Pionites leucogaster	fh
Pionopsitta barrabandi	fh
Pionus menstruus	fh
Amazona ochrocephala	ft

CUCULIFORMES, CUCULIDAE

Piaya cayana	fh,ft
Piaya minuta	fe
Crotophaga ani	fe,cf,ma,rm,sg
Crotophaga major	ma,rm,sm

STRINGIFORMES, STRIGIDAE

Otus watsonii	fh,ft
Lophostrix cristata	fh
Pulsatrix perspicillata	fh

CAPRIMURGIFORMES, NYCTIBIDAE

Nyctibius aethereus	fh
Nyctibius grandis	fh,fd

CAPRIMURGIFORMES, CAPRIMULGIDAE

Podager nacunda	cp,ri
Nyctidromus albicolus	fg,fe
Nyctiphrynus ocellatus	fh
Caprimulgus rufus	fe,fh
Caprimulgus sericocaudatus	fe

APODIFORMES, APODIDADEA

Chaetura brachyura	u
Chaetura cinereiventris	u
Chaetura egregia	u
Tachornis squamata	cf

APODIFORMES, TROCHILIDAE

Phaethornis supercilliosus	fh,ft
Phaethornis ruber	fe
Thalurania furcata	fh,ft
Hylocharis cyanus	ft

TROGONIFORMES, TROGONIDAE

Trogon melanurus	fh,ft
Trogon viridis	fh,ft

CORACIIFORMES, ALCEDINIDAE

Ceryle torquata	rm
Chloroceryle aena	rm,sm
Chloroceryle amazona	rm
Chloroceryle americana	rm,ma
Chloroceryle inda	rm,sm

CORACIIFORMES, MOMOTIDAE

Momotus momota	fh,ft

PICIFORMES, GALBULIDAE

Galbula cyanescens	fh,fd
Galbula dea	fh

PICIFORMES, BUCCONIDAE

Melacoptila semicincta	fh
Monasa morphoeus	fh
Monasca nigrifrons	ft
Chelidoptera tenebrosa	fe,rm
Notharchus macrorhynchos	fh

PICIFORMES, CAPITONIDAE

Capito niger	fh

PICIFORMES, RAMPHASTIDAE

Pteroglossus beauharnaesii	fh
Pteroglossus flavirostris	fh,ft
Pteroglossus inscriptus	fh
Selenidera reinwardtii	fh
Ramphastos tucanus	fh,ft
Ramphastos vitellinus	fh,ft

PICIFORMES, PICIDAE

Melanerpes cruentatus	fe
Piculus chrysochloros	fh,ft
Celeus elegans	ft,fh
Celeus grammicus	ft
Campephilus rubicollis	fh,ft

PASSERIFORMES, DENDROCOLAPTIDAE

Dendrocincla fuliginosa	fh,ft
Dendrocincla merula	fh
Sittasomus griseicapillus	cd,fg,fd
Glyphorynchus spirurus	fh,ft
Dendrexetastes rufigula	fh
Xiphocolaptes promeropirhynchus	fh
Xiphorhynchus guttatus	fh,ft,fd
Xiphorhynchus spixii	fh

PASSERIFORMES, FURNARIIDAE

Synallaxis rutilans	fh,ft
Ancistrops strigilatus	
Automolus ochrolaemus	fh,ft
Xenops minutus	fh,ft
Xenops milleri	fh,ft

PASSERIFORMES, FORMICARIIDAE

Cymbilaimus lineatus	fh
Taraba major	fd,ft,fe
Thamnophilus aethiops	fh
Thamnophilus amazonicus	fh
Thamnophilus schistaceus	fh
Myrmotherula longipennis	ft
Myrmotherula axillaris	fh,ft
Myrmotherula brachyura	fh
Myrmotherula mentriesii	fh,ft
Myrmotherula sclateri	ft
Cercomacra cinerascens	fh,ft
Myrmoborus myotherinus	

Myrmoborus leucophrys	ft
Hypocnemis cantator	fh,ft
Hypocnemoides maculicauda	ft
Sclateria naevia	ft,sm
Myrmeciza hemimelaena	fh,ft
Hylophylax poecilinota	fh,ft
Gymnopithys salvini	fh
Dichrozona cincta	
Formicarius colma	fh
PASSERIFORMES, TYRAMNIDAE	
Myiopagis gaimardii	fh,ft
Myiopagis viridicata	fh,ft
Mionectes oleagineus	fh,ft
Leptopogon amaurocephalus	fh,ft
Myiornis ecaudatus	fe
Hemitriccus zosterops	fh,ft
Hemitriccus iohannis?	cd,cp
Ramphotrigon ruficauda	fh,ft
Tolmomyias poliocephalus	fh
Onychorhynchus coronatus	fh
Pyrocephalus rubinus	fe,cp
Ochthoeaca littoralis	rm.ma
Attila bolivianus	ft
Attila spadiceus	fh,ft
Rhytipterna simplex	fh,ft
Laniocera hypopyrra	fh,ft
Myiarchus tyrannulus	fh,ft,fe
Myiodynastes (maculatus) solitarius	fh,ft,fg
Empidonomus aurantioatrocristatus	fh,ft,fg
Empidonomus varius	fh,ft,fg
Tyrannus melancholicus	u
Tyrannus savana	rm,cp,cd
Tyrannus tyrannus	
Pachyramphus minor	fh
Tityra semifasciata	fh,ft,fg
'PASSERIFORMES, PIPRIDAE	
Schiffornis major	ft
Schiffornis turdidus	fh,ft
Piprites chloris	fh
Tyranneutes stolzmanni	fh
Heterocercus linteatus	ft
Machaeropterus pyrocephalus	fh,ft
Pipra fasciicauda	fh,ft
Pipra rubocapilla	fh,ft
PASSERIFORMES, COTINGIDAE	
Lipaugus vociferans	fh,ft
Querula purpurata	ft
Gymnoderus foetidus	fh,ft
Iodopleura isabellae	
PASSERIFORMES, HIRUNDINIDAE	
Progne chalybea	u
Progne tapera	u
Atticora fasciata	ri,rm
Stelgidopteryx ruficollis	ri,rm,cp
Riparia riparia	ri,rm,cp
PASSERIFORMES, TROGLODYTIDAE	
Thryothorus genibarbis	fh,ft
Troglodytes aedon	fe,sg,bg
Microcerculus marginatus	fh
PASSERIFORMES, EMBERIZIDAE, EMBERIZINAE	
Ammodramus humeralis	cp
PASSERIFORMES, EMBERIZIDAE, CARDINALINAE	
Saltator maximus	fe,fh,ft
PASSERIFORMES, EMBERIZIDAE, THRAUPINAE	
Hemithraupis flavicollis	fh,ft
Tachyphonus cristatus	fh
Habia rubica	fh,ft,fd
Ramphocelus carbo	fe,sg
Thraupis palmarum	fe,sg
Thraupis sayaca	fe,sg,ft
Euphonia chlorotica	cp,cd,fe
Tangara velia	fh,ft
Tangara mexicana	fh,ft
Dacnis cayana	fh,ft
Tersina viridis	fe,rm
PASSERIFORMES, EMBERIZIDAE, PARULINAE	
Phaeothlypis fulvicauda	fh,sm
PASSERIFORMES, VIREONIDAE	
Vireo (olivaceus) chivi	bt bi
Hylophilus hypoxantha	bt
Hylophilus semicinereus	bt bm
PASSERIFORMES, ICTERIDAE	
Psarocolius bifasciatus	bi bt
Psarocolius angustifros	bt bt
Cacicus cela	bi bm
Scaphidura oryzivora	bi bp ma

ft =terra firme
fh =lower stature forest
ft, fh (order altered if species more prevelant in one or the other.)
cd, cf, cp = cerrado, seasonally flooded grassland, campo
fe = forest edge
ri, rm, sm river, river margin, stream margin
ma = marsh

The expedition also allowed Killeen, Tucker and a Bolivian student, Teddy Siles, to study the past ecological history of the region. The crater is situated on the

interface of the Amazon forest and the vast open savannas of eastern Bolivia. A preliminary evaluation of the images identified patches of low forest north of the

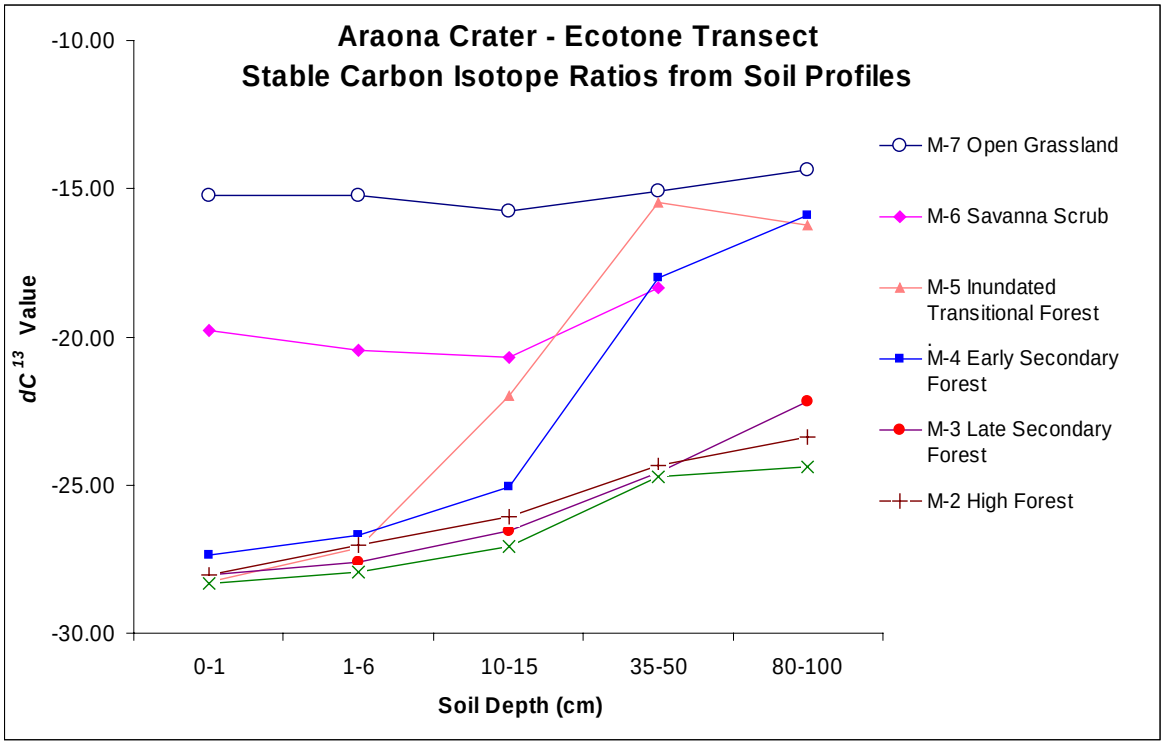


Figure 3. Diagram of soil profiles established a long a savanna – forest ecotone near the Araona Impact Crater on the Manupari River (La Paz, Bolivia).

current savanna – forest edge, leading them to hypothesize that the forest – forest ecotone has migrated South in recent history. The expedition provided them with a unique opportunity to test this hypothesis using soil samples collected along a transect across the savanna forest ecotone.

Table 2. Summary of the vegetation structure at seven soil sample sites established on the ecotone transect.

	Woody Cover	Density	Mean Height	Basal Area
M-1 High Forest	> 100 %	48	23	3.15
M-2 High Forest	> 100 %	52	25	4.39
M-3 Late Secondary Forest	> 100 %	53	22	1.98
M-4 Early Secondary Forest	> 100 %	53	19	2.31
M-5 Inundated Transitional Forest	> 100 %	64	8	1.43
M-6 Savanna Scrub	25 - 30 %	2	2	0.06
M-7 Open Grassland	0 - 5 %	0	-	-

Soil organic matter (SOM) provides a record of the vegetation that occupied a site in the past. The grass species in the savanna at Noel Kempff Park use the C_4 metabolic pathway and therefore contains an elevated amount of the stable

carbon isotope ^{13}C when compared to the forest plants. The relative amount of ^{13}C is quantified as the ratio of ^{13}C to ^{12}C and expressed as a per mil deviation from a geological standard (dC^{13}). Savanna grass tissue has a dC^{13} value of approximately -12, while forest plants range from -25 to -30. Over time, the SOM at a site will mirror the stable carbon isotope value of the vegetation growing on it. For example, SOM in an area, which has been covered with tropical savanna grassland will have a dC^{13} value approaching that of the live savanna grass tissue. In the event of a change in vegetation, the SOM will serve as an indicator of past vegetation at the site. If SOM with a dC^{13} value of between -20 and -25 were found under savanna vegetation, it would indicate that the area was previously occupied by forest vegetation.

Preliminary evidence from the soils samples taken indicates that the Amazon forest has expanded southward in recent geological time, an indication of past climate change (Figure 3). Even the most northern soil pits (M-1, M-2 and M-3) taken some 20 km North of the current boundary showed some evidence of C4 grasses in the lowest (and oldest) part of the soil profile, while the proxy sample taken in open grassland south of the airstrip near the Araona Village (M-7) showed no evidence of recent forest cover. The transitional sites all show evidence of past movement in the forest – savanna ecotone. The two sites that are currently forested (M-4 and M-5) had dC13 values in the upper horizon typical of forest vegetation, while deeper soil profiles were more like those found in the savanna soils (M-7). Similarly, the savanna patch found in the center of the crater had top soil characteristics intermediate to open grassland and closed forest, reflecting the its grass sward and the presence of a numerous shrubs and herbaceous forbs (Table 2).