UNIVERSITY OF UTAH

DIVISION OF BIOLOGICAL SCIENCES

MISCELLANEOUS PAPERS

NUMBER 2 JUNE 1963

INSTITUTE OF ENVIRONMENTAL BIOLOGICAL RESEARCH

BIOLOGICAL-ECOLOGICAL ASPECTS OF BETATAKIN CANYON NAVAJO NATIONAL MONUMENT ARIZONA

by

Angus M. Woodbury

This work was accomplished in part under support from the U. S. National Park Service, Regional Office No. 2, Santa Fe, New Mexico, Order No. R033-553, dated June 12, 1962.

CONTENTS

ILLUSTRATIONS

INTRODUCTION

Betatakin Canyon in the Navajo National Monument, Arizona, is cutting a thousand feet in depth headward into a highland plateau covered with a pinyon-juniper pigmy conifer forest. This canyon has a profile of cliffs cut through Navajo, Kayenta, and Wingate sandstones which represent three out of a series of five great sandstone cliff-making sedimentary formations laid down in this region during earlier geological times, all of Jurassic age (Baker, et al., 1936:45-49). According to Stokes and Holmes (1954:34-41), all five originally covered this region as shown in Figs. 1 to 5. It is presumed that the upper two, Mt. Carmel and Entrada sandstones have been mostly if not entirely removed by erosion at Betatakin.

The great system of Segi canyons drains a series of canyon heads similar to that of Betatakin, providing great scenic features, Fig. 6. Ecologically the primary effect of such a canyon head is to cut the aquafers carrying sparse supplies of water percolating through the sandstone and to shut out of the canyon depths much of the daily sunshine. This reduces potential evaporation and enhances higher humidity in the canyon depths. In effect, it is a miniature Zion Canyon draining in opposite direction. It has a "canyon effect" as described for Zion by Woodbury (1933).

The aquafers cut by the canyon range from percolating water emerging as springs and through minor seepage areas that moisten the cliff faces to porous spaces in the sandstone that allow water to evaporate from its surface without visible wetting. Water emerging from such aquafers is the primary agent in the development of alcoves and caves although the structure of the sand in the dunes from which the sandstone was formed has an important bearing upon the path of the aquafers, the point of emergence at the surface, and the erosion resistance of the rock. The development of alcoves into caves is accelerated by the presence of water. Size of caves is often correlated in a general way with the amount of water involved.

The "canyon effect" is produced mainly by the high canyon walls shutting out the daily sunlight. The deeper and narrower the canyon, the more the sunshine is excluded and less sunshine provides less energy available for evaporation of water. In effect, the climate is inverted from that of a mountain so that there is a gradation downward toward cooler and more humid conditions in the bottom. This inverted climate is correlated with flora and fauna to match. However, canyons are so irregular in aspect that there are many anomalies in distribution of the plants and animals.

Normally, a high mountain such as Navajo, Fig. 7, has an arrangement of vegetation belted like that shown in Fig. 8 which depicts a generalized arrangement on a mountain in Utah. The belts usually turn upward on south-facing slopes and dip downward on the north side. This drawing is approximately typical of Navajo Mountain visible from Navajo National Monument except that its base is in the pinyon-juniper pigmy forest belt and its summit in the large conifers does not reach the tundra zone.

Although a deep and narrow canyon has a general resemblance to an inverted mountain, actually there are detailed differences in the natural forces sculpturing the physiographic features. Some of these are shown in the canyon sketch in Fig. 9. The direction a canyon runs helps in determining the aspect

Maps shown in Figs. 1 to 5 illustrate the former distribution and thickness of the five principal cliff-forming sandstones of southeastern Utah and adjacent states around Four Corners, according to U S G S Prof. Paper 183: 45-49. Each succeeding map lies above the preceding maps. See Stokes and Holmes (1954:34-41).

KAYENTA SANDSTONE

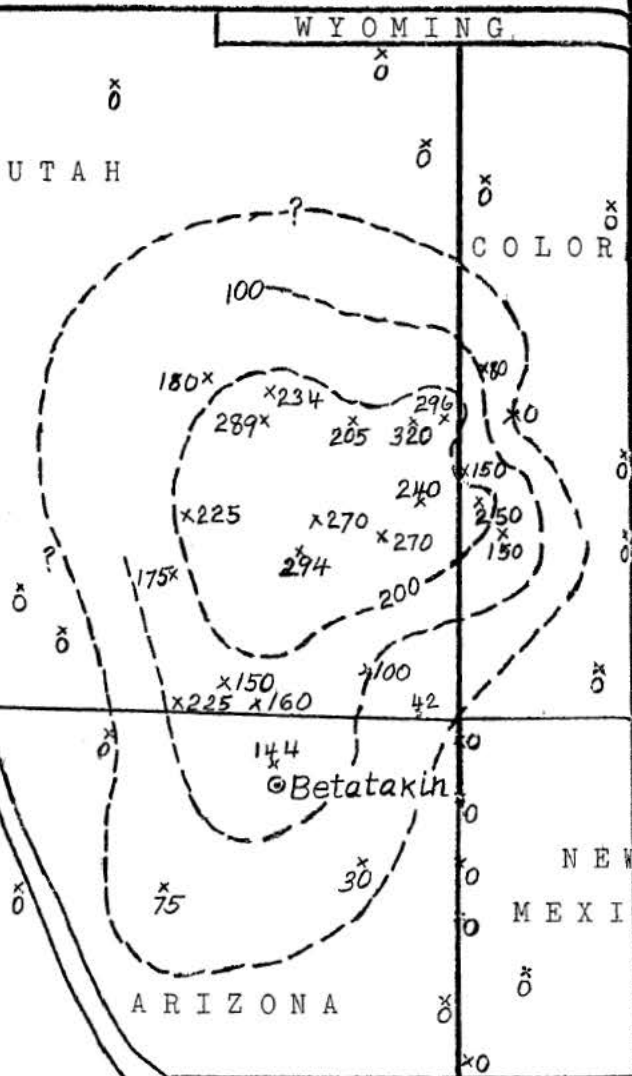


Fig. 2. Distribution of Ka
Sandstone of Jurassic

WINGATE SANDSTONE

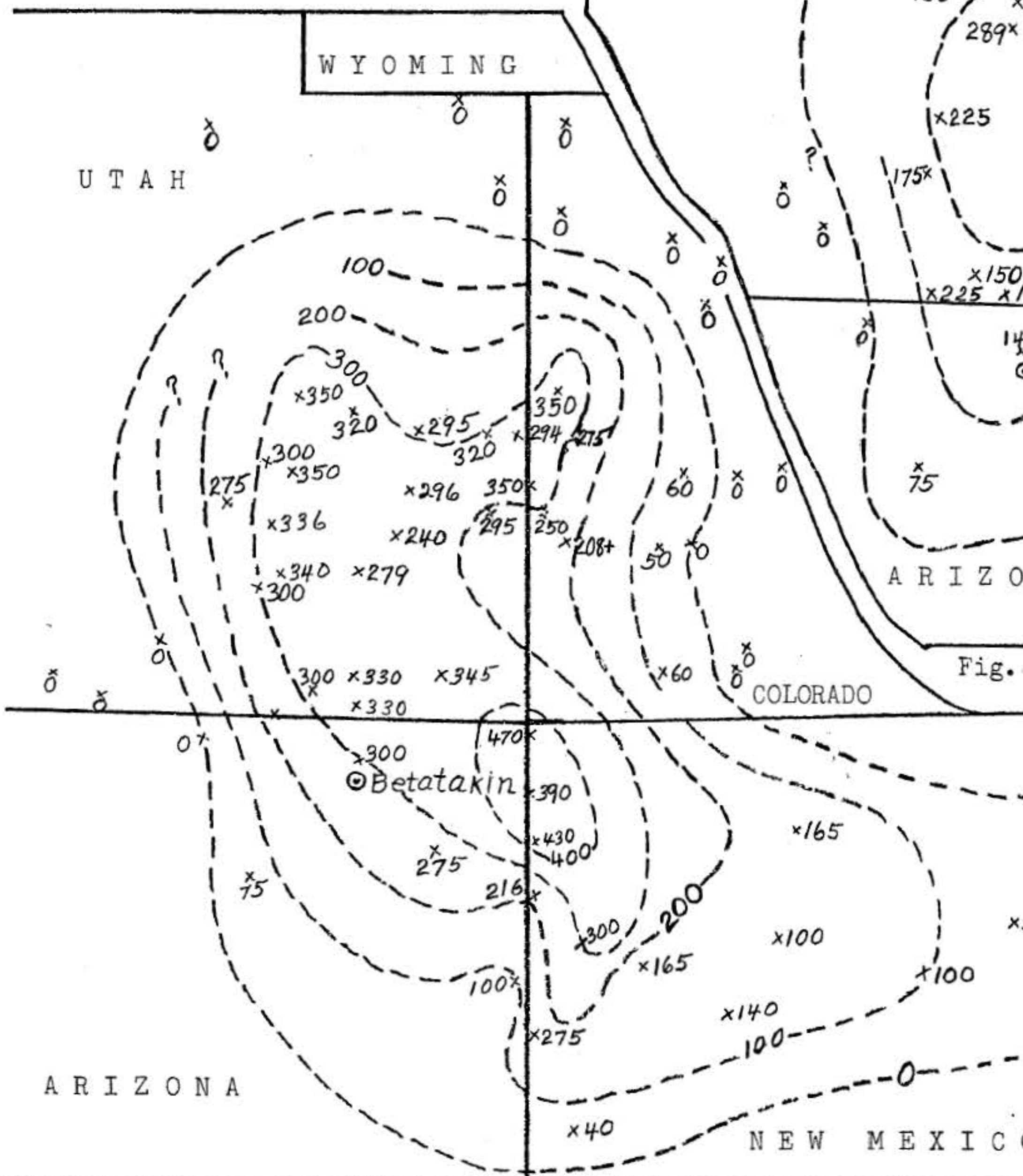


Fig. 1. Distribution of the Wingate Sandstone of Jurassic Age.
U S G S Prof. Paper 183:45, and Stokes and Holmes (1954:34-41).

CARMEL SANDSTONE

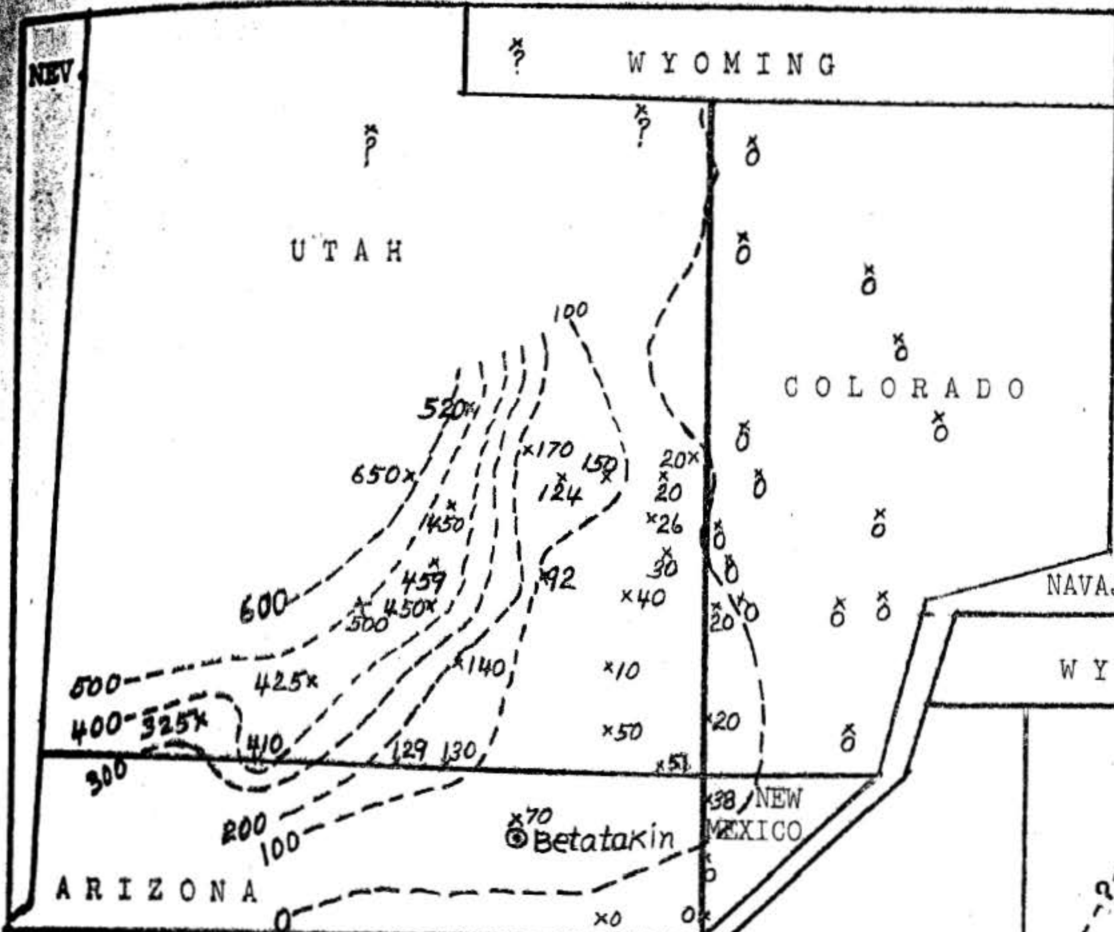


Fig. 4. Distributic of the Carmel Sar stone of Jurassic Age.

NAVAJO SANDSTONE

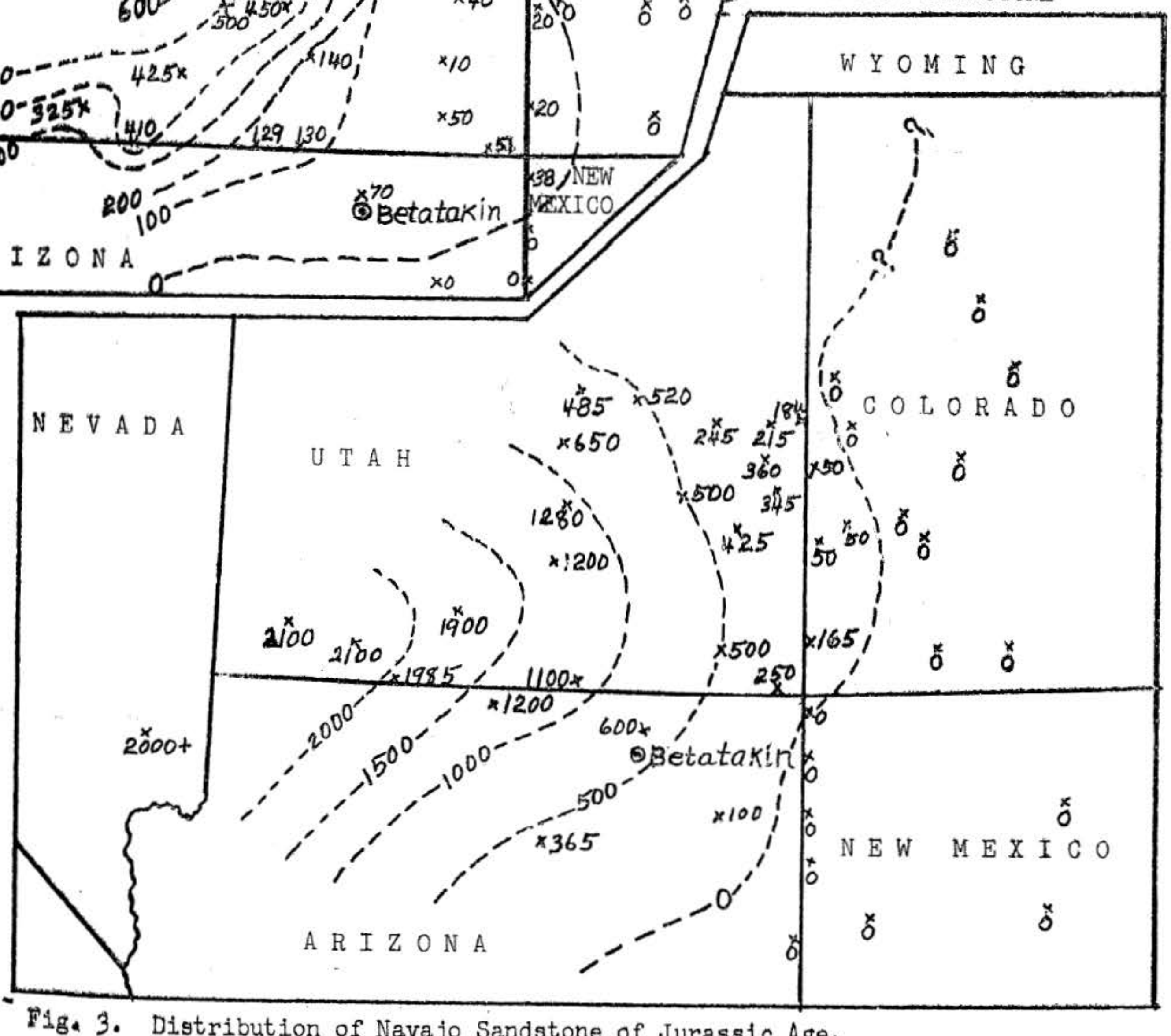


Fig. 3. Distribution of Navajo Sandstone of Jurassic Age. U S G S Prof. Paper, 183:47, and Stokes and Holmes (1954:34-41).

ENTRADA SANDSTONE

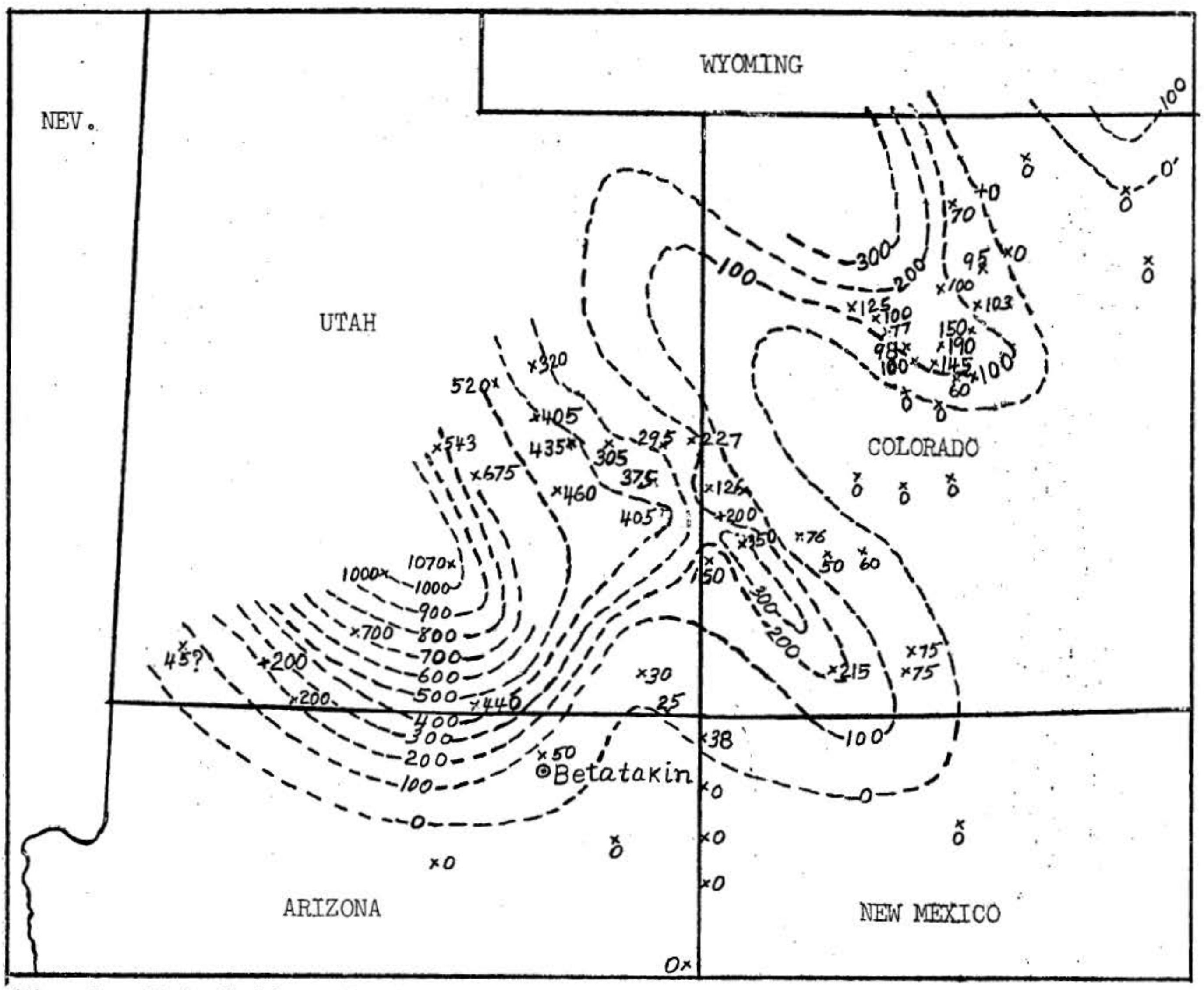


Fig. 5. Distribution of Entrada Sandstone of Jurassic Age.
U S G S Prof. Paper, 183:49, and Stokes and Holmes (1954:34-41).

and exposure to sunshine of the canyon slopes. In the temperate zone, the sides would be much alike in a north-south canyon and would differ most from each other in an east-west canyon. The northeast direction of Betatakin Canyon provides differences of intermediate proportions in the two sides.

A lone mountain such as Navajo rising high above the surrounding terrain, pierces successively less dense air at higher elevations and will in general have more intense solar radiation reaching its summit than its base. More of the re-radiation from its surface will be trapped by the denser atmosphere at lower altitudes and "hold the heat" better than that above. Furthermore, the mountain can lose nearly all of its re-radiation from the horizontal upward with little compensatory return.

In reverse, a canyon such as Betatakin, dipping steeply below the surrounding terrain, penetrates successively more dense air at lower altitudes in the canyon and will in general have less intense solar radiation reaching the bottom because of the greater "straining" action of the denser air at greater depths. With more of the earlier morning and later afternoon sunshine shut out of the canyon at successive depths, less energy is received but the denser air at the bottom traps and holds a larger proportion of that received. Furthermore, much of the re-radiation from the bottom is intercepted by the canyon walls, re-radiated from wall to wall and held below.

Since water absorbs and holds a much larger proportion of incident solar energy than rock or soil, vegetation composed mainly of water acts as a heat reservoir. Short desert vegetation cannot store much heat from sunshine and it is rapidly lost by radiation during a desert night. Larger vegetation, such as the pinyon-juniper forest on the plateau, the oaks, aspens, firs and birches of the canyon depths are able to store a larger proportion of the solar energy received during the day and maintain a relatively more constant supply of re-radiation during the night.

Despite these differences between a high mountain and a deep canyon, the total effect in determining the vegetation belting shows considerable parallelism. The pinyons and junipers characteristic of the plateau at Betatakin surround the base of Navajo Mountain and dwindle out upward on the mountain slope, Fig. 9. A similar dwindling occurs downward into the canyon at Betatakin, except as it is interrupted by the cliffs, Fig. 6.

Ascending a mountain, the brush belt usually occurs above the pigmy conifers and gives way at higher altitudes to aspen and fir or spruce conifers. In some places, the brush may be interspersed with ponderosa pines. The aspen often serves as a nurse cover for firs or spruces. In Betatakin Canyon, the pigmy conifers give way downward to oak brush and this in turn gives way to aspen downward in the bottom. The aspen here has not served as a nurse cover for firs. Douglas firs occur, however, in specially sheltered nooks at the bases of cliffs.

Where aquafers provide water for streams in the bottom, the streamsides are usually lined with clumps of birch bushes or small trees, often associated with dogwood. On terraces behind the streamside, the boxelder is not uncommon. In certain places, moist soil bears meadow-like stands of the primitive horsetails (Equisetum) and meadow rue.

TSEGI CANYON HEADS

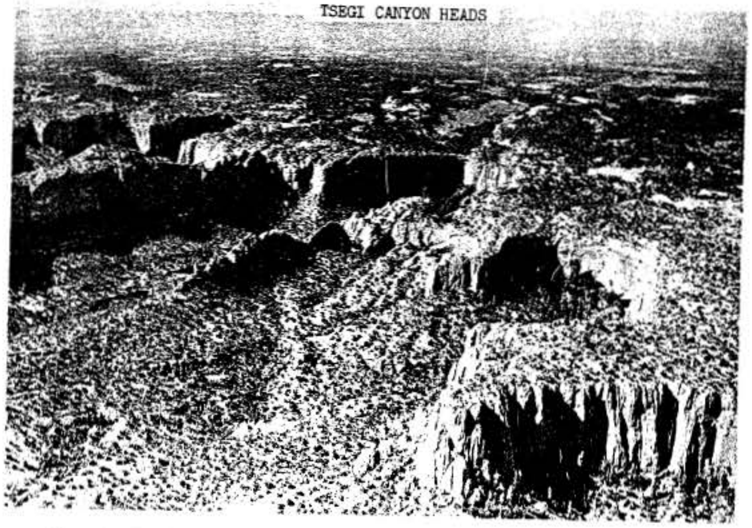
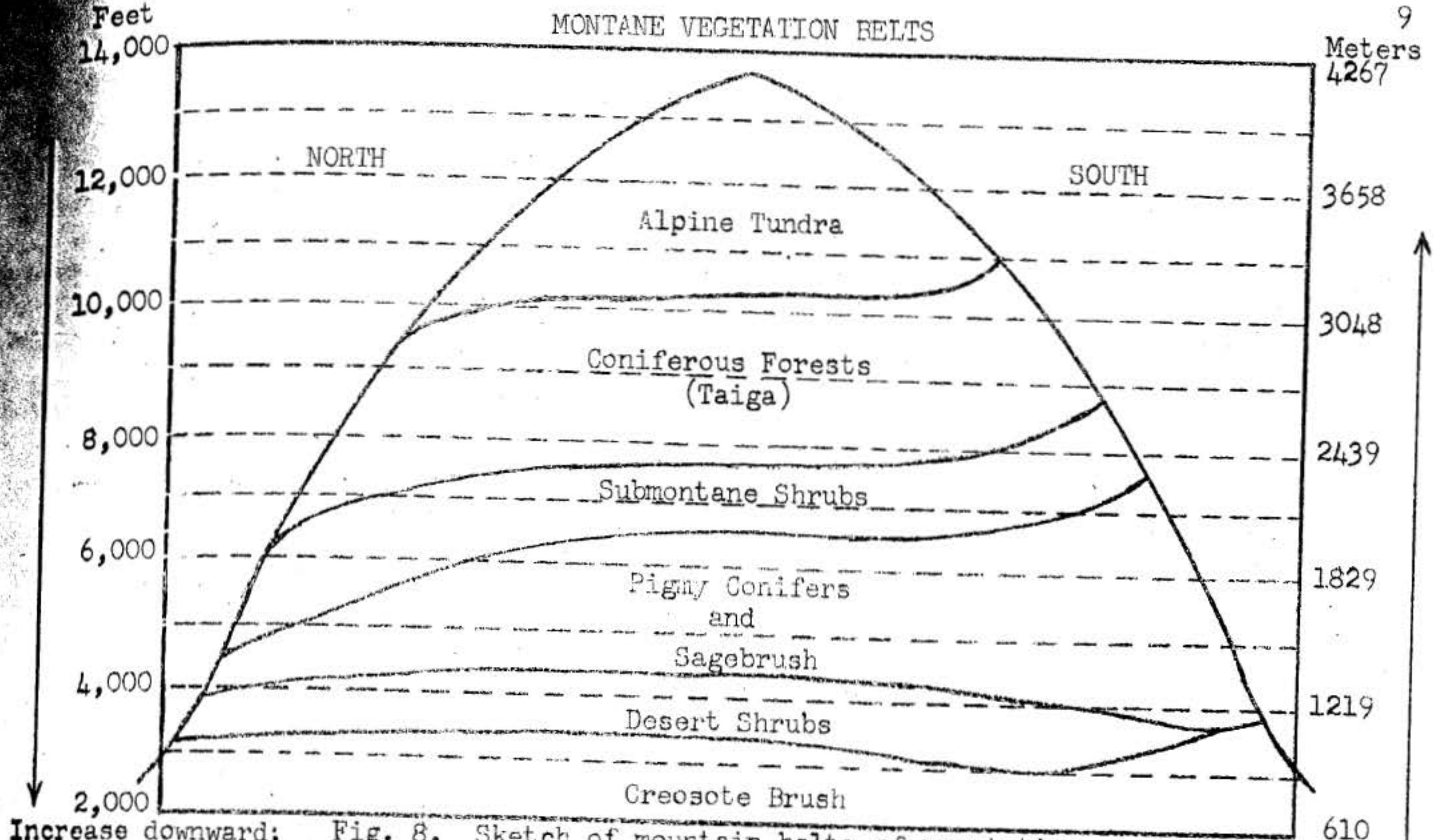


Fig. 6. Looking into Tsegi Canyon country showing pigmy conifers and sagebrush on the landscape and large conifers in sheltered nooks of canyon heads. Photo by American Exploration Society, 1937.

NAVAJO MOUNTAIN

Fig. 7. A laccolithic dome, Navajo Mountain, tilting the Navajo Sandstone up the slope and subjecting it to deep canyon cutting. American Exploration photo, 1937.

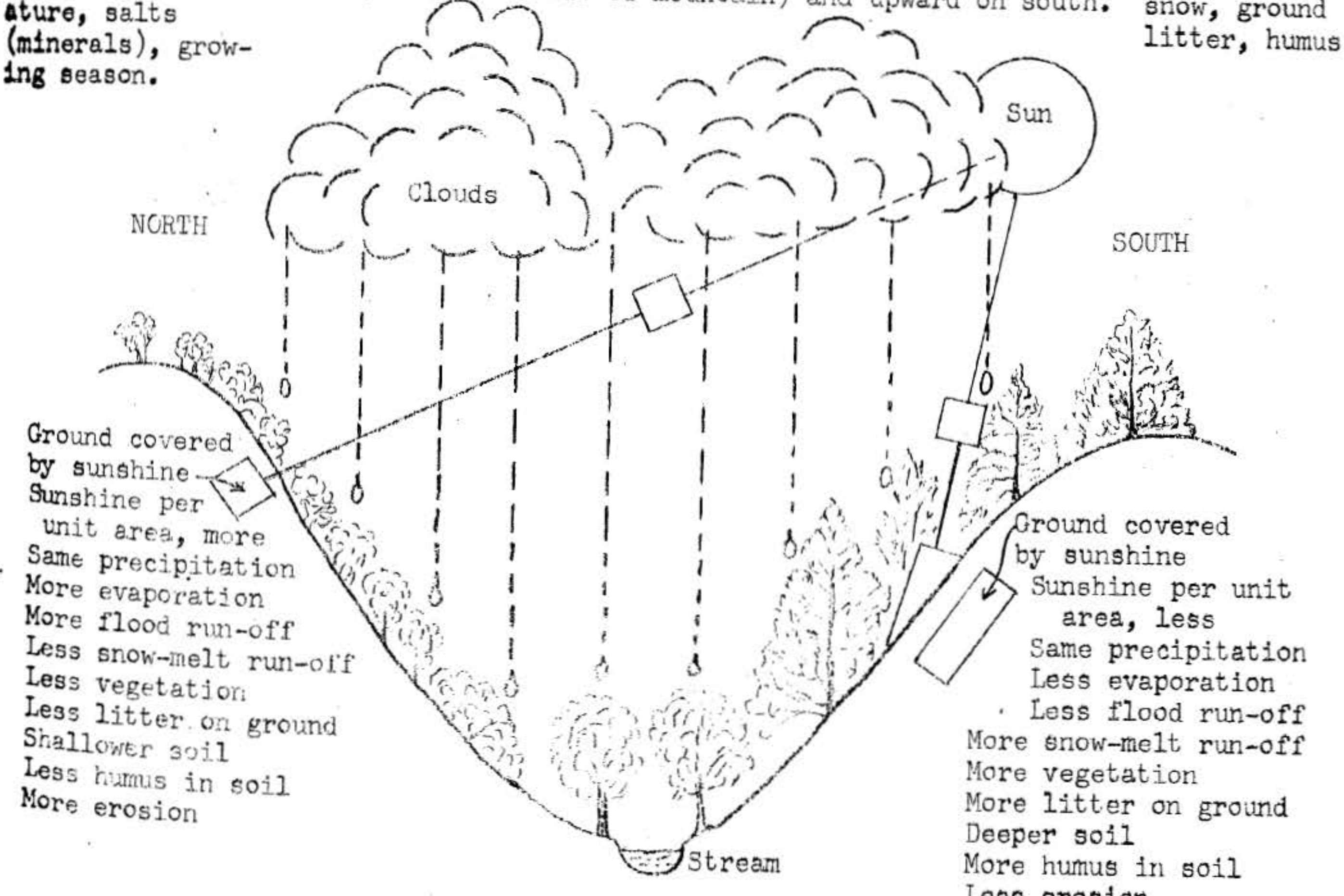
MONTANE VEGETATION BELTS



Increase downward: Air pressure (oxygen), temperature, salts (minerals), growing season.

Fig. 8. Sketch of mountain belts of vegetation in Utah. The belts dip downward on north-facing slopes (north side of mountain) and upward on south.

Increase upward: Light, moisture, snow, ground litter, humus.



EFFECTS OF ASPECT AND SLOPE IN CANYONS

Fig. 9. Diagram showing effects of aspect and slope on north and south-facing slopes in an east-west canyon in a semi-arid region of western United States.

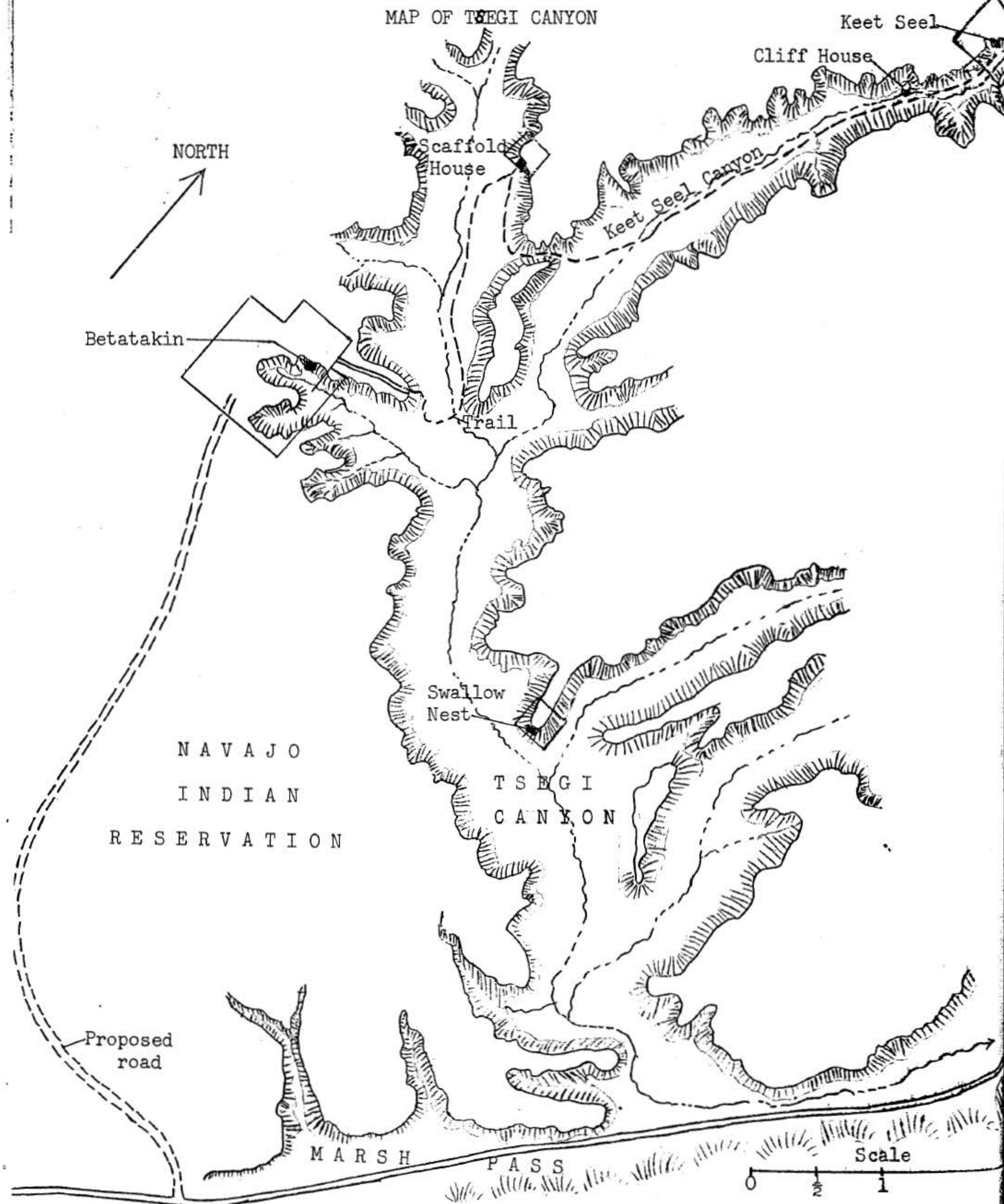


Fig. 10. Map of Tsegi Canyon showing location of ruins.

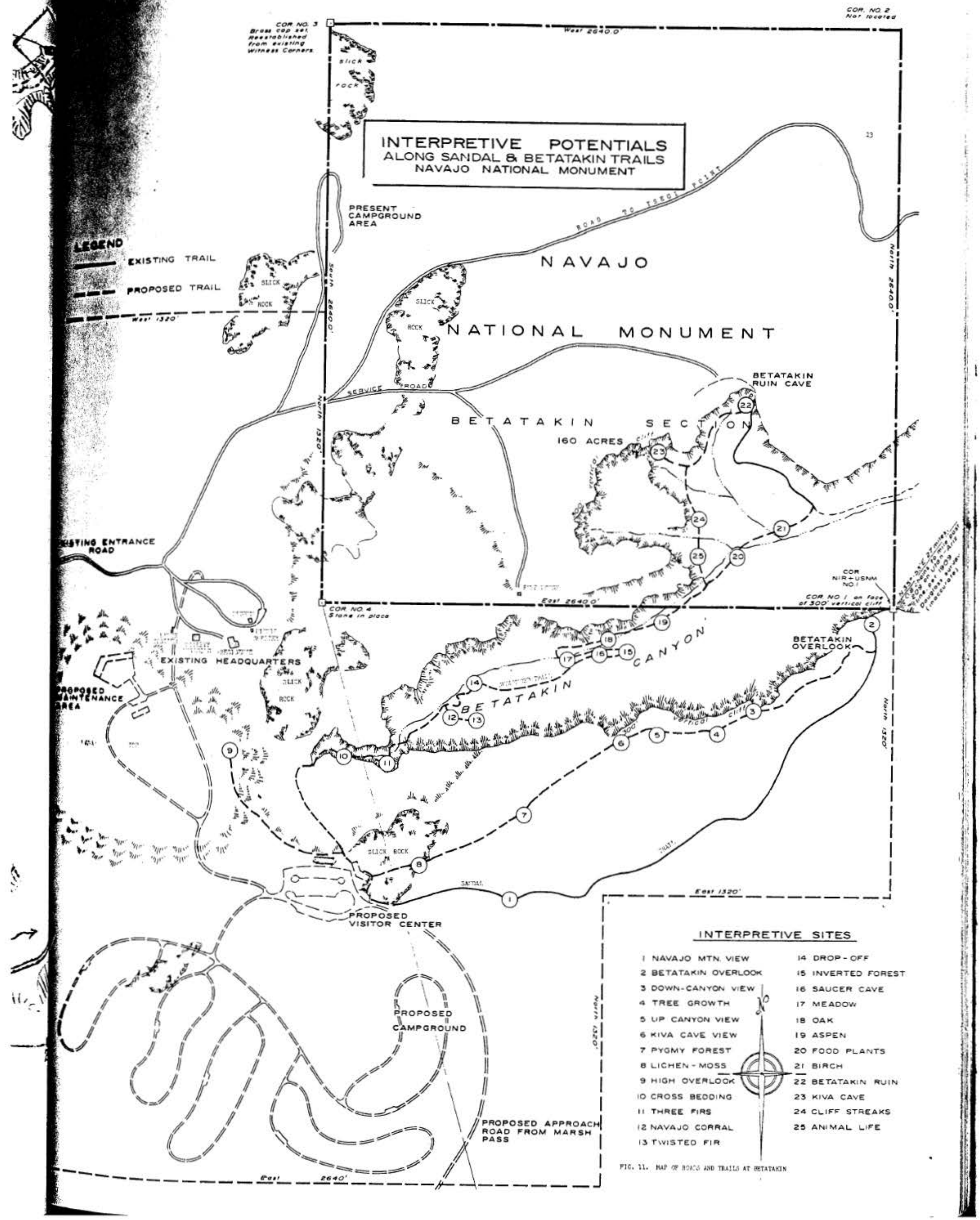


FIG. 11. MAP OF ROADS AND TRAILS AT BETATAKIN

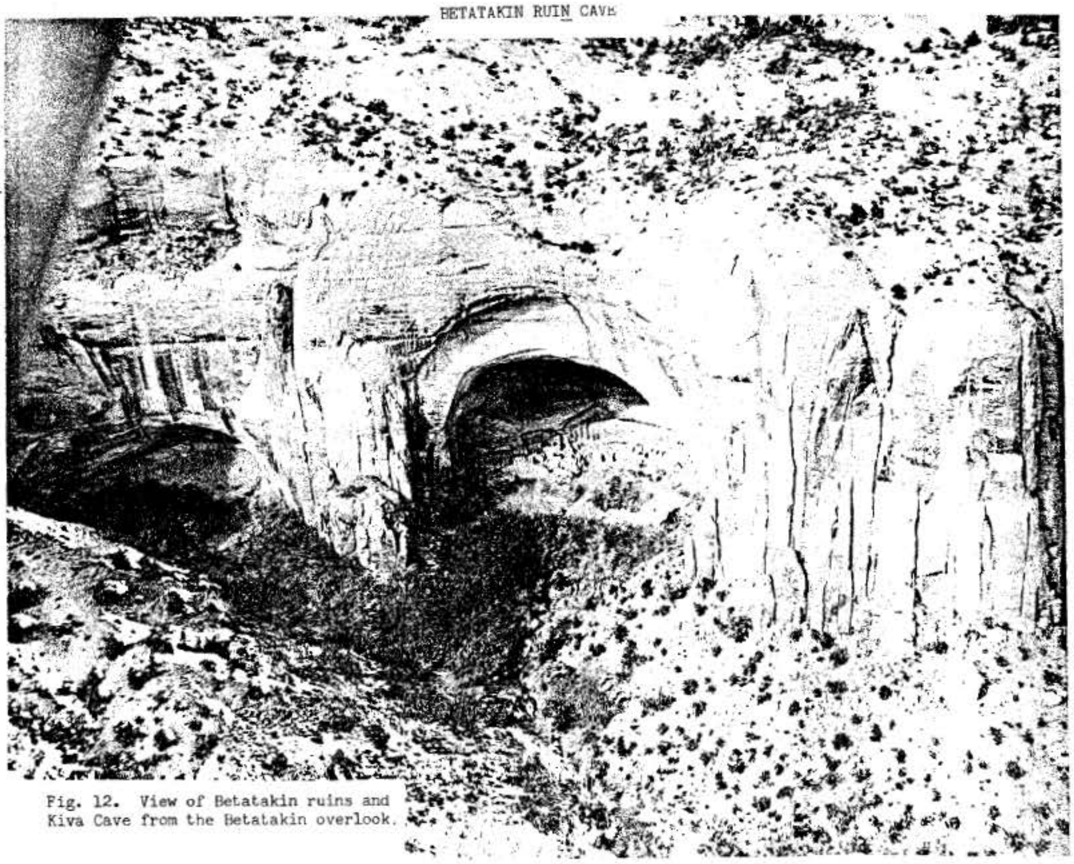


Fig. 12. View of Betatakin ruins and Kiva Cave from the Betatakin overlook.

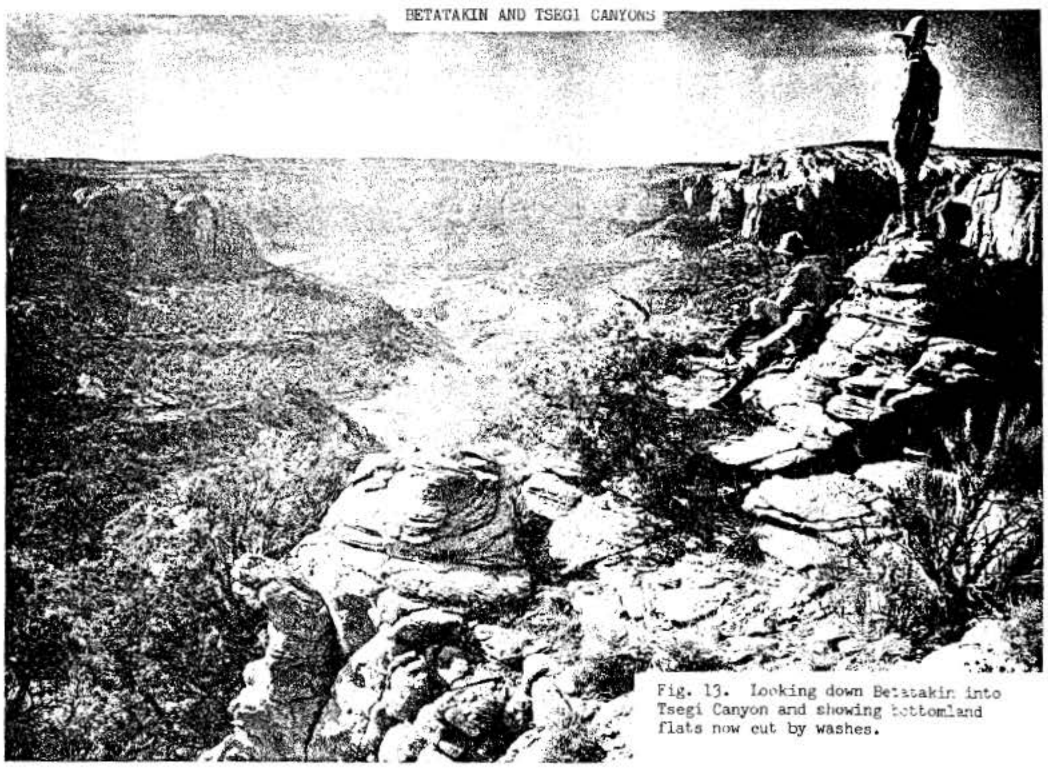


Fig. 13. Looking down Betatakin into Tsegi Canyon and showing bottomland flats now cut by washes.

PIGMY CONIFER FORESTS

The pigmy conifers of pinyon pines and junipers having a distinct ecological appearance on the landscapes of the region, Fig. 6, generally range from 10 to 30 feet in height and from about 5000 to 7500 feet or more in altitude. Within that range, they often share dominance with the big sagebrush which usually takes possession in fine grained soils of canyon bottoms and valleys while the pigmy conifers dominate the ridges and hills with coarse soil, sand or rocks, Fig. 6.

While these trees and sagebrush generally dominate the landscape, yet many other plants occupy minor niches or microhabitats between the dominant trees. Where bare rock is exposed, lichens may cover the surface and pioneer the way for moss to become established and expand. The accumulation of soil in the moss may offer a roothold for seed plants to become established and gradually encroach on the bare area. Other plants may follow one another in irregular sequence until the pigmy conifers come into possession.

Conspicuous Plants

Some of the more conspicuous members of this vegetation type at Betatakin include the following:

Pinus edulis Engelman	Double-leaf pinyon pine
Juniperus monosperma (Engelm) Sargent	One-seed juniper
Artemisia tridentata Nutt.	Big sagebrush
Elaeagnus argentea Pursh.	Silver buffaloberry
(or Shepherdia rotundifolia Parry.	Silver seal)
Cercocarpus sp.	Mountain mahogany
Chrysothamnus spp.	Rabbitbrush
Cowania stansburiana Torr.	Cliff rose
Fendlera rupicola Gray.	Fendlera bush
Gutierrezia sarothrae (Pursh) Britt	Matchweed
Opuntia sp.	Prickly pear cactus
Opuntia sp.	Dry-fruited cactus
Opuntia erinacea Engelm & Bigel.	Grizzly bear cactus
Opuntia whipplei Engelm & Bigel.	Prostrate cholla cactus
Echinocereus fendleri (Engelm) Rumpler.	Hedgehog cactus
Echinomastus johnsonii (Parry) Baxter	Beehive cactus
Cleome serrulata Pursh.	Purple beeflower
Gilia aggregata (Pursh) Spreng.	Scarlet gilia
Pentstemon spp.	Pentstemon

Birds of the Pigmy Conifers

Birds are probably the most conspicuous element of the native fauna although lizards and insects may be more often observed. Despite its irregularities of cover, the pigmy conifer vegetation covers more area than any other cover type in the Navajo country and more birds appear to be adapted to live in that habitat than any other in the region. The following birds are permanent residents, spending the major part of their lives among those dwarf trees and seldom straying outside of their influence:

Pigmy Conifer Forests

Permanent Residents Limited to Pigmy Conifers

- Gymnorhinus cyanocephalus Wied. . . . . Pinyon jay
- Parus inornatus ridgwayi Richmond . . . . Plain titmouse
- Psaltriparus minimus plumbeus (Baird) . . . . . . Common bushtit
- Thryomanes bewickii eremophilus Oberholzer. . . . Bewick wren

The following birds are breeders of the pigmy conifers, seldom, if ever, breeding in other habitats, but usually migrate elsewhere to spend the winter:

Breeders Limited to Pigmy Conifers

- Phaelaenoptilus nutallii nutallii (Audubon) . . Poor-will
- Myiarchus cinerascens cinerascens (Lawrence). . Ash-throated flycatcher
- Empidonax wrightii Baird. . . . . Gray flycatcher
- Polioptila caerulea amoenissima Grinnell. . . . Blue-gray gnatcatcher
- Dendroica nigrescens (Townsend) . . . . Black-throated gray warbler

Many other birds inhabit the pigmy conifers but overflow into the other types of habitat as well. The following are permanent residents of, but not limited to, the pigmy conifers:

Residents not Limited to Pigmy Conifers

- Falco sparverius sparverius Linnaeus . . . . . . Sparrow hawk
- Bubo virginianus pallescens Stone. . . . . Great horned owl
- Asio otus tuftsi Godfrey. . . . . Long-eared owl
- Colaptes cafer collaris Vigors . . . . Red-shafted flicker
- Dendrocopos villosus leucothorectis (Oberholser) Hairy woodpecker
- Parus gambeli gambeli Ridgway. . . . . Mountain chickadee
- Sitta carolinensis nelsoni Mearns. . . . . White-breasted nuthatch
- Carpodacus mexicanus frontalis (Say) . . . . . . House finch

The following birds are breeders in, but not limited to, pigmy conifers. They usually leave in the winter.

Breeders not Limited to Pigmy Conifers

- Zenaidura macroura marginella (Woodhouse). . . . Mourning dove
- Archilochus alexandri (Bourcier and Mulsant) . Black-chinned hummingbird
- Tyrannus vociferans Swainson . . . . Cassin kingbird
- Sayornis saya (Bonaparte). . . . . Say phoebe
- Sialia currucoides (Bechstein) . . . . Mountain bluebird
- Sialia mexicana bairdi Ridgway . . . . Western bluebird
- Vireo solitarius plumbeus Coues. . . . . Solitary vireo
- Spizella passerina arizonae Coues. . . . . Chipping sparrow

Wide ranging birds that cover large territories may include the pigmy conifers as part of their operations and may be found at Betatakin occasionally.

Wide Ranging Birds of Pigmy Conifers

- Cathartes aura teter Friedmann . . . . Turkey vulture
- Accipiter striatus velox (Wilson). . . . . Sharp-shinned hawk
- Accipiter cooperi (Bonaparte). . . . . Cooper hawk
- Buteo jamaicensis calurus (Cassin) . . . . Red-tailed hawk
- Aquila chrysaetos canadensis (Linnaeus). . . . Golden eagle
- Falco mexicanus Schlegel . . . . Prairie falcon
- Chordeiles minor henryi Cassin . . . . Common nighthawk

Many other birds, too numerous to list, may visit the pigmy conifers as migrants, wanderers, or accidentals.

DEEP CANYON VEGETATION

The mountain vegetation persisting in the head of Betatakin Canyon consists mainly of relict patches of the following plants:

Terrestrial Plants

Pseudotsuga menziesii (Mirb) Franco	Douglas fir
Populus tremuloides Michx	Quaking aspen
Quercus gambelii Nuttall	Gambel oak

Streamside Plants

Equisetum sp.	Horsetail
Betula fontinalis Sargent	Waterbirch
Cornus sp.	Dogwood
Acer interius Britt	Boxelder

Birds of the Deep Canyon

These relict patches of mountain vegetation in the head of Betatakin Canyon are so small in size by comparison with the widespread pigmy conifer forests that a full complement of animals normally associated with large areas of such vegetation should not be expected here. Small populations of certain species of closely associated birds have been observed in this vegetation but many of the species found here either overflow into adjacent pigmy conifers or are overflows from that vegetation. Birds usually associated with this type of vegetation and likely to be found here, include the following:

Birds of Deep Canyon Vegetation

Dendrocopos pubescens leucurus (Hartlaub)	Downy woodpecker
Empidonax difficilis hellmayri Brodkorb	Western flycatcher
Contopus sordidulus veliei Coues	Western wood pewee
Cyanocitta stelleri macrolopha Baird	Steller jay
Aphelocoma coerulescens woodhousei Baird	Scrub jay
Sitta canadensis Linnaeus	Red-breasted nuthatch
Myadestes townsendi (Audubon)	Townsend solitaire
Piranga ludoviciana (Wilson)	Western tanager
Pheucticus melanocephalus melanocephalus (Swainson)	Black-headed grosbeak
Pipilo erythrophthalmus erythrophthalmus Swarth	Rufous-sided towhee

Birds Overflowing from Pigmy Conifers

Zenaidura macroura marginella (Woodhouse)	Mourning dove
Colaptes cafer collaris Vigors	Red-shafted flicker
Dendrocopos villosus leucothorectis (Oberholser)	Hairy woodpecker
Parus gambeli gambeli Ridgway	Mountain chickadee

Birds of Cliffs, Ledges and Boulders

Bubo virginianus pallescens Stone	Great horned owl
Strix occidentalis lucida (Nelson)	Spotted owl
Aeronautes saxatalis saxatalis (Woodhouse)	White-throated swift
Petrochelidon pyrrhonota (Vieillot)	Cliff swallow
Corvus corax sinuatus Wagler	Common raven
Catherpes mexicanus conspersus Ridgway	Canyon wren
Salpinctes obsoletus obsoletus (Say)	Rock wren

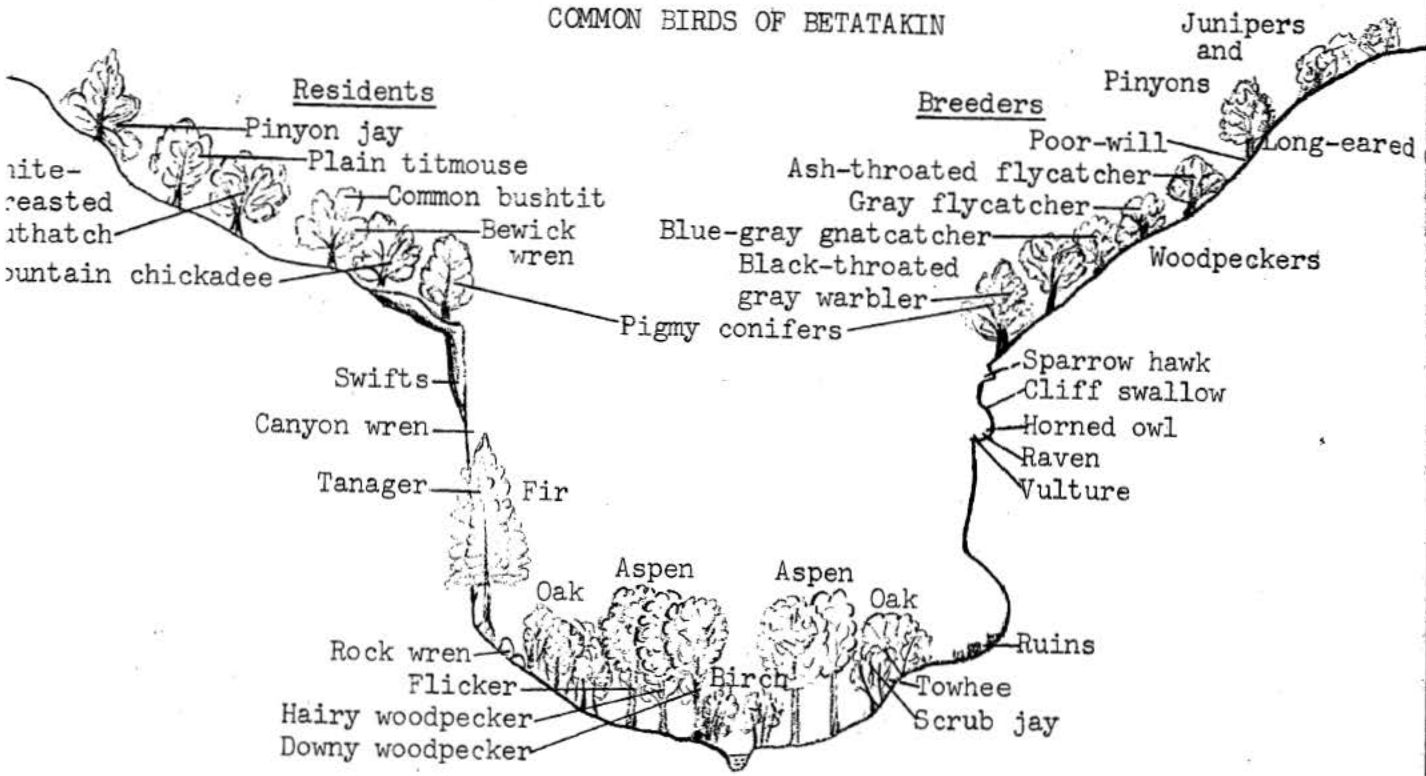


Fig. 14. Sketch of Betatakin Canyon showing ecological setting of common vegetation and common birds.

OTHER ANIMALS OF BETATAKIN

The highly mobile birds that can fly over the landscape and see the various habitats available have an advantage in making their choice of niches they inhabit than the less mobile animals that must travel the land surface and cannot skip over unsuitable habitat by flight. For this reason, these vertebrates will be treated in a general way without specific integration with the vegetation.

AMPHIBIANS

The amphibians are associated at some time in their lives with water. In this southwestern desert where water is very scarce, the known amphibians are associated with small streams, ponds or temporary pools widely spaced in the desert. In Betatakin, the principal source of such water is in the springs and small streams in the depths of the canyon and in temporary pools in the slick rock or in potholes in the bottom of washes. A salamander and three toads have been found at similar places in the surrounding region and should occur at Betatakin. The salamander is known from Cow Springs and the three toads from Shonto. The salamander seldom strays far from water even in the adult stage but the toads may spread from the breeding ponds where the tadpoles are reared long distances into surrounding range where they hide underground during winter and dry weather and emerge when it rains. Those expected to be here are the following:

AMPHIBIA (class) . . . . Amphibians

Ambystomidae (family) . . . . Mole salamanders
Ambystoma tigrinum nebulosum Hallowell. . . . Arizona tiger salamander

Pelobatidae (family) . . . . Spadefoot toads
Scaphiopus hammondi hammondi Baird. . . . Hammond spadefoot

Bufonidae (family) . . . . Toads
Bufo punctatus Baird and Girard. . . . Red-spotted toad
Bufo woodhousei woodhousei Girard. . . Rocky Mountain toad

REPTILES

Our reptiles are free from the requirement of water for breeding purposes and only the garter snake which lives around aquatic habitats is associated with water. All of the other snakes and lizards obtain water in their food supplies and have behavior patterns that help them conserve this supply so they do not ordinarily drink in nature. The reptiles expected to be found in the Tsegi Canyon system, including Betatakin, include the following:

REPTILIA (class) . . . . Reptiles

LIZARDS

Iguanidae (family) . . . . Iguanid lizards
Crotaphytus collaris auriceps Fitch and Tanner . . . . Yellow-headed collared lizard

Usually associated with open rocks and boulders from pigmy conifers downward.

Reptiles

Crotaphytus wislizenii wislizenii Baird and Girard . . . Leopard lizard
Usually associated with sand below pigmy conifers and may occur in Tsegi Canyon branches.

Holbrookia maculata approximans Baird . . . . Speckled earless lizard
Found in the lowland flats of Klethla Valley and may occur in the low bottoms of Tsegi Canyon branches.

Phrynosoma douglassi hernandesi Girard . . . . Mt. short-horned lizard
Well distributed through pigmy conifers and lower lands.

Sceloporus undulatus elongatus Stejneger . . . . Northern plateau lizard
Usually associated with cliffs and rocks from pigmy conifers downward.

Sceloporus graciosus graciosus Baird & Girard. . . Sagebrush lizard
As common name indicates, it is usually associated with sagebrush.

Teidae (family) . . . . Whiptails and racerunners

Cnemidophorus tigris septentrionalis Burger . . . Northern whiptail
This checkered or spotted lizard is usually associated with open flats or sandy areas.

Cnemidophorus sacki innotatus Burger . . . . Plateau whiptail
This striped lizard overlaps the habitat of the preceding spotted lizard but usually occurs at slightly higher elevations and may be found in Betatakin Canyon.

SNAKES

Colubridae (family) . . . . Colubrid snakes

Thamnophis elegans vagrans Baird & Girard. . . . Wandering garter snake
Found on Laguna Creek west of Kayenta and could well extend up the Tsegi Canyon to Betatakin.

Masticophis taeniatus taeniatus Hallowell. . . . Desert striped whipsnake
Well distributed through the region and could well occur at all levels at Betatakin.

Pituophis catenifer deserticola Stejneger. . . . Great Basin gopher snake
A dry land snake that could occur in pigmy conifers or in Betatakin Canyon.

Lampropeltis getulus californiae Blainville. . . . California kingsnake
Variety boylii B & G, found near Tuba City and might be found in Betatakin Canyon.

Crotalus viridis nuntius Klauber . . . . Hopi rattlesnake
This is the small pink rattler of lowland sandy areas.

Crotalus viridis viridis Rafinesque . . . . Prairie rattlesnake
This has a greenish tinge and usually occurs at intermediate or higher altitudes, known in the Tsegi system only from a small area near Swallow Nest, 3½ miles above Marsh Pass (Milton Wetherill).

MAMMALS

Among the mammals, only the bats can, like the birds, fly over many habitats and select the ones they prefer. They are mostly nocturnal foragers through air spaces for food and retire to suitable secluded shelter for rest in the daytime. Most of them prefer dark caves, cracks or crevices in cliffs. Since Betatakin Canyon is well supplied with daytime retreats and provides a generous supply of night-flying insects from the dense vegetation in the canyon, it is to be expected that most of the bats endemic in the southwest will occur here. Dr. S. D. Durrant has estimated that the following bats should be present:

MAMMALIA (class) . . . . Mammals

CHIROPTERA (order) . . . Bats

Vespertilionidae (family) . . . . Vespertilionid bats
- *Myotis volans interior* Miller . . . . Long-legged myotis
- *Myotis californicus stephensi* Dalquest. . . . . . . California myotis
- *Pipistrellus hesperus hesperus* (A. Allen) . . . . Western pipistrelle
- *Eptesicus fuscus pallidus* (Young) . . . . Big brown bat
- *Corynorhinus townsendi pallescens* Miller. . . . . . Big-eared bat
- *Antrozoas pallidus pallidus* (LeConte) . . . . Pallid bat

RABBITS

The most commonly observed mammals on the landscape are the rabbits. They occur almost everywhere but are probably not as common in heavy forests as in the more brushy or open habitats. Jack rabbits which live on the surface and hide in the daytime in special "forms" or shelters are usually active at night and are more conspicuous in the evening or early morning. The cottontails that usually retreat to burrows in the daytime are usually more secretive than the jack rabbits and not so conspicuous. Betatakin is within the range of the following rabbits that should be found here. Of the two cottontails that are likely to overlap in habitat, the Nuttal is likely to be found at slightly higher elevations than the Audubon.

LAGOMORPHA (order) . . . . Rabbits and allies

Leporidae (family) . . . . Rabbits
- *Lepus californicus texianus* Waterhouse. . . . . Black-tailed jack rabbit
- *Sylvilagus nuttallii pinetus* (J. A. Allen). . . Nuttall cottontail
- *Sylvilagus audubonii warreni* Nelson . . . . . . Desert cottontail

RODENTS

Most numerous of all the mammals in this region are the rodents although many of them, especially the nocturnal species, are seldom observed in nature. All of the local rodents, except the porcupine, use underground burrows. Of those that do, all except the pocket gopher, habitually forage above ground and retreat to the burrow for shelter, rest and nesting. Ordinarily, they control small territories around their burrows. Many of them are nocturnal foragers and are hidden in their burrows in the daytime. Those that are active in the daylight, mainly the squirrels, chipmunks, and prairie dogs, may be conspicuous elements of the fauna on the landscape. The following rodents are estimated by Dr. Durrant to occur in this region although some of them may not be found in the monument.

RODENTIA (order) . . . . Rodents

Sciuridae (family) . . . . Squirrels and allies
Cynomys gunnisoni zuniensis Hollister. . . . Gunnison prairie dog
Citellus spilosoma cryptospilotus (Merriam). Spotted ground squirrel
Citellus variegatus grammurus (Say). . . . . Rock squirrel
Citellus leucurus cinnamomeus (Merriam). . . White-tailed antelope squirrel
Eutamias cinereicollis cinereicollis (Allen) Gray-collared chipmunk

Geomyidae (family) . . . . Pocket gophers
Thomomys bottae aureas Allen . . . . Valley pocket gopher

Heteromyidae (family) . . . . Kangaroo rats and allies
Perognathus flavus hopiensis Goldman . . . . Silky pocket mouse
Perognathus apache apache, Merriam . . . . . Apache pocket mouse
Perognathus intermedius crinitus Benson. . . Rock pocket mouse
Dipodomys ordii longipes (Merriam) . . . . . Ord's kangaroo rat

Cricetidae (family) . . . . Native rats and mice
Onychomys leucogaster pallescens Merriam . . Northern grasshopper mouse
Reithrodontomys megalotis megalotis (Baird). Western harvest mouse
Peromyscus crinitus auripectus (Allen) . . . Canyon mouse
Peromyscus maniculatus rufinus (Merriam) . . Deer mouse
Peromyscus maniculatus sonoriensis (LeConte) Deer mouse
Peromyscus boylii rowleyi (Allen). . . . . . Brush mouse
Peromyscus truei truei (Shufeldt). . . . . . Pinyon mouse
Peromyscus difficilis nasutus (Allen). . . . Rock mouse
Neotoma stephensi relicta Goldman. . . . . . Stephen's woodrat
Neotoma albigula laplataensis F. W. Miller . White-throated woodrat
Neotoma cinerea arizonae Merriam . . . . . . Bushy-tailed woodrat

Erethizontidae (family) . . . . American porcupines
Erethizon dorsatum couesi Mearns . . . . . . Porcupine

CARNIVORES

In contrast with the rabbits and rodents, which are mainly vegetarian or insectivorous in diet, are the carnivores of this region that are primarily predators on vegetarians. In general, the rabbits and rodents have a higher rate of reproduction than the carnivores and supply extra numbers beyond those needed to maintain themselves that can be harvested by the carnivores as prey without disrupting the prey populations. Most of the predators of this region concentrate attention upon capturing rabbits and rodents but others are concerned mainly with the ungulates to be treated next in this sequence.

In general, carnivore population numbers will be regulated largely by the numbers of surplus prey that they can harvest. In turn, they exert a regulating pressure upon prey population numbers, but it must not be assumed that they are the only regulators. Weather, parasites, diseases, food supplies and many other lesser factors play their parts in helping to regulate population numbers, relegating the influence of predators to an important place in a series of controls.

Human experience has shown that one of the most efficient ways of increasing the crop of wild game for human taking is the reduction of predators so that man can harvest what the predators would otherwise take. A small area like Navajo National Monument cannot be managed on national park standards, independent of control practices in surrounding areas. It is entirely possible that reduction of predators outside may allow undue increases of prey within that cannot be controlled without human intervention. This is a problem that will need attention over the years.

The case history of the Kaibab Game Preserve in Kaibab National Forest is a good example that may be useful in interpretive planning. When set aside as a game preserve in the first decade of this century, deer populations were exceedingly low. A concerted campaign against deer predators, mountain lions, coyotes and wild cats, brought such rapid resurgence of deer populations that within the third decade deer were so numerous they were overgrazing their range, destroying much of the vegetation cover, and starving to death by the thousands on their winter range. Such a startling change brought reversal of policies and provided for human hunting to save a smaller population of deer from the carnage of heavy over-populations.

Dr. Durrant has estimated that the following carnivores may occur in the region but some of them may not be found in Betatakin Canyon:

CARNIVORA (order) . . . . Carnivores

Canidae (family) . . . . Coyotes, foxes and allies
  Canis latrans mearnsi Merriam. . . . . Coyote
  Urocyon cinereoargenteus scotti Mearns . . . Gray fox

Procyonidae (family) . . . . Raccoon allies
  Bassariscus astutus arizonensis Goldman. . . Ringtail

Mustelidae (family) . . . . Weasels and allies
  Mustela nigripes (Audubon and Backman) . . . Black-footed ferret
  Spilogale putorius gracilis Merriam. . . . . ~~Spotted~~ skunk

Felidae (family) . . . . Cats
  Lynx rufus baileyi Merriam . . . . Bobcat

UNGULATES

Heavy grazing of domestic sheep in suitable areas around the monument certainly reduces the potential grazing capacity for native wild ungulates in the region and the small area within the monument is not likely to affect this potential significantly. The only wild ungulate that would occur naturally inside the monument is the mule deer but it has doubtless been exterminated in this part of the Navajo Country. It is estimated by mammalogists that the natural range of the pronghorned antelope included some of the desert flats in this region, but it has also doubtless been exterminated here. These two ungulates listed below were probably present during aboriginal times.

ARTIODACTYLA (order) . . . . Even-toed ungulates

Cervidae (family) . . . . Deer and allies
  Odocoileus hemionus crooksi (Mearns). . . . Mule deer

Antilocapridae (family) . . . . Pronghorn
  Antilocapra americana americana (Ord) . . . Pronghorned antelope

INVERTEBRATES

Invertebrates have not been well studied in this region. It is known in a general way that there is a large population of insects, numerous arachnids, a few millipeds, centipeds, and crustaceans, and several mollusks inhabiting the monument. Local mollusks are associated with dense or medium dense vegetation, most of them inhabiting moist litter under trees or bushes. Among other arthropods, centipeds may be found under stones almost any place but millipeds are likely to be more limited, like the mollusks, to moist litter, mainly under the deep canyon vegetation. Insects may be found in practically all habitats, aquatic and terrestrial. Isopods are likely to be limited to moist litter habitats but other crustaceans occur in streams or ponds, at least one in temporary pools that fill after rainstorms.

MOLLUSKS

Most mollusks are associated with water or moist habitats but a few are adapted to medium or mesic conditions of moisture in the habitats they occupy. None is adapted to live in the severe deserts of the southwest. The driest habitat occupied is likely to be that under juniper trees in the pigmy conifers probably occupied by a species of Pupilla. The deep canyon vegetation in Betatakin is a veritable oasis for snails which live mainly in the shady litter under trees and bushes. Those known to occur here in the canyon, collected by Milton Wetherill and Angus M. Woodbury (specimens at University of Utah) in 1938 include the following:

GASTROPODA (class) . . . . Snails

Helicidae (family) . . . . Helix snails
Vallonia pulchella (Muller). . . . . Smooth midget snail

Pupillidae (family) . . . . Columnar snails and relatives
Vertigo coloradensis (Cockerell) . . . . Colorado columnar snail

Achatinidae (family)
Cochlicopa lubrica (Muller) . . . . Fusiform snail

Zonitidae (family) . . . . Leaf snails and allies
Vitrina alaskana Dall . . . . Alaskan glassy snail
Vitrea indentata (Say) . . . . Indented leaf snail
Euconulus fulvus alaskensis (Pilsbry). . . . . Conical leaf snail
Zonitoides arborea (Say) . . . . Tree snail

Endodontidae (family)
Gonyodiscus cronkhitei (Newcomb) . . . . Cronkhite snail
Gonyodiscus cronkhitei anthonyi (Pilsbry). . . Anthony snail

CRUSTACEANS

Crustaceans are mainly marine organisms but some are freshwater forms and a few of the isopods have achieved terrestrial existence under humid conditions. Adaptations that permit use of aquatic gills for breathing in air include gill covers that help protect them from desiccation, living in humid habitats, activity when humidity is high, and curling into a ball (pill bug) during dry conditions.

Crustaceans

Freshwater forms are common in most streams and they sometimes occur in small streams or springs of desert regions, especially where dense aquatic vegetation provides suitable habitat. The following are known to occur in this region and may occur at Betatakin.

CRUSTACEA (class) . . . . Crustaceans
Data from Stanley Mulaik

ISOPODA (order) . . . . Isopods (pillbugs)

There are no known native isopods in this region but exotic species are known to follow modern human extension. There were probably none in Betatakin when the aborigines lived there but may have been introduced since then. There are probably none in the pigmy conifers but some species may be found in the litter under the vegetation in the deep canyon.

Armadillidiidae (family)

Armadillidium vulgare Latreille 1804
A ubiquitous isopod found almost everywhere and widely distributed in Arizona and Utah, likely to be found at Betatakin.

Porcellionidae (family)

Cylisticus convexus De Geer 1778
Associated with human activities mainly in streamside vegetation under litter and logs and likely to occur in the deep canyon.

Metaponorthus pruinosus (Brandt) 1853
Another widespread homophile likely to occur in Betatakin.

Porcellio laevis Latreille 1804
Occurs throughout Arizona and southern Utah.

Porcellio scaber Latreille 1804
Known from Utah and Arizona; it should be here.

NOTOSTRACA (order)

Apodidae (family)

Apus longicaudus LeConte. . . . Tadpole shrimp
One of the puzzles of the American southwest, it is found in temporary pools and playa lakes almost everywhere, active when water is present, disappearing when dry. Specimens were taken from a pool in the slick rock above the canyon on Sept. 21, 1962, the next day after it rained and filled the pool. Its life history is not known.

AMPHIPODA (order) . . . . Scuds and allies

Talitridae (family)

Hyallela knickerbockeri (Bate) 1862
Widely distributed in springs and small streams of surrounding region and may be expected in aquatic vegetation in small streams in the deep canyon.

Gammaridae (family)

Gammarus fasciata Say
Like the preceding, it may be found in aquatic habitat of Betatakin.

MILLIPEDS

Millipeds are in general very sensitive to low moisture conditions and are not abundant in desert areas. They occur mostly in the vicinity of springs and streams, under dense vegetation, or in caves of certain types. Being slow moving creatures of sedentary habits, they have in the course of time responded by adaptation to factors of isolation to a remarkable degree and species are often restricted to very limited areas or to a single oasis or canyon. It is probable that distinctive forms may be found in the dense vegetation of Betatakin Canyon.

In desert areas, most species burrow into deep litter or into the ground during dry weather, sometimes to considerable depths and remain dormant until a rain or fresh stream activates them and they regain the surface. Millipeds are often missed in general collecting but special attention to hunting them at different seasons of the year, especially in the spring when soils and litter are moist or after a storm that has brought them to the surface may bring to light forms that are now unknown.

So far as known, little collecting of millipeds has been done in Betatakin but the following are known to occur in this region or in neighboring areas and are suspected of occurring here. There may be others.

Millipeds have developed special adaptations that help protect themselves from many marauders that would otherwise prey upon them. One of these adaptations is a chemical that is capable of generating poisonous cyanide gas. The chemical substance stored in a chamber can be released through a valve into a chamber containing a catalyst that generates the gas. This passing out through an opening above each leg is an effective repellant to ants and other would-be predators.

DIPLOPODA (class) . . . . Millipeds
Data from R. V. Chamberlin

JULIDA (order) Chamberlin 1938

Paraiulidae (family) Bollman 1893

<u>Aniulus bollmani</u> Causey 1952

A widespread species known from Arizona and Utah as well as more eastern states may be represented here.

<u>Taijulus tiganus</u> (Chamberlin) 1910

A common Utah milliped inhabiting streamside vegetation may extend into Arizona.

CHORDEUMIDA (order) Chamberlin 1943

Rhiscosomididae (family) Sylvestri 1909

<u>Tingupa</u> Chamberlin 1910

A species of this genus may be represented at Betatakin.

Lysiopetalidae (family) Wood 1865

<u>Colactis</u> Loomis

Species of this genus occur in Arizona in narrow geographical ranges. One may be represented here.

SPIROBOLIDA (order) . . . . Cylindrical millipeds

Atopetholidae (family) Chamberlin 1918

Arinolus Chamberlin 1940

Members of this genus are common in Arizona where they seem prone to speciation under conditions of isolation and are likely to be represented in Betatakin. Other genera may also be represented here.

CENTIPEDS

As centipeds are carnivorous and free ranging in habit, the species are usually more widely distributed than the millipeds and do not show as much restrictions to local ranges. They are usually easy to find and are generally well known. Like other desert invertebrates, they are generally restricted by lack of moist habitats but are free to move around to find suitable places. Ordinarily, they are active at night or after storms when humidity is most favorable in preventing desiccation. The following centipeds probably occur in the region and may be found at Betatakin.

CHILOPODA (class) . . . . Centipeds
Data from R. V. Chamberlin

SCOLOPENDRA (order)

Scolopendridae (family)

Scolopendra polymorpha Wood. . . . The centiped

This large form, well known throughout the southwest as "the centiped" is likely to be found at Betatakin

Geophilidae (family)

Members of this group are commonly found in leaf litter or underlying soil.

Geophilus rubens Say

This wide-ranging species occurs across the United States and is likely to occur in this region.

Chilenophilidae (family)

Arctogeophilus xenoporus (Chamberlin)

Common in Utah as far south as Washington and San Juan counties and may extend southward into Arizona.

Himantariidae (family)

Gosiphilus minor arizonicus (Chamberlin)

LITHOBIIDA (order)

Short fast moving centipeds, commonly collected.

Henicopidae (family)

Lamyctes pinampus Chamberlin

A western species known from southern Utah and may extend into Arizona.

Gosibiidae (family)

Gosibius arizonicus Chamberlin

Known from Arizona and southern Utah.

Centipeds

Lithobiidae (family)
Lithobius arizonae Chamberlin
Ranges from Arizona into San Juan and Washington counties, Utah.

Oabius sanjuanus Chamberlin
Known from the San Juan River banks.

Tidabius tivius Chamberlin
Widespread across the country; known from San Juan County and adjacent areas.

Ethopolidae (family)
Archepolys gosobius Chamberlin
Known from southeastern Utah and may extend into Arizona.

INSECTS

Insects are so ubiquitous and so varied that they may be found in all habitats - pigmy forest, deep canyon, rocks and cliffs, and springs or streams of water. They are certain, when better studied, to include species of nearly all the major groups ranging from the simple primitive wingless forms through intermediate stages of life histories passing through incomplete metamorphosis such as eggs, nymphs, and adults, to complete metamorphosis of eggs, nymphs, pupae, and adults, and even to hypermetamorphosis in which the nymphs have several specialized forms.

They will also include species that range the gamut of feeding, from aquatics that feed in the water and terrestrial forms that feed on vegetation through predators to parasites and hyperparasites. No attempt will be made to identify the species that may occur at Betatakin. Only some general considerations of major groups will be given.

Aquatic Insects

Some of the major groups of insects are primarily aquatic organisms in their developmental stages, but several of the major orders that are primarily terrestrial, have aquatic representatives. Aquatic insects usually spend their nymphal or larval and their pupal stages in the water but emerge into the air for reproduction in their adult stage. A number of aquatic bugs and beetles are aquatic in the adult stage also but carry bubbles of air with them for use in their air-breathing apparatus. Those primarily aquatic groups include the mayflies (Ephemeroptera), the dragonflies (Odonata), the stoneflies, (Plecoptera), and the caddisflies (Trichoptera). There is a probability that each of these orders may have one or more representatives in the stream of the deep canyon. Adult dragonflies are not uncommon and are conspicuous inhabitants of the landscape. Others may require careful observation to find.

Aquatic representatives of terrestrial orders are likely to be found among the bugs (Hemiptera), the moths (Lepidoptera), the beetles (Coleoptera), and the two-winged flies (Diptera). In 1958, collecting in the tributaries of the Colorado River in Glen Canyon yielded specimens of 7 species of mayflies, 13 dragonflies, and 8 caddisflies among the aquatic orders and 11 species of bugs, one moth, 23 beetles, and 18 two-winged flies (Smith, Musser and McDonald, 1959:186-193). Since Betatakin lies within the drainage system into Glen Canyon there is a probability that representatives of these groups will be found in the stream in the deep canyon and some may even occur in temporary pools.

Terrestrial Insects

Representatives of the primitive wingless insects, the springtails (Collembola), and possibly of the bristle-tails (Thysanura) probably occur in many places especially in the litter under vegetation. Most of them are so small that they are easily overlooked.

The grasshoppers, crickets and allies of the order Orthoptera are certain to be more obviously represented. Grasshoppers are likely to be encountered in almost every habitat on warm summer days as they hop or flutter in the air but the crickets (Gryllidae), praying mantids (Mantidae), and the walking sticks (Phasmidae) are likely to be concealed among the living vegetation or the litter under it, while the "bald-headed" sand cricket, (Stenopelmatus) is likely to be buried in the soil or sand in the daylight and abroad at night.

Termites (Isoptera) are not well adapted to desert conditions and may not be plentiful, if not absent, in the pigmy conifers and desert but should be common in the dense vegetation of the deep canyon, especially in dead and decaying logs or smaller litter.

There will be many species of bugs that are vegetarians, especially among the families of the stink bugs (Pentatomidae), the chinch-bugs (Lygaeidae), the leaf bugs (Miridae), and lesser numbers of such families as squash bugs (Coreidae), stilt bugs (Neididae), lace bugs (Tingidae), and other smaller groups. These have the mouthparts adapted as a tube for sucking juices and pierce plant leaves, flowers or stems to get the sap. In addition, there are numerous species that suck the liquids (blood) from animals. Some of them feed on small invertebrates, including other insects while others feed on vertebrates, such as reptiles, birds and mammals, including man. These include the well known kissing or assassin bugs (Reduviidae), damsel bugs (Nabidae), ambush bugs (phymatidae) which are camouflaged to look like flowers and ambush other insects that come there for nectar, and the small pirate bugs (Anthocoridae) that feed on small plant lice (aphids).

Among the closely related homopterans (Homoptera) that also have sucking mouthparts and many have the whole wing transparent instead of only one half as in the Hemiptera, there may be ample representation here of plant lice (aphids), leafhoppers (Cicadellidae), treehoppers (Membracidae), spittlebugs (Cercopidae), and cicadas (Cicadidae). These are mostly small insects except the cicadas which are conspicuous both in size and in song. These spend their larval and pupal stages underground, in some cases remaining there for years before emerging as adults. Plant lice may be found at times on almost any of the common plants. Other kinds may be less common and more difficult to find unless they occur in irruptive numbers when the hoppers may look like a swarm as you pass through them.

There may be a few representatives of the nerve-winged neuropterans, especially of the lacewings and the antlions. The conical craters of the larvae of the latter are very conspicuous in fine sandy areas, especially in protected places under overhanging rocks or ledges. The delicate lacewings sometimes collect around lights at night.

Perhaps the most numerous representatives will be found among the beetles. Here will be several species of metallic (Buprestidae) and long-horned (Cerambycidae) wood borers that bore as larvae into many kinds of trees; leaf beetles

(Chrysomelidae) that eat the soft parts out of leaves; flower, fruit and seed beetles of different families; bark beetles (Cucujidae, Scolytidae) that eat the cambium layer under the bark; ground beetles (Carabidae) and darkling ground or stink beetles (Tenebrionidae); root beetles whose larvae live underground (Scarabaeidae); and many other groups that are mostly plant feeders. In addition, there are many predaceous forms that feed on other insects or other invertebrates, such as the ladybug beetles that feed on many kinds of insects, the tiger beetles (Cicindelidae), scavenger beetles such as the dermestids (Dermestidae), several groups of predaceous aquatic beetles, and many other groups with specialized adaptations.

Among the Lepidoptera, there will be representatives of many families of butterflies and moths although few species have been collected and identified. A few that are known to occur in the region and may occur here include representatives of the following families: the beautiful swallowtail butterflies, the sulfur and white butterflies whose larvae are great agricultural pests, the brush-footed butterflies, the lycaenid butterflies, the familiar hawk moths, tiger moths, measuring worm moths, snout moths, gelechid moths and many others.

Among the two-winged flies, we can expect a few pestiferous mosquitoes, gnats, deerflies, snipeflies, flesh flies, tachinid flies, and muscid flies. There may be many species of the mimicking beeflies, pugnacious robber flies, attractive flower flies, and ephydrid flies. Lesser numbers of many other families will no doubt occur here. There may be a few species of parasitic flies of birds and mammals and these same vertebrates may harbor many species of parasitic fleas.

Among the four-winged hymenopterans, there will be many representatives of the ichneumons, wasps, bees, ants and allies. Most numerous will probably be the colonial ants found almost everywhere. Other numerous kinds will include the vespid paper wasps, the sphecid digger wasps, spider wasps, burrowing wasps, mining bees, leaf-cutter bees and honey bees. There may also be large numbers of ichneumon, braconid and chalcid parasites. Lesser numbers representing many other families may also be expected.

ARACHNIDS

Arachnids are primarily predaceous or parasitic forms with specialized mouthparts adapted for crushing and extracting the juices (blood) from small invertebrates or adapted for sucking blood from vertebrates. Spiders occur in almost every habitat and many of them are revealed by their webs even if they themselves are inconspicuous. Scorpions are usually active at night and are usually hidden in the daytime under rocks, logs or other shelter.

Solpugids of the order Solpugida are ferocious-looking tiny monsters that make their marauding expeditions at night when they are seldom observed by human eyes. They are widely distributed throughout the western states from Washington to Texas but are poorly known because so few specimens have been collected. They are almost certain to occur at Betatakin and any specimens found should be collected and preserved for scientific study. They may represent poorly known or new species.

Several species of parasitic ticks and numerous species of mites may be found on local vertebrates but they are not often likely to be observed in nature. Some of them are human pests and it is probable that the aborigines were plagued with them. Free-living mites occur in the litter under almost all plants.

ECOLOGY OF THE ABORIGINAL INHABITANTS

If it is assumed that landscapes today are the product of continuing natural processes of the past, the physiographic setting of the aboriginal inhabitants could not have been vastly different from the landscapes of today. There is little doubt that the canyon, the cliffs, the cave, the springs of water, the pigmy conifer forest, the deep canyon vegetation, and associated animals were essentially the same then as now, except for minor changes wrought by the natural processes of erosion, biotic modifications and human activities.

Among the natural processes of erosion affecting the landscape are (1) carrying silt from the land surface by rains and melting snows into streams that carry it away, (2) erosive cutting of washes or stream banks by floods, (3) undermining cliff bases by erosion of softer rocks and consequent spalling of the cliff face, (4) development of alcoves and caves by water emerging from cliffs, (5) covering rock faces with desert varnish, (6) blowing of sand and silt by winds, and many other processes.

Among the biotic modifications affecting the landscape are (1) covering the rock surfaces with lichens and mosses, (2) rooting of plants in soil and rock crevices that help to anchor the soil in place, (3) covering the surface with litter that helps to hold precipitation and prevent run-off, (4) shading the ground and slowing evaporation, (5) grazing the vegetation by animals, (6) trampling the litter into the soil by animals, (7) opening holes and turning the soil by burrowing animals and plant roots, (8) concentrating soil fertility in the surface layer, and many other processes.

Among post-aborigine human-associated activities that have affected the landscape at Betatakin are (1) heavy livestock grazing, especially in surrounding areas, (2) a cycle of wash-cutting erosion that lowered the stream bed leaving partial terraces of the former level, (3) exerting grazing pressure on palatable plants that reduces their proportion in the plant cover and gives emphasis to non-palatable plants, (4) reducing populations of many animals through food competition, (5) local extermination of the ungulates, deer, and prong-horned antelope, (6) reduction of carnivores by hunting and trapping and many other practices.

How much these landscape-changing processes have affected the Betatakin scene is not known and can only be accurately evaluated by careful investigation but a rough overall assessment indicates that (1) the agricultural lands used by the aborigines have reverted to natural vegetation or been washed away by wash-cutting erosion, (2) many rockfalls have broken away from the cliff faces, (3) aboriginal trails have been covered by erosion or overgrown with vegetation, (4) composition of the vegetation and associated animals have changed in minor undetermined ways, except for (5) extermination of the ungulate deer and antelope and reduction of their predators and (6) perhaps in other ways.

The most direct evidence of the ecology of the aborigines could be derived from artifacts found in the Betatakin ruins, but since they are not available, it will have to be deduced from (1) comparable data from other sources, (2) from present day ecological knowledge, and (3) assessment of potential value of biological resources by comparison with uses of similar resources by modern Indians in the region.

Ecology of Aborigines

Although those aboriginal people were gardeners raising maize (corn), beans, cucurbits, cotton, and turkeys, they were otherwise partly dependent upon and closely associated with the native flora and fauna. It is certain, therefore, that they must have been annoyed, infected, or infested with obnoxious pollens, diseases, pests, or parasites that may have been reservoired in or transmitted by native plants and animals. They must also have been affected directly by great fluctuations in the natural crops of native food plants, game, or other plants and animals utilized by them. Some of these major fluctuations activated by long-range weather conditions may have been instrumental in forcing the final evacuation of Betatakin probably prior to A. D. 1300.

The separation of Betatakin from other similar centers of culture in this region practically insures that there was a good deal of isolation, especially in the exchange of products. Commerce of any kind must have been limited to things that could be carried on the person since they had no beasts of burden nor wheeled vehicles. Travel into the Tsegi Canyon system was much easier than climbing the cliffs onto the plateau.

Betatakin lies in a region with a semi-arid climate where only the high mountains or deep canyons receive enough precipitation to maintain a dense cover of vegetation. The lower lands of the region have desert characteristics, sparse desert gray vegetation, dry washes, sharp physiographic features, blowing sand, and vivid green lines of thrifty foliage along streamsides. The gray desert plants usually show special characteristics adapted to parsimonious use of water, such as wax-coated leaves, protective hairs, leaves reduced in size or transformed into spines. Betatakin lies at an intermediate altitude where desert adaptations are not so severe.

The arid climate of the region is due largely to the nature of the winds that bring so little moisture with them and yield little precipitation. The general climate is characterized by low rainfall, low relative humidity, little cloudiness, great intensity of sunshine in summer, and great variations in temperature. It is well understood that precipitation ordinarily increases with altitude but the rate of increase is affected by other factors, especially physiography, winds, humidity and temperature. The precipitation and altitude at 18 stations in the surrounding region based upon U. S. Weather Bureau records up to 1957 have been plotted in Fig. 15 to show deviations from the assumed straight line relationships. Where Betatakin fits into the pattern is not known but it is probable that the bottom of the canyon would receive more precipitation than the line in the graph indicates for its altitude, probably as much as that received on the plateau in which it is cut. The pattern is probably little different from that affecting the aborigines.

Studies of the physiography, terrain, and climate give the impression that aboriginal populations must have been limited largely by the limited area available for agriculture or horticulture, the sparse crops gatherable from the native plants and animals, and the pests, parasites, and diseases that affected them. The amount of land available for agriculture will require further investigation to determine. The other factors can be estimated in a general way from other sources of information.

SOURCES

Averitt, Paul, Janis S. Detterman, John W. Harshbarger, Charles A. Repenning and Richard F. Wilson, 1955. Revisions in correlation and nomenclature of Triassic and Jurassic formations in southwestern Utah and northern Arizona. Bull. Amer. Ass'n. Petroleum Geologists, 39 (12):2515-2524.

Baker, A. A., C. H. Dana, and J. B. Reeside, Jr., 1936. Correlation of the Jurassic formations of parts of Utah, Arizona, New Mexico and Colorado. U S G S Prof. Paper, 183:47.

Brand, Donald D., 1937. Univ. of New Mexico Bulletin, Anthropological Series, 2:49-54.

Chamberlin, R. V. and D. T. Jones, 1929. A descriptive catalog of the Mollusca of Utah. Bull. Univ. Utah 19(4):1-203.

Durrant, S. D., 1959. Mammals of Glen Canyon. In Ecological studies of the flora and fauna of Glen Canyon. U U Anthro. Papers, 40:73-103.

Elmore, Francis H., 1944. Ethnobotany of the Navajo, Univ. New Mexico Bull. 392:17-90.

Hargrave, Lyndon L., 1939. Bird bones from abandoned Indian dwellings in Arizona and Utah. Condor 41:206-210.

Jones, Volney H., 1945. Archaeological studies in northeast Arizona, Univ. of Calif. Press, Berkeley. 159-160.

King, Dale S., 1949. Nalakihu Excavations at a Pueblo III Site on Wupatki National Monument, Ariz. North. Ariz. Soc. Science & Art, 23:183. Flagstaff.

McGregor, John C., 1941. Winona and Ridge Ruin. North. Ariz. Soc. Sci. & Art. 18:309, Flagstaff.

Muma, Martin H., 1951. The arachnid order Solpugida in the United States. Bull. Amer. Mus. Nat. Hist. 97(2):35-141.

__________ Supplement 1, 1962. Amer. Mus. Novitates, 2092:1-44.

National Park Service, 1962. Preliminary prospectus for road and trailside interpretation, Navajo National Monument. Southwest Region, National Park Service, Santa Fe, 35 pp.

Peck, George A., 1959. Pollen Survey of Metropolitan Salt Lake City, Utah. Your Health, Utah State Dept. Health, 16(3):1-16, Div. of Health Ed.

Robbins, Wilfred William, John Peabody Harrington and Barbara Freire-Marreco, 1916. Ethnobotany of the Tewa Indians, Smithsonian Inst. Bur. of Amer. Ethnology 55:38-75.

Smith, Gerald, Guy Musser, and Donald B. McDonald, 1959. Aquatic survey tabulation. Appendix A in Ecological studies of the flora and fauna of Glen Canyon. U U Anthro. Papers, 40:177-194.

SOURCES (continued)

Smith, Watson, 1952. Excavations in Big Hawk Valley Wupatki National Monument, Arizona. North. Ariz. Soc. Science & Art. 24:203, Flagstaff.

Steward, Julian H., 1938. Basin-Plateau Aboriginal Sociopolitical Groups, G P O, Bur. Amer. Ethnology, 120:346.

Stokes, W. L. and C. N. Holmes, 1954. Jurassic Rocks of South Central Utah. Fifth Annual Field Conference, Intermountain Association of Petroleum Geologists, p. 34-41.

Taylor, Walter W., editor of papers by 26 authors. 1957. The identification of non-artifactual archaeological materials. Nat. Acad. Sci.- Nat. Res. Council 565:1-64.

Woodbury, Angus M., 1931. A descriptive catalog of the reptiles of Utah. Bull. Univ. Utah 21(5):1-129.

__________1956. Ecological check lists. Dugway, Utah. U U Great Salt Lake Desert Series, Salt Lake City, 125 pp.

__________1960. Ecology of the aboriginal inhabitants of the Glen Canyon Region. Unpublished manuscript, 130 pp.

__________1959. Amphibians and reptiles of Glen Canyon. In Ecological Studies of the flora and fauna of Glen Canyon, U U Anthro. Papers, 40:135-148.

Woodbury, Angus M. and Henry N. Russell, Jr., 1945. Birds of the Navajo Country. Bull. Univ. Utah 35(14):1-160.

Yanovsky, Elias., 1936, Food plants of the North American Indians. U. S. Dept. of Agr. Misc. Publ. 237:1-64.