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SOME ASPECTS OF THE KNEELING NUN RHYOLITE TUFF

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The Kneeling Nun Rhyolite Tuff, or Kneeling Nun tuff as it is commonly called, was named by Elston (1953). It is a welded ash flow that crops out to the south and southeast of Santa Rita. A slide block of the tuff, called the Kneeling Nun, stands at the foot of the cliffs above the Santa Rita (Chino) Pit. The formation was named for this prominent landmark. The tuff has been mentioned by Kuellmer (1953) and was described by Jicha (1954) in outcrops of similar ash-flow tuff on the eastern side of the Black Range near Hillsboro and Lake Valley. Rocks closely resembling the Kneeling Nun tuff have been mapped or described by Kuellmer (1954) in the Black Range, and by Hernon and others (1964) north of Fierro.

The Kneeling Nun tuff is a crystal-rich rhyolite to quartz latite welded ash-flow tuff at its type area south of Santa Rita. Seriate and fractured phenocrysts, which consist mostly of quartz and of lesser and varying amounts of sanidine and plagioclase, constitute from about 25 to 60 percent of the rock. Megascopic biotite, opaque oxides and numerous lithic inclusions are also present. Pumice fragments, undetectable in hand specimen, can be observed in minor amounts under the microscope, but they are generally obscured by extreme welding and devitrification. The tuff ranges from 200 to 600 feet in thickness, and it dips southwest at an average of 10 degrees. The base is everywhere either disconformable on or transitional with clastic and volcanic units of the underlying Sugarlump tuffs. The upper surface is erosional.

The Kneeling Nun ash-flow tuff shows a zonal lithologic pattern corresponding to that of a simple cooling unit (terminology of Smith, 1960). All zones are transitional, the lower ones more abruptly so. Near Santa Rita the recognizable zones are, from the base up:

A. *Zone of poor to moderate welding.* This zone is characterized by incipient shard welding, little deformation, massive structure, and a white to grayish-pink color. Where the base is exposed, the zone is seen to rest disconformably on bedded and lenticular air-fall tuffs and water-worked sandstones of the Sugarlump tuffs. The thickness varies erratically and the zone is commonly missing. Where present, it has been previously grouped with the Sugarlump tuffs.

B. *Zone of moderate to dense welding.* Some part of this zone forms the usual Kneeling Nun—Sugarlump contact. Compaction, flattening, and welding of glassy components have given the rock a eutaxitic banding, which increases upward and then disappears where welding has been intense. Irregular to lenticular cavities are common, and the zone has a peculiar sheeted appearance. The color ranges from a mottled pink to pale red.

C. *Zone of dense welding.* Because of extreme welding this zone is dense and massive; it is a prominent cliff former. It has blocky to columnar jointing and forms the distinctive escarpment to the south of, and overlooking, the Chino Pit. Eutaxitic banding and pore spaces are generally absent. The rock is conspicuously rich in crystals and has a granitoid appearance. Color ranges from grayish-red to medium red.

D. *Upper zone of moderate to poor welding.* The upper zone is essentially the mirror image of zones A and B. The transition from the zone of dense welding is obscure and apparently irregular. Northeast of City of Rocks State Park the zone is recognized by the progressive upward development of eutaxitic banding and ashy nature above the columnar-jointed densely welded zone. These changes are paralleled by an increase in porosity and a lightening in color from medium red to grayish-pink. Fracture varies from blocky to sheeted. Mineral-filled, roughly lenticular cavities are common.

Weathered zones, buried stream channels, and an irregular surface indicate prolonged post-depositional erosion. Where the Kneeling Nun tuff is disconformably capped by later silicic flows and ash flows, the highest stratigraphic unit (zone D) is preserved. Normally, in a complete, simple ash-flow cooling unit, an upper zone of partial welding grades into a zone of no welding, i.e., into incoherent pumice. These features are not present in the type area, and because the material is easily eroded it is assumed to have been rapidly removed.

All parts of the Kneeling Nun tuff have been pervasively devitrified. In the densely welded zones the groundmass consists of spherulites of cristobalite and feldspar or of granophyric aggregates of quartz and feldspar. All pumice has collapsed and coalesced into wavy lenticles. In one partially devitrified specimen from the base of the zone of dense welding (C), large glassy areas contain compressed and distorted shards molded against and around the numerous phenocrysts. Distorted but individual shards remain in the zone of poor to moderate welding (A) at the base

of the ash flow. In the upper, moderately welded zone (D), vapor-phase crystallization has been superimposed on devitrification. Here ghost pumice structures contain coarse aggregates of silica and feldspar, and open spaces are lined with, or contain, meshworks of the same material. The latter are the mineral-filled vesicles characteristic of this zone.

A comparison of the character, zones, and zonal variations of the Kneeling Nun tuff with some established concepts of ash-flow tuffs (Smith, 1960; Ross and Smith, 1961) prompts the following observations:

1. The Kneeling Nun ash flow resulted from emplacement by flowage of a very hot, gas-emitting volcanic ash in essentially one episode. As such it constitutes, at the type area, a *simple* cooling unit.

2. Abrupt zonal variations at the base (zones A, B, and C) reflect changes due to an irregular buried topography. These variations are difficult to evaluate. Since the thickness of the Kneeling Nun cooling unit at any one place is the major control of degree and amount of welding, a thicker partially welded zone developed at the expense of the densely welded zone, may reflect a topographic high beneath the unit. The reverse condition is also true. The fact that the basal zones are generally thin may also indicate that the section is not far from the source area.

3. An unknown but perhaps considerable part of the Kneeling Nun tuff has been removed by erosion. Because of the appreciable average thickness of the densely welded zone, the high degree of compaction, the extent of devitrification, and the presence of granophyric groundmass quartz (if primary), the initial thickness of the cooling unit must have been considerably greater than the maximum at the type area (600 feet). Cooling was slow.

4. Pervasive devitrification, vapor-phase crystallization, and numerous large lenticular cavities common to some zones indicate that large quantities of volatiles were released from solution after emplacement. The cavities probably reflect the entrapment of this gas under a large lithostatic load.

5. All zones of the Kneeling Nun tuff are abnormally rich in crystals (for ash-flows), and this must have affected much of the original pyroclastic nature of the rock. This may also have some bearing on the paucity of large pumice fragments in those zones where welding would not have obliterated them. Some parts of the densely welded zone are essentially a crystal aggregate, containing up to 60 percent fractured, seriate phenocrysts. In thin section, the rock appears to be almost a mylonite. In contrast, the moderately welded zones average approximately 30 percent phenocrysts. These variations may be attributed to intense compaction upon welding.

6. Considering the lateral variation and wedging characteristics of typical ash-flow sheets and their zones with distance from source, we may assume that:

A. At the type area south of Santa Rita, the Kneeling Nun tuff represents a segment of the flow at an intermediate distance from its origin.

B. Near the source area of the Kneeling Nun tuff, the rock should be a massive, predominantly densely welded volcanic pile that could conceivably reach a thickness of 1500 to 2000 feet. In the absence of surface field relations it might be mistaken for a hypabyssal granitoid intrusive.

C. The distal end of the ash flow, if present and exposed, should be dominantly a poorly welded to non-welded tuff above a sequence of air-fall tuffs. It may bear little lithologic resemblance to any part of the Kneeling Nun tuff at the type area.

D. The simple cooling unit of Kneeling Nun tuff, at any distance from the immediate source, will probably grade into, interfinger with, and incorporate additional ash flows from other source areas. The ash flow will thus become one or more *compound* cooling units. The zonal and lithologic complexities introduced under such conditions may become enormous; this is particularly true of the complex volcanic and structural relations that exist to the north and northwest in the Mogollon Plateau (see Elston, this guidebook), and to the east in the Black Range. For genetic and time-space reasons, the simple (or compound) cooling unit is the logical map unit. However, it appears likely that descriptions based on only a few vertical sections rarely characterize the three-dimensional sheet. Only gross comparisons are possible over a large area. However, because of the dependence of ash-flow character on the numerous variables inherent in the system, the change in any one or set of variables will correspondingly affect the appearance of the rock body. It is thus unlikely that two or more welded ash flows will show no overall differences. Petrographic studies of phenocryst assemblages in conjunction with careful field work are the most significant techniques at present for differentiating the closely similar ash flows of a limited area.

The Kneeling Nun Rhyolite Tuff may be considered a "member" of an as yet unnamed and unrecognized compound cooling unit "formation." Based on such similarities in physical and chemical makeup as mentioned above, the following occurrences of ash flows are tentatively assigned to the simple cooling unit of which the Kneeling Nun is a part:

1. A belt of scattered east-dipping outcrops on the eastern flank of the Black Range. This belt generally

runs from south of Lake Valley to north of Hillsboro. In Tierra Blanca Canyon, 6 miles southwest of Hillsboro, the section appears as (or more) complete than that south of Santa Rita. The upper moderately welded zone extends upward into the zone of poor welding.

2. Scattered outcrops underlying late basaltic andesite 1 to 2 miles north of Fierro. The outcrops are thin and they consist of the lower poorly to densely welded zones. The rock rests for the most part on the Cretaceous Colorado Formation.

3. The part of the Black Range mapped by Kuellmer (1953), consisting largely of a massive, tabular body of welded rhyolitic ash-flow tuff with an estimated minimal thickness of 1300 feet. The ash flow extends along the crest and the western slopes of the range southward to the Cooks Peak area. Its northward extent is unknown. In all the areas I have observed, the body of the rock is partially to densely welded and is identical or nearly identical to the corresponding zones of the Kneeling Nun section, 10 to 20 miles to the southwest. A thin belt of non-welded to poorly welded tuff, which overlies the ash flow and underlies a Miocene(?) clastic unit, crops out 2½ to 4 miles northeast of San Lorenzo. This may be a portion of the stratigraphic cap of the ash-flow unit. Abundant small foreign inclusions pervade the rock, and phases containing xenoliths 10 to 20 feet in diameter were mapped west of Kingston by Kuellmer. He has interpreted this and other evidence as indicating proximity of the area to a major eruptive center. Considering all stratigraphic and lithologic evidence to date, it appears as if this was in fact the vent area of the Kneeling Nun cooling unit. Work currently in progress should determine the validity of this hypothesis.

The proximity in space and time of the Sugarlump tuffs to the Kneeling Nun ash flow, including a number of petrologic similarities, strongly suggests that these two have, in part at least, a genetic affinity. One or more of the volcanic units in the Sugarlump tuffs may belong to a compound cooling unit of which the Kneeling Nun may be a part, as previously mentioned; some may be the air-fall ash that preceded emplacement of the Kneeling Nun simple cooling unit.

The problems inherent to ash-flow tuff interpretation are numerous and varied. The recognition of such tuffs and their zonal variations is a problem, and the distinction between welded tuff and lava flow is often obscure. For the complete geologic understanding of any volcanic terrane in which they occur, a knowledge of ash flows and their variations is essential. The Mogollon Plateau, and indeed most of southwest New Mexico, is just such a volcanic terrane. The so-called Datil Volcanic Series includes welded and non-welded ash-flow tuffs in tremendous volume. The Kneeling Nun ash flow is one small example. It is to be expected that, as studies in southwest New Mexico progress, many, if not most, of the rhyolitic to dacitic "lava flows" will be reinterpreted as welded ash-flow tuffs.

It is significant that the Kneeling Nun simple cooling unit represents the essentially en masse emplacement on the surface of many cubic miles of pyroclastic material. This in itself implies a certain amount of structural readjustment at or near the source area to account for the sudden draining of the magma chamber. Moreover, the Kneeling Nun tuff belongs to a volcanic complex (Datil) representing apparently continuous evolution of ash-flows that were closely allied in space and time, and the total volume of this pyroclastic material undoubtedly approaches many thousand cubic miles in southwestern New Mexico. Much of the late Cretaceous and early Tertiary structural evolution must be related to these deposits. Great volumes of additional magma are presumed to have remained intrusive as plutons and stocks, and thus to have produced many of the ore deposits of the region. The great volumes of ash-flow material on the Mogollon Plateau suggest that this topographic feature is a large volcano-tectonic depression, being the accumulative result of post-extrusion collapse structures. The Kneeling Nun ash flow is probably directly associated with a part of the development of this tectonic feature.

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