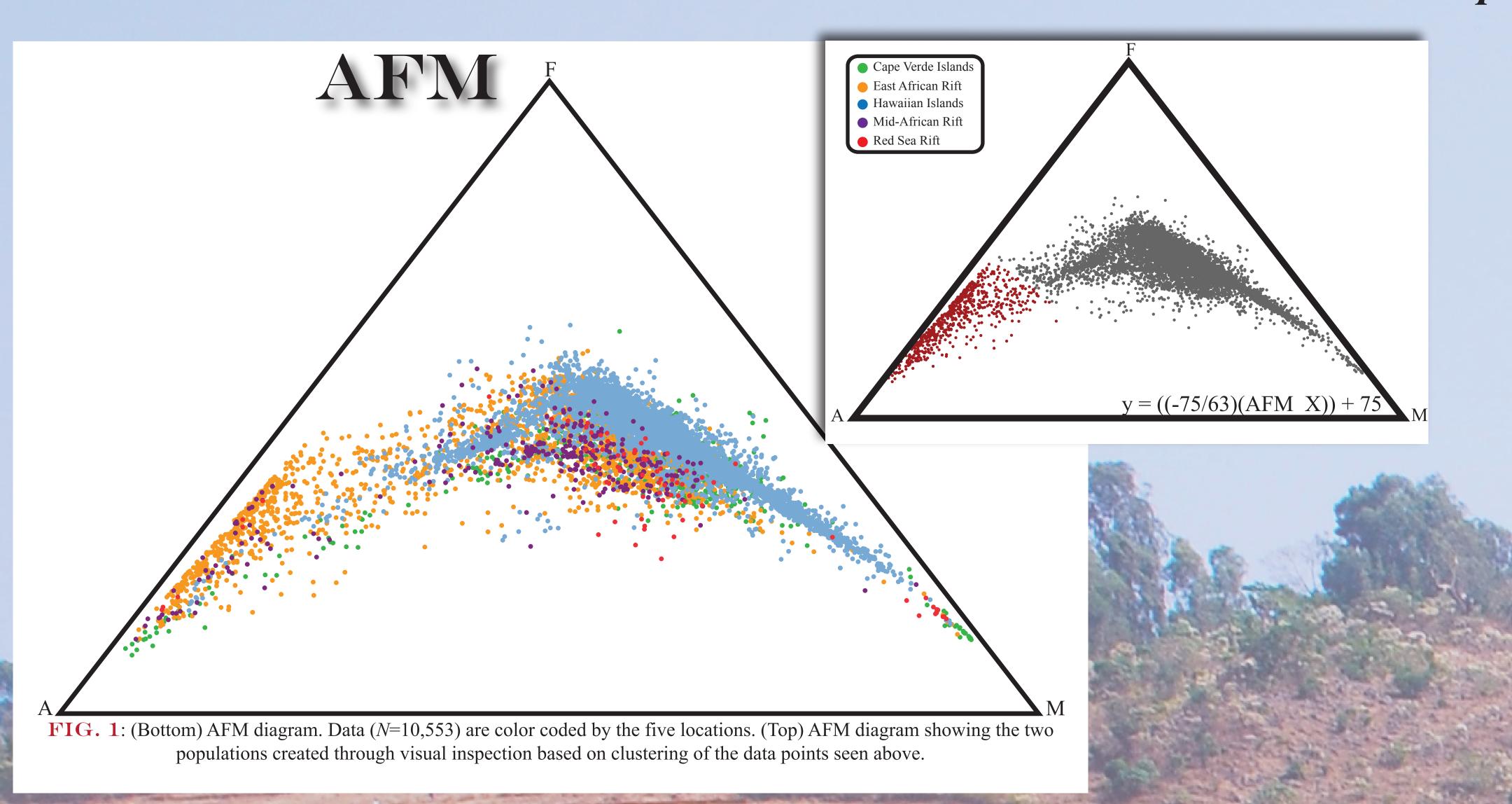
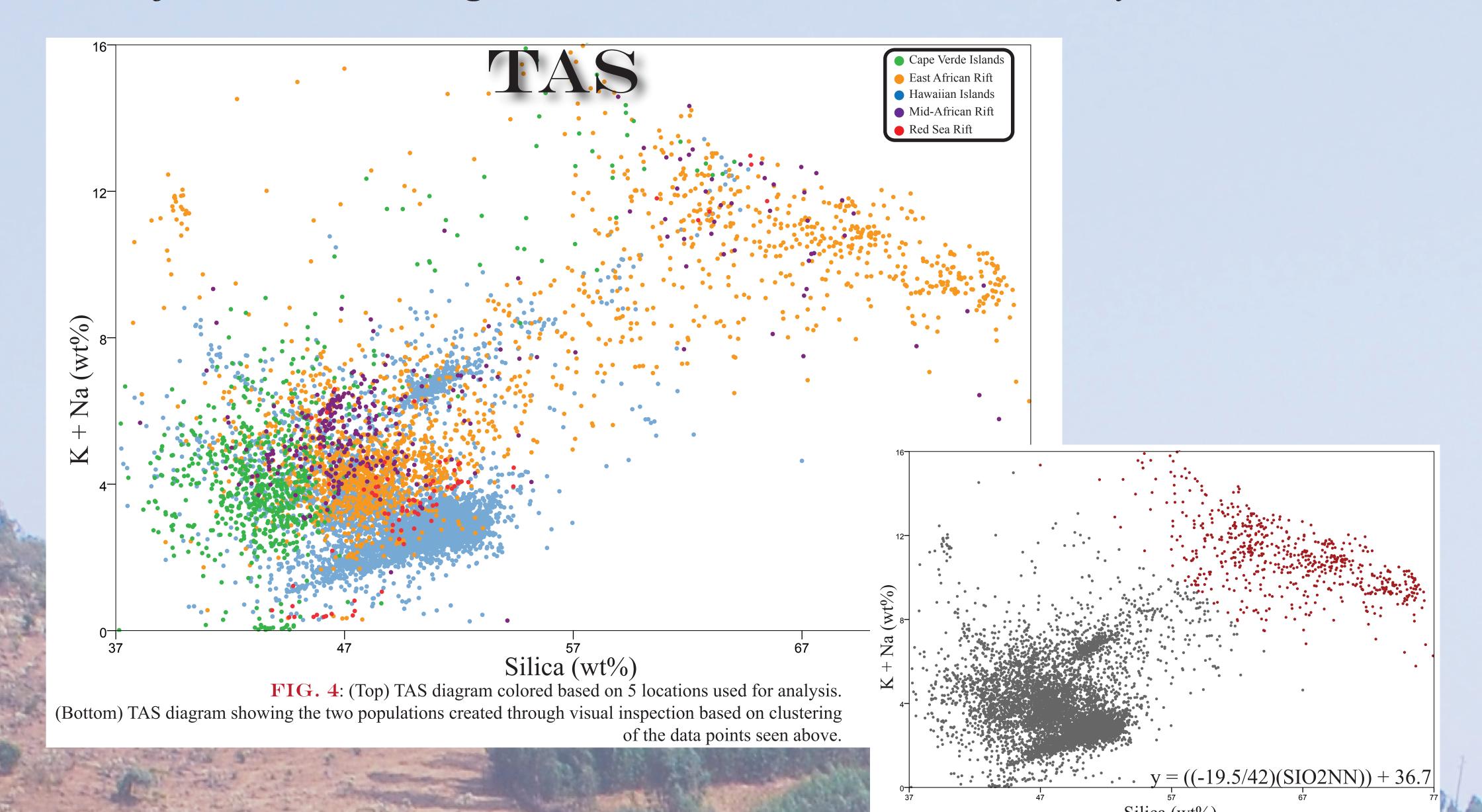
# STATISTICAL COMPARISON OF THE GEOCHEMISTRY OF VOLCANIC BEDROCKS AND SOILS FROM PODOCONIOSIS-ASSOCIATED REGIONS ON THE AFRICAN CONTINENT

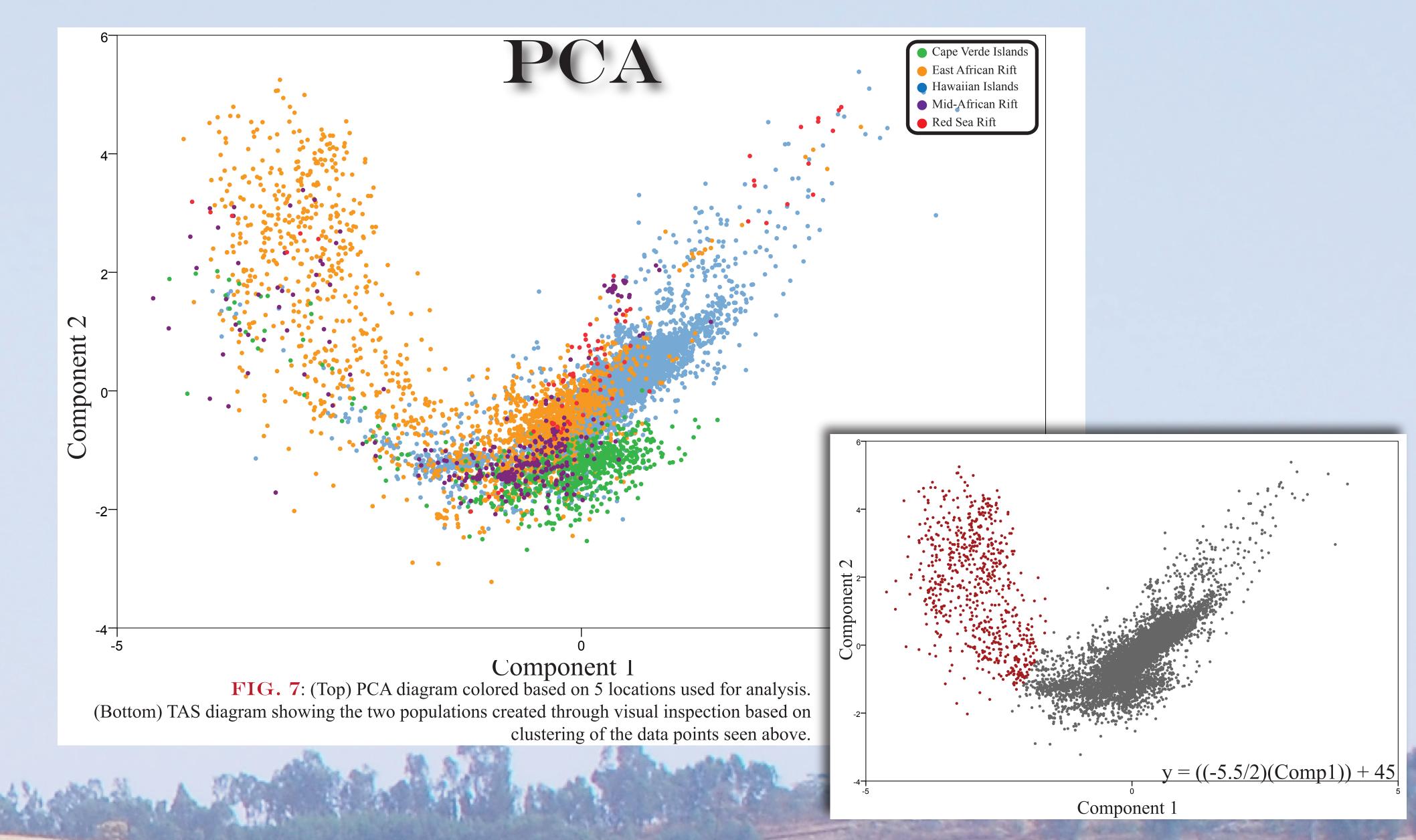


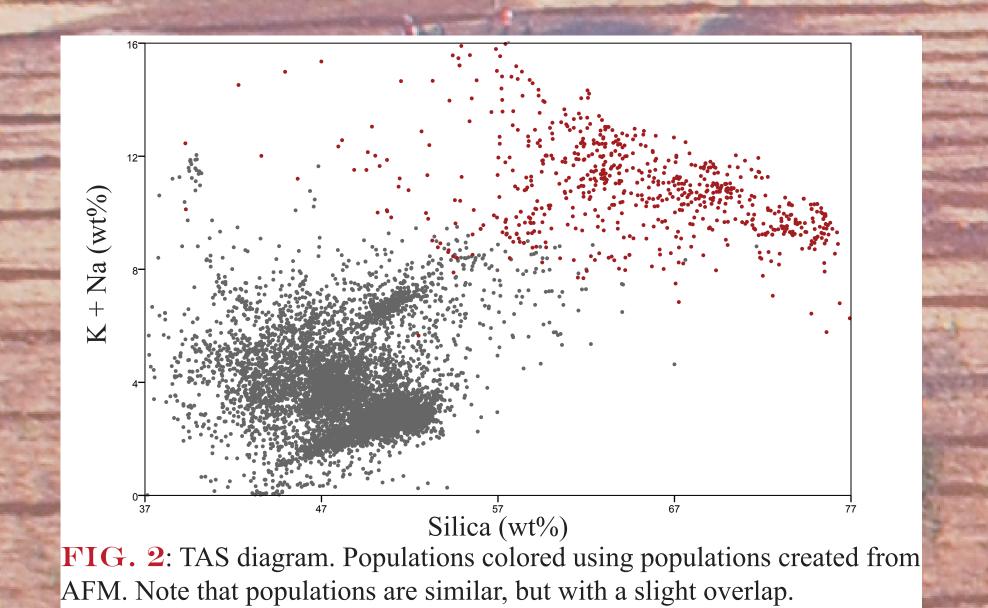
Jamey N. Cooper, Allen M. Cooper, Benjamin L. Clausen, and Kevin E. Nick

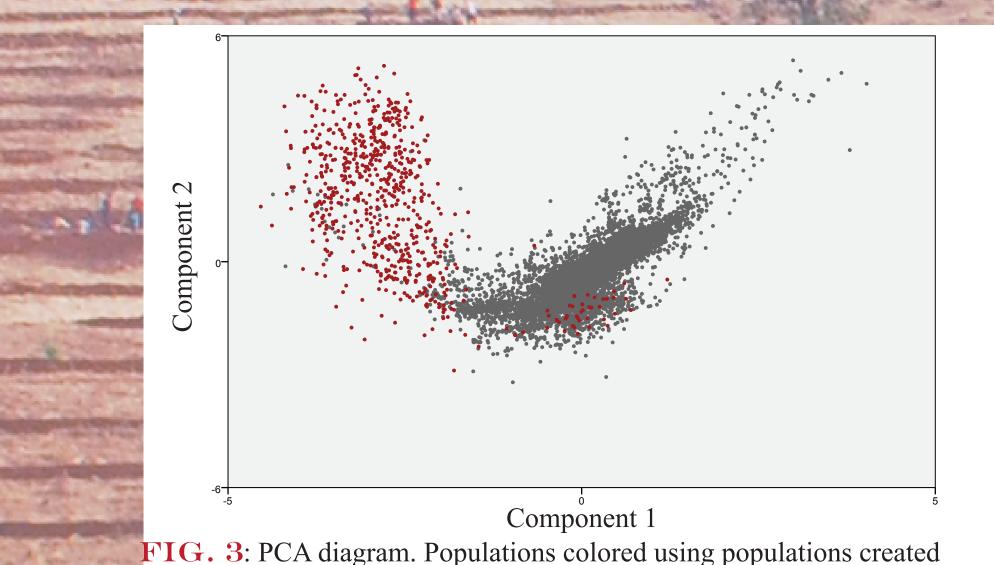
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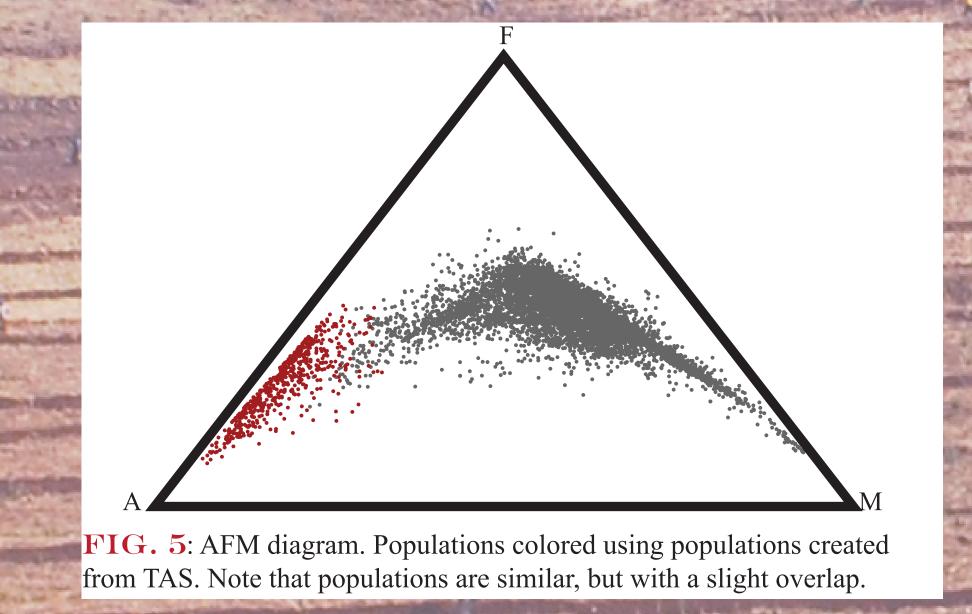


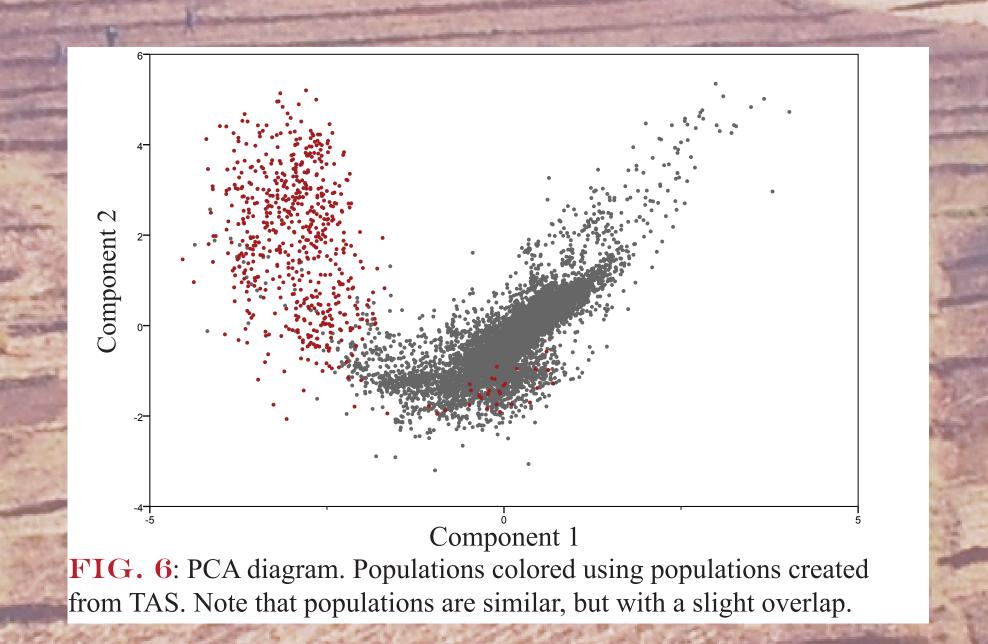


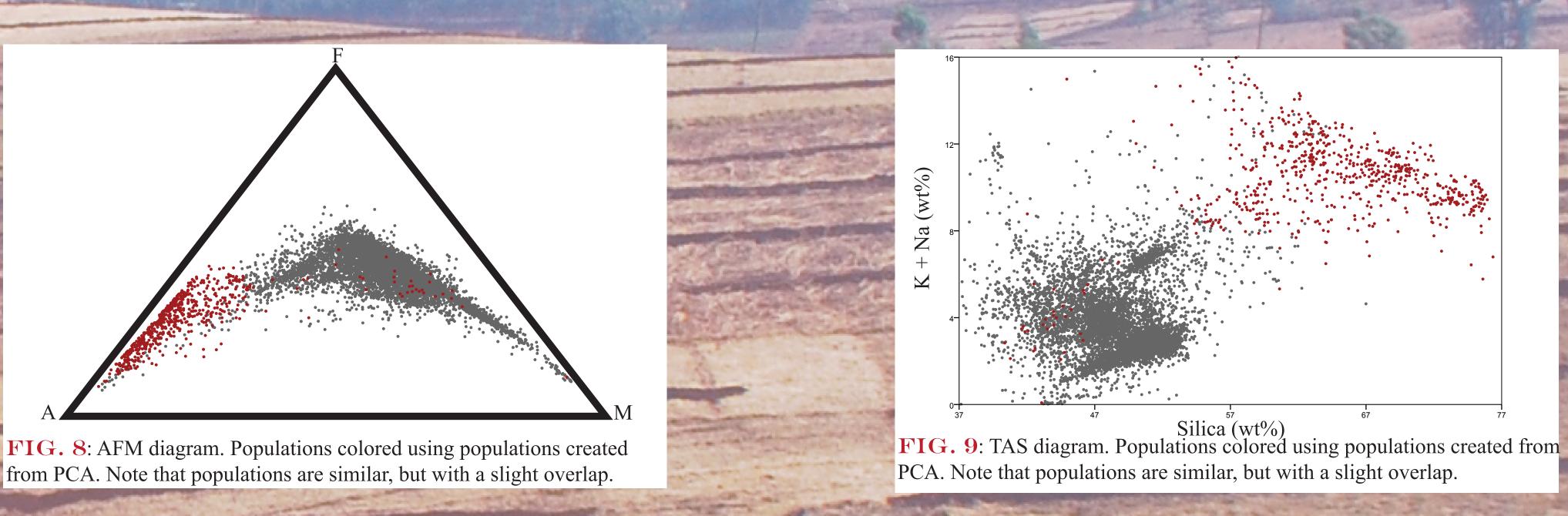




from AFM. Note that populations are similar, but with a slight overlap.







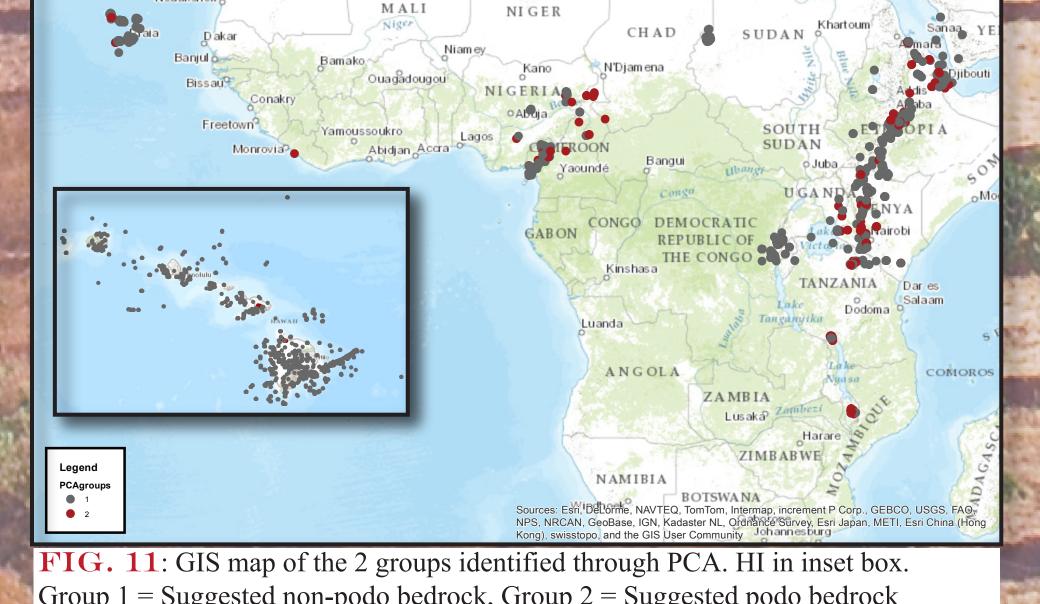
differentiation trend.

### **ABSTRACT**

Podoconiosis is a disease causing swelling in the lower limbs attributed Using both descriptive and multivariate statistics, we analyzed ten or combinations of components in complex data sets that might otherwith podoconiosis-endemic regions.

o minerals moving from the soil, through the skin, and into the lym- major oxides of the bedrock of four rift locations (Cape Verde Islands, phatic system. The disease is largely limited to rift zones around the East African Rift, Mid-African Rift, Red Sea Rift) on the African contiworld with the highest incidence in Africa. Although particulate silicon nent. The Hawaiian Islands were included as a control group since they and aluminum have been suggested as causative agents of the disease, are not known to have cases of podoconiosis. Descriptive analyses an association between the minerals and podoconiosis has been identi-showed separation of each of the African locations into two geochemified in only a few cases. The underlying bedrocks and soils from rift cally distinct populations, one of which had no counterpart in the Hazones associated with podoconiosis have not been fully investigated waiian Islands. Principle component analysis also indicated a geowith specific focus toward the disease. Statistical analyses have proven chemically unique population within the African locations. Separation valuable for classifying the geological composition of both rocks and of the populations is most influenced by K<sub>2</sub>O, MgO, Na<sub>2</sub>O and SiO<sub>2</sub>. soils, with multivariate approaches revealing underlying components We propose that the unique African population, which is high in alkali, magnesium and silicon, is responsible for the irritant particles associwise remain unidentified. We applied multivariate analyses to a compiate ated with podoconiosis. We also propose that a comparison of soil lation of bedrock samples from rift zones from the GEOROC database samples from Ethiopia (a known podoconiosis hotspot) will show the o look for statistical patterns of relative element abundance associated same statistical separation of geochemical populations between podoconiosis-endemic and non-endemic locations.

FIG. 10: GIS map of the 5 locations used for this study. HI in inset box.



## Group 1 = Suggested non-podo bedrock, Group 2 = Suggested podo bedrock

## BACKGROUND

ing components or combinations of components. Principle component lated with the presence of podoconiosis (Molla, et. al, 2014). analysis (PCA) (Muller 2008, Daunis-I-Estadella, 2006, Grunsky discriminate function analysis (DFA) (LeMaitre 1976) are only a few of the tools available in the multivariate statistical toolshed. These tools can often help simplify complex problems through the use of mathematical models.

Human diseases, including podoconiosis, are some of the most complex problems that we can find to study. Though present in at least 19 countries and a prevalence of approximately four million individuals, very little is known about the etiology of this disease (Davey, Tekola, & Newport, 2007; Desta, Ashine, & Davey, 2003).

The earliest work in the 1960's and 70's, proposed a correlation to several environmental factors such as annual rainfall, elevation, and in particular, the soil that individuals farmed in (reviewed in Price 1990). nigher proportion of affected individuals. Further work revealed claysized birefringent particles within the lymphatic systems of affected individuals. Current theory suggests that Silicon and/or some combination with Aluminum is perhaps the cause of podoconiosis (Blundell, Henderson, & Price, 1989; Price & Henderson 1978; Heather & Price, 1972. Several other experiments have been done looking into the presence of other elements that show higher levels in the soil than normal, leading to a few other potential "culprits" to be named as well, includ- that is also basaltic in origin but is not associated with podoconiosis.

One of the greatest challenges in any area of research is trying to form ing: Be, Ca, Cr, Fe, K, Mg, Mn, Na, Ni, Ti, Zn and Zr (Frommel et. al a single, coherent structure out of lots of data. Multivariate statistical 1993; Fyfe & Price, 1985; Blanke et. al. 1983; Davies & Townsend analysis has proven to be a successful method for identifying underly- 1983). More recent work suggests that clays, mica and quartz are corre-

1992), multivariate analysis of variance (MANOVA) (Gao 2000) and The majority of locations associated with podoconiosis can be found identify the mechanism of this disease, which will limit our ability to

Many researchers noted the tropical "red soils" in locations that had a The goals of our research are to (1) characterize the composition of volcanic bedrock of regions associated with podoconiosis and of regions ther podoconiosis research. We analyzed data from six areas, five of African Rift and Red Sea Rift) are associated with either modern or historic occurrences of podoconiosis, and one location (Hawaiian Islands)

near rift zones, and the majority of cases are found on the African continent where the well-known East African rift and the Central African rift can both be found. This research attempts a preliminary meta-analysis of the rift zone geochemistry of the African Plate with a specific focus on regions of known podoconiosis presence. Our analyses examined igneous rock data rather than soil data. Although podoconiosis has been associated with soils, we feel an analysis of the parent rock's composition will be beneficial as it can provide a useful start for further research into the pedogenesis of the irritant soils previously connected with podoconiosis and may provide more insight into the geologic causes of this complex disease. Without a direct cause we will remain unable to recognize its pathophysiology or remediate.

not associated with podoconiosis, and (2) compare those compositions in order to identify associations of elements of potential interest for furwhich (Cameroon Line, Cape Verde Islands, East African Rift, Mid-

	NAME OF TAXABLE PARTY.	AND RESERVED TO SHARE THE PARTY OF THE PARTY	The second second second		the second second	STATE OF THE OWNER, WHEN	AND THE RESERVE OF THE PARTY OF
H	AFM		FM	TAS		PCA	
		1	2	1	2	1	2
The second	N	9924	630	9861	693	9849	704
	SiO <sub>2</sub> (wt%)	49.37	65.92	49.35	64.67	49.36	64.33
4	TiO <sub>2</sub> (wt%)	2.62	0.60	2.62	0.71	2.62	0.80
	$Al_2O_3$ (wt%)	13.86	14.84	13.82	15.26	13.85	14.78
	Fe <sub>2</sub> O <sub>3</sub> (wt%)	11.42	5.44	11.45	5.57	11.42	6.07
	CaO (wt%)	10.31	1.48	10.33	1.90	10.32	2.22
	MgO (wt%)	8.28	0.46	8.32	0.63	8.29	1.08
N.	MnO (wt%)	0.18	0.21	0.18	0.21	0.18	0.22
	K <sub>2</sub> O (wt%)	0.82	4.66	0.80	4.60	0.81	4.30
1	Na <sub>2</sub> O (wt%)	2.75	6.27	2.72	6.26	2.74	6.00
	P <sub>2</sub> O <sub>5</sub> (wt%)	0.40	0.13	0.40	0.17	0.40	0.20

**TABLE 1**: Oxide averages for both groups from AFM, TAS and PCA analysis. Averages are in weight percent.

		1	2				
	K <sub>2</sub> O	925	004				
	MgO	.907	154				
	CaO	.890	176				
	Na <sub>2</sub> O	843	.363				
	$TiO_2$	.640	384				
	FeT	.626	.610				
	$SiO_2$	253	.922				
	$P_2O_5$	044	829				
	MnO	261	.770				
	$Al_2O_3$	403	.741				
TABL	<b>E</b> 2: Co	mponents	retained	from			
PCA. Boxes indicate the component the							
oxide plots on. Data is clr transformed.							
The state of the s							

		Hawaiian Islands	0.000
1		Mid-African Rift	0.000
		Red Sea Rift	0.000
	East Africa Rift	Cape Verde Islands	0.000
700		Hawaiian Islands	0.000
The same of		Mid-African Rift	0.082
		Red Sea Rift	0.600
44.00	Hawaiian Islands	Cape Verde Islands	0.000
TO THE		East Africa Rift	0.000
-		Mid-African Rift	0.000
		Red Sea Rift	0.004
	Mid-African Rift	Cape Verde Islands	0.000
		East Africa Rift	0.082
MERCA		Hawaiian Islands	0.000
		Red Sea Rift	0.971
COUNTY OF	Red Sea Rift	Cape Verde Islands	0.000
The M		East Africa Rift	0.600
		Hawaiian Islands	0.004
		Mid-African Rift	0.971
	TABLE 3. AN	NOVA significance	for
- 14		10 111 Significance	101
	$SiO_2 vs Al_2O_3$		
	The second second		THE RESERVE

pe Verde Islands East Africa Rift

#### **METHODS**

Data for 13 elements (Si, Ti, B, Al, Cr, Fe, Ca, Mg, Mn, Ni, K, Na, P) were downloaded September 2012 from the Geochemistry of Rocks of the Oceans and Continents (GEOROC) website (http://georoc.mpch-mainz.gwdg.de/georoc/) for the six locations mentioned above. Prescreening of data led to omission of three elements, Br, Cr, and Ni (due to low sample size) and one location, Cameroon Line (high number of outliers). Zeroes in the original data were treated as rounded zeros (below-detection values) and replaced using additive zero replacement (Aitchison, (1986, pp. 266-269). All data were center-log ratio (clr) transformed (Eric C.

Grunsky, 2010; Pawlowsky-Glahn & Egozcue, 2012). Final data analysis was run using 10 oxides and five locations [FIG. 10] (Cape Verde Islands [N = 718], East African Rift System [N = 1926], Hawaiian Islands [N = 7502], Mid-African Rift System [N = 328], Red Sea Rift [N = 79]) and ten oxides (SiO<sub>2</sub>, TiO<sub>2</sub>, Al<sub>2</sub>O<sub>3</sub>, Fe<sub>2</sub>O<sub>2</sub>, CaO, MgO, MnO, K2O, Na<sub>2</sub>O and P<sub>2</sub>O<sub>5</sub>) providing a total of 10,553 samples. All statistics were run using SPSS (v22, Statistical Package for Social Sciences, Inc., Chicago, Illinois, USA).

#### ANALYSIS

Descriptive Statistics: tation was used and missing data was excluded pairwise. All data were plotted in three diagrams and color coded by geographic region IFIGS. 1, 4 AND 7]. In all three of the diagrams, the African locations show two distinct population clusters. This physical Our PCA analysis retained two components [TABLE 2]. PC1 acseparation was found in AFM (Alkali [K+Na], Fe, Mg) [FIGS. 1-31, TAS (Total alkali silica) [FIGS. 4-6] and PCA analysis CaO, Fe<sub>2</sub>O<sub>3</sub>, and TiO2 with positive loadings. Component 2 included [FIGS. 7-9]. Based on the results, two groups were created by visual inspection of the natural boundaries of the populations and recoded in SPSS to further analyze the characteristics of each group **TABLE** 1 shows N values for each of the two groups create through analysis as well as average weight percent values for each of the oxides, which are very similar among the three descriptive plots. The Hawaiian Islands, do not show the same clustering, their 2<sup>nd</sup> population being extremely small. FIGURE 11 provides a map of One final analysis was conducted to explore a theory (Price & Henderwhere the two PCA groups plot geographically. Though a fairly clear difference can be seen between major regions, no pattern is evident within any particular region.

#### Principle Component Analysis:

Though ongoing research into podoconiosis has suggested a number of both geological and biological factors involved in its onset, specific identification of the factors has remained elusive. Thus, PCA seemed to be the perfect method for exploratory analysis of the large dataset w had at our disposal. Factors identified through this process should idenfy the combination of elements that may prove to be a key ingredient

son, 1978) that some ratio of silica to aluminum was associated with podoconiosis. A one-way ANOVA was conducted on the ratio of silica to aluminum for each sample. Results showed a significant main effect for the ratio (F(4, 10582)=203.955, p < 0.001,  $\eta^2 = 0.072$ ). Post hoc tests

in the complex system that leads to onset of podoconiosis. Varimax ro-

counted for 43.0% of the variance PC2 for 34.0% of the variation. Com-

ponent 1 included K<sub>2</sub>O and Na<sub>2</sub>O with negative loadings, and MgO,

P<sub>2</sub>O<sub>5</sub> with a negative loading, and SiO<sub>2</sub>, MnO and Al<sub>2</sub>O<sub>3</sub> with positive

loadings. Results from factor analysis led to the formation of two

groups. Component 1 seems to be related with a calc-alkaline differen-

tiation trend while component 2 seems to be related to a mafic-felsic

revealed significant differences between the Cape Verde Islands and al other locations and the Hawaiian Islands and all locations. No differences were found between East Africa Rift, the Mid-African Rift and the Red Sea rift. Results can be found in TABLE 3. Nonparametric Kruskal-Wallis ANOVA yielded results identical to the parametric ANOVA. This correspondence supports our interpretation of the para-

#### CONCLUSION

We have identified two major conclusions from our data analysis: 1) The bedrock geology associated with podoconiosis show the presence of a unique group which contains high numbers of samples from the East Africa Rift but only minimal numbers from Hawaii. This group that this is the typical bedrock that is responsible for any irritant particles associated with podoconiosis.

2) The role of SiO<sub>2</sub> alone or in combination with Al<sub>2</sub>O<sub>2</sub> has frequently been identified as the irritant or causal factor for podoconiosis. Our analyses support the presence of high amounts of SiO, in the bedrock. We also show a significant difference in the SiO, to Al,O, ratio between is high in alkali and silica and low in iron and magnesium. We propose the Hawaiian Islands and the East Africa, Mid-African and Red Sea

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