LOCALIZATION OF VOLCANIC STRUCTURES IN THE MIOCENE VOLCANIC FIELD OF LESVOS ISLAND, NORTHEASTERN AEGEAN, COMBINING REMOTE SENSING METHODS WITH FIELD EXPLORATION.

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ABSTRACT

Remote sensing techniques are combined with field investigations in order to accurately characterize the not easily recognizable due to erosion volcanic structures of the 17 my volcanic field of Lesvos. LANDSAT-TM and SPOT-PAN satellite images and the Digital Elevation Model (DEM) of the targeted areas were digitally processed in order to reveal specific geological characteristics such as radial caldera faults, areas of hydrothermal alteration, drainage network, and lava domes, both internal and external to the caldera structures. Six caldera structures have been recognized (Sigri, Mesotopos, Agra, Vatoussa, Stipsi and Skalohori). Four of them have been identified for the first time and reported here and two are reported in the literature in the general areas of Vatoussa and Stipsi but their true size and geometry have been verified by field investigations and are reported herein.

KEY-WORDS: Miocene volcanic structures, applied ore deposit research, remote sensing, Landsat-TM and Spot-PAN images.

INTRODUCTION

Previous work in literature indicates that a large number of epithermal ore deposits are spatially related to ash-flow caldera settings (White and Henderson, 1990, Lipman, 1992, Rytuba, 1994, Milesi et al, 1999). Once formed, ash-flow (or ignimbrite) calderas can clearly provide favorable conditions for mineralization such as border faults, highly porous intracaldera rocks, hydrothermal and meteoric water circulation. However, ash-flow calderas are not necessarily mineralized. In some cases, neighboring calderas, apparently formed under similar conditions appear either barren or mineralized such as the Los Frailes and Rodalquilar-Lomilla calderas in southeastern Spain (Rytuba et al 1990, Cunningham et al, 1990). Therefore, the detection of caldera structures, apart from its obvious usefulness in volcanological studies, is also of great interest for the applied ore deposit research as in the detection of epithermal precious metal deposits in geothermal fields.

Epithermal gold deposits are formed in relatively small depths (up to 2 Km), therefore they rarely appear in volcanic fields that were active before Tertiary. In very recent volcanic fields, such ore deposits are not favored, due to the fact that the time of the hydrothermal activity, and consequently of the leaching and deposition of ions is relatively short (e.g. Nisyros), while in older volcanic fields the likely host volcanic structures are not easily identifiable due to erosion as is the case of the Miocene volcanic field of Lesvos. On Lesvos two caldera structures are reported in the literature: the Vatoussa caldera in the western part of the island (Pe-Piper, 1980b) and the Stipsi caldera in the northeastern part of Lesvos (Pe-Piper, 1998, Rokos et al, 2000).

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During the last decades, Landsat and Spot satellite images have demonstrated a special facility for use in detection of circular features. Most of these features are volcanic or intrusive in nature and many have been recognized initially on Landsat and Spot images (Smist, 1974).

Remote sensing techniques combined with field investigations have been used in this study for the detection and localization of such volcanic structures.

GEOLOGICAL FRAMEWORK

The island of Lesvos (Fig.1) in the east-central Aegean Sea, 10 km west of the coast of Asia Minor, consists of thick Miocene volcanic rocks in a series of stratovolcanoes that extend SW-NE across the center of the island (Pe-Piper and Piper, 1993). Miocene volcanism in northern Hellas and the Aegean Archipelago was the result of the subduction of Africa under Eurasia but with a different geometry of plates than the one, which has resulted in the present Quaternary Volcanic Arc, which lies more to the south. On the flanks of the stratovolcanoes, acid pyroclastic rocks onlap metamorphic basement. Lesvos is part of the belt of late Oligocene - mid Miocene calc-alkaline to shoshonitic volcanism in northern and central Aegean Sea and western Anatolia. The shoshonitic volcanic rocks range in compositions from andesite to rhyolite in the form of flows, domes and pyroclastic rocks (Pe-Piper and Piper, 1993). The island was mapped at 1:50000 by Hecht (1972-1976). Pe-Piper (1980b) refined the stratigraphic sequence, using petrography and geochemistry to classify the lava units (Pe-Piper 1980a), and by using paleomagnetic stratigraphy as a correlation tool (Pe-Piper & Piper 1980). The following volcanic units were distinguished, from oldest to youngest (I to v): *v) Mytilene Unit, iv) Sykaminea Unit,* iii*) Acid Volcanics Unit (Sigri Pyroclastics, Polychnitos Ignimbrite* and *Kapi Rhyolites), ii) Skoutaros Unit i) Lower Lava Unit.*

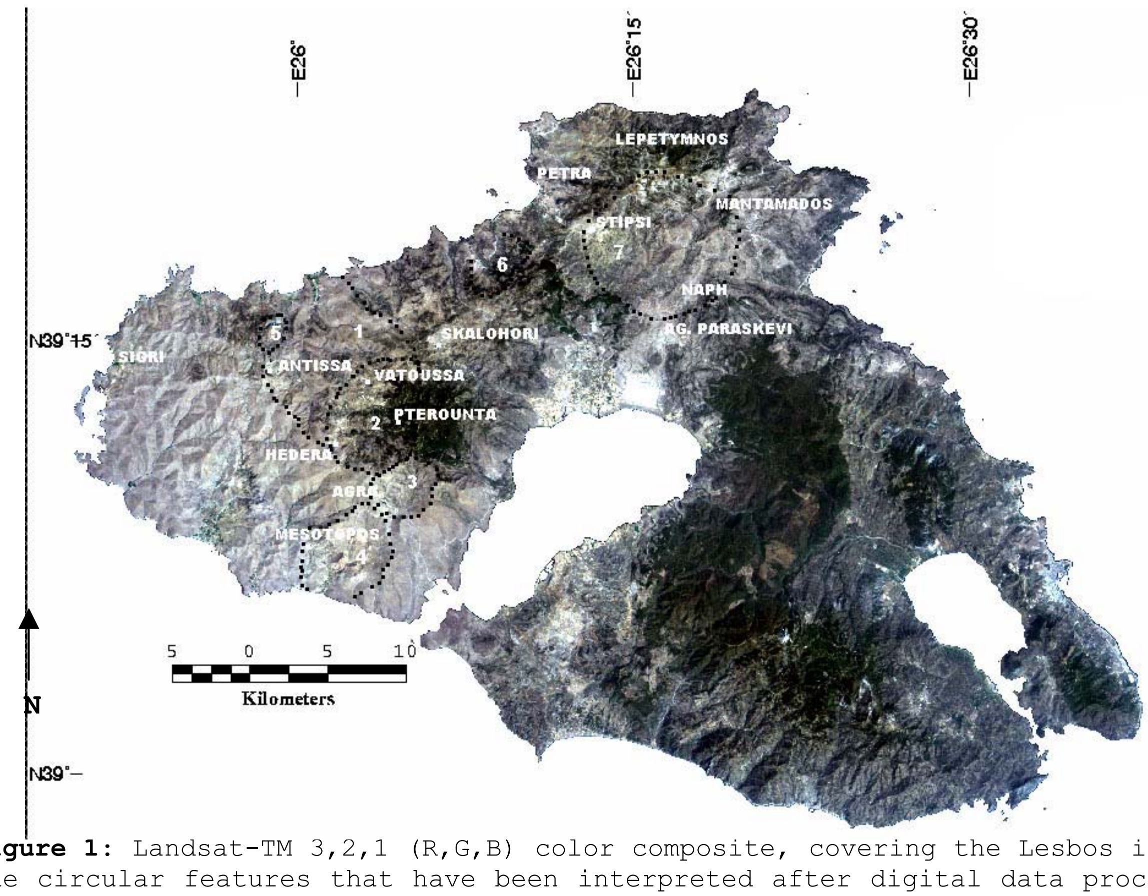


Figure 1: Landsat-TM 3,2,1 (R,G,B) color composite, covering the Lesbos island. The circular features that have been interpreted after digital data processing are delineated with black dashed lines.

DATA ACQUISITION

A combination of remote sensing and fieldwork data have been used for the detection and mapping of the Miocene calderas. The relevant output images were generated from the analysis and processing of:

1. a Landsat-TM satellite image of Lesvos island, with a spatial resolution of 30x30 m pixel size, which was acquired on 20 August 1999,
2. a SPOT panchromatic (SPOT-Pan) satellite image of the same area, with a spatial resolution of 10x10 m pixel size, which was acquired on 12 July 1999, and
3. the Digital Elevation Model (DEM) of the study area of the island, generated from the 30 m contours of the topographic maps.

DIGITAL DATA PRE-PROCESSING

The satellite data were preprocessed in order to remove the geometric distortions and to bring the remote sensing images into registration with one another. With the use of topographic maps of the study area, the images were geometrically corrected and georeferenced to the HGRS 87 (Hellenic Geodetic Reference System). The geometric correction had an average RMS error of approximately 0.4 pixels for both images.

The raster (satellite images and DEM) and vector (caldera borders) layers have been implemented in the GIS environment of ER-MAPPER 6.21.

DIGITAL DATA PROCESSING – FIELD OBSERVATIONS

In a preliminary phase, six circular features were detected in the general area of Lesvos (Fig.1, locations 1, 2, 3, 4, 5 and 7), from the Spot-Pan and Landsat-TM overview, some of which exhibit circular drainage patterns and photolineaments which were interpreted as radial faults (Fig.2F).

Five of them are located in the western part of the Lesvos island and one in the eastern part (Fig.1).

In order to reveal the volcanic structures of the western part of the island several false color composites (FCC) were constructed using the 7 bands of the Landsat-TM satellite image. Finally the FCC 5,7,3 (R,G,B) was selected as the most informative TM band combination for the interpretation of the geological features. These multispectral Landsat-TM data were merged with the higher resolution Spot-panchromatic image to obtain a color composite of enhanced resolution without loss of multispectral information (Zumsprekel and Prinz, 2000).

In order to enhance the circular features, the above data set was overlain on the digital terrain model (DEM) of the western part of Lesvos. This resulted in the addition of the third dimension to the remotely sensed data, which has enhanced the identification of the volcanic structures. The Sigri, Vatoussa, Agra (Fig.2A) and Mesotopos (Fig.2A,2D) calderas were delineated on this overlay and one more subcircular structure was detected northeast of Skalohori Village (Fig.2A).

In the next data-processing phase, a slope map was produced from the DEM of western Lesvos. The slope map was superimposed on the DEM in order to obtain a three-dimensional view of the circular features in combination with the slope information. This technique was employed to remove the effect of vegetation which was present on the FCC 5,7,3 (R,G,B) and depict the borders of the volcanic structures with greater accuracy (Fig.2B,2C). The removal of the vegetation effect was vital especially in the Vatoussa area (Fig.1) From the interpretation of the above data set, it was concluded that all volcanic structure external walls have gentle dips with the exception of the Skalohori structure where external walls have steeper dips. This it may be concluded that the Skalohori caldera is comparatively a younger structure (Fig.2E).

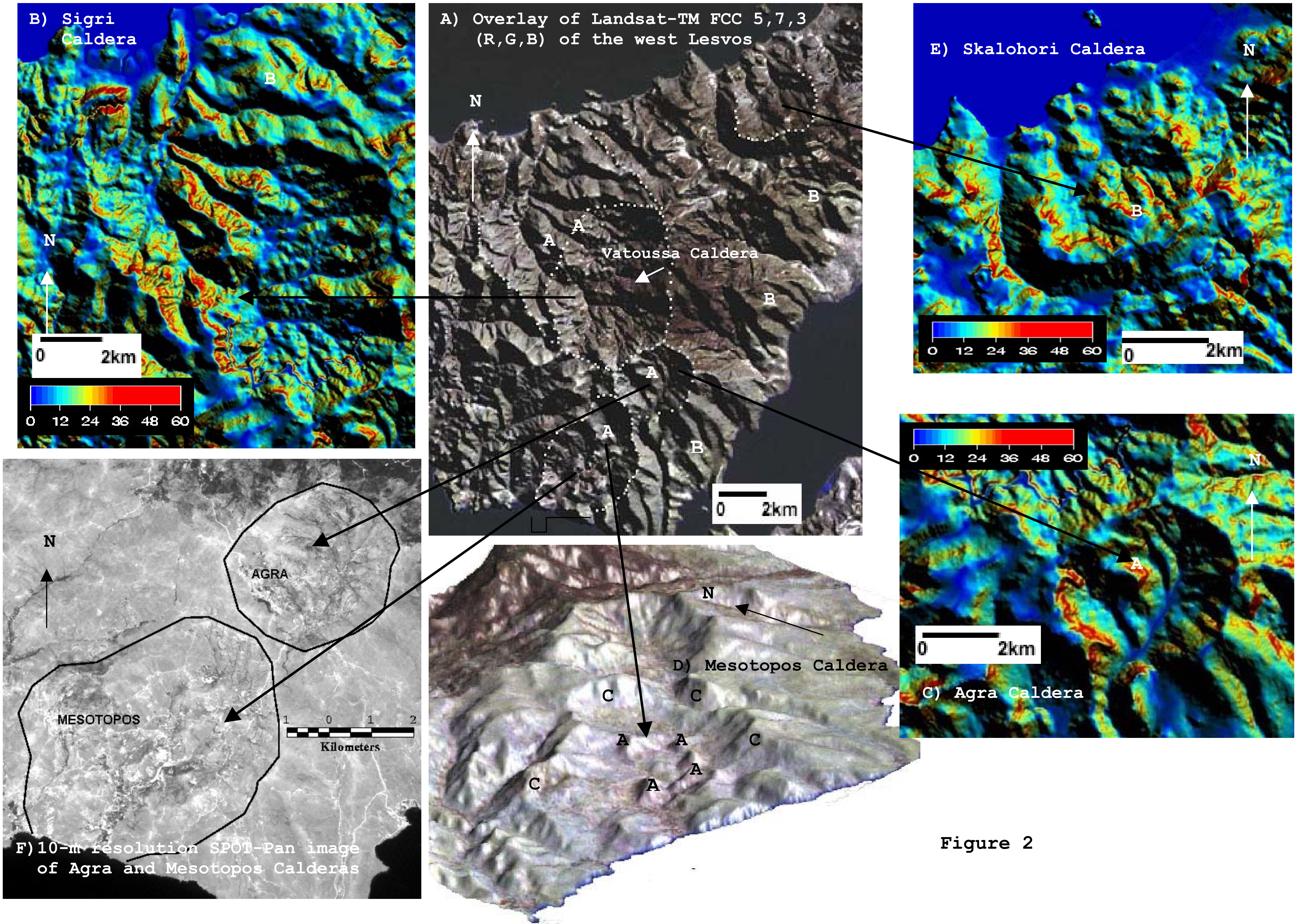
The First Principal Component (PC1) was used for the delineation and description of the Stipsi caldera in the eastern part of the Lesvos island (Fig. 3). This component is dominated by topography (it exaggerates the relief) (Sabins, 1997) and assembles most of the spectral information provided by Landsat-TM (Rokos et al, 2000).

Finally, the results of the digital image analysis were checked in the field in order to verify in-situ the quality of the interpretation of the geological feauters. Six out of the seven volcanic structures mentioned above as well as radial faults (Mesotopos and Agra calderas) and lava domes were verified, whereas the seventh circular feature (Fig.1, circular feature 5, north of Antissa,) was a marble quarry. The six circular features identified by remote sensing techniques displayed remnant caldera rims, megabreccia formations (Vatoussa), internal and external lava domes, outward dipping external flank, caldera faults and intense hydrothermal alteration of flat caldera floors (Stipsi, Vatoussa and Mesotopos Calderas) (Kouli et al, in preparation).

SIGRI CALDERA

An almost elliptical volcanic structure with a size of 13.3x9.5 km was recognized in the western part of the island of Lesvos (Fig.2A,2B) with maximum length axis NNW-SSE directed. The Sigri Caldera is defined as follows: its western rim passes west of Antissa Village, which is amphitheatrically built on the caldera wall. From the fieldwork, extremely coarse breccias seem to be related with this part of the caldera while radial faults are well displayed on the caldera wall, on both sides of the main road near Antissa. Its southern rim passes north of Agra while the eastern rim is defined from the south to the north by the Roufta, Profitis Helias and Kouratsona domes. The Sigri Caldera northwards is open to the sea. During fieldwork intense hydrothermal alterations were identified in Vatoussa, Pterounda and Hedera areas. Associated felsic domes display 'High Sulfidation' hydrothermal alteration patterns. The kaolinite alterations were first reported by Hecht (1972-76) and Pe-Piper (1980b) in Pterounda and Hedera. The large size of Sigri Caldera justifies the large volume of pyroclastic material such as the Sigri Pyroclastic Formation. The orientation of logs of the Petrified Forest, which is enclosed in the Sigri Pyroclastic Formation, proves that they have been shoved from the east (Velizelos, 1998) and in particular from the Sigri Caldera, which is the most likely source of the pyroclastic material.

Figure 2: A: Overlay of enhanced resolution Landsat-TM FCC 5,7,3 (R,G,B) on the DEM of western Lesvos. Five caldera structures are delineated with white dashed lines. Lava domes and flows are shown with the letters A and B respectively, **2B: Sigri Caldera:** Shaded DEM of the caldera with slope map overlay. The lava flows which are responsible for the small slope values of the northern part of the caldera wall are apparent (are indicated with the letter B), as well as a smaller circular structure (Vatoussa Caldera) inside the major caldera, **2C: Agra Caldera:** Shaded DEM of the caldera with slope map overlay. The lava dome inside the structure is indicated with the letter A, **2D: Mesotopos Caldera:** A 3-dimensional view of the volcanic structure rotated westwards. Caldera walls and the circularly situated lava domes are shown by the letters C and A respectively, **2E: Skalohori Caldera:** Shaded DEM of the Skalohori area with slope map overlay. The steep dips of the external walls may indicate that this structure is a volcanic vent. Its interior is filled with a lava flow (letter B) directed NNW-SSE, **2F:** 10 m resolution Spot-Pan image of the Agra and Mesotopos calderas. The circular drainage network of Agra and the lineaments in the Mesotopos and Agra Calderas are easily interpreted as radial faults.



B) Sigri Caldera
B
N
0 2km
0 12 24 36 48 60
A) Overlay of Landsat-TM FCC 5,7,3 (R,G,B) of the west Lesvos
N
A
A
Vatoussa Caldera
B
B
A
A
B
0 2km
E) Skalohori Caldera
N
B
0 12 24 36 48 60
0 2km
0 12 24 36 48 60
N
A
0 2km
C) Agra Caldera
N
AGRA
MESOTOPOS
1 0 1 2
Kilometers
F) 10-m resolution SPOT-Pan image of Agra and Mesotopos Calderas
N
D) Mesotopos Caldera
C
C
A
A
C
A
C
A

Figure 2

VATOUSSA CALDERA

The caldera described by Pe-Piper (1980b) from the same area is known as the Vatoussa Caldera. This is a smaller structure (7.17x5.50 km) nested in the southern part of the major Sigri Caldera (Fig.2A). The southern borders of the two structures coincide. To the west, the Vatoussa Caldera passes west of Hedera and turns towards Vatoussa, which it encloses within its northwestern rim (Fig.1).

MESOTOPOS CALDERA

An irregular circular structure sized 6.3x5.2 km with its maximum length axis directed NNE-SSW is situated in the southwest part of Lesvos (Fig.2A,2D). Along its periphery there are several discontinuities due to lava flows. Its northeastern part is particularly steep and passes south of the Agra Caldera rim. This part of the caldera wall displays most of the radial faults (Fig.2F), which have been verified in the field. In the southwest rim passes west of Mesotopos Village, built within the caldera. Southwards, the caldera is open to the sea whereas to the southeast it is bordered by lava domes. Plenty of lava domes of the Sykaminea Unit are circularly situated inside the caldera following ring faults, with increasing concentration towards the south (Fig.2D). Kaolinite and alunite alterations have been reported in Mesotopos Caldera (Tsoli, 1981, Parcharidis, 1999) and have also been sampled by us during fieldwork for further study.

AGRA CALDERA

This is an almost circular caldera (4.3x3.9 km) parasitic to the south of the large Sigri Caldera and in the northeast of Mesotopos Caldera (Fig.2A,2C). Its maximum length axis is directed NNE-SSW. Its northwest rim coincides with the southern part of the Sigri Caldera. Its southwest rim borders the northeastern part of Mesotopos Caldera. Radial faults appear on the caldera wall along almost the whole extent of its periphery, with the exception of a small part in the west where they are interrupted by a lava dome (Fig.2C). The caldera consists of lavas of the Sykaminea Unit. These lavas seem to have been extruded to the east coming from Agra Caldera (Fig.2A). The southern part of the caldera displays a small discontinuity, probably due to lava extrusions.

SKALOHORI CALDERA

It is an almost circular sized (4,1x3.1 km) caldera/vent situated to the east of Sigri Caldera (Fig.2A). Its maximum length axis is directed NNE-SSW. Its flanks are outwards-dipping (Fig.2E) and its rim passes northeast of Skalohori while in the north it is open to the sea due to a lava extrusion of the Skalohori Unit, perpendicular to the maximum length axis. Radial faults and circular drainage network are displayed particularly in the outer margin of the elevated wall. This structure does not display areas of alteration.

STIPSI CALDERA

The eastern part of the island includes a caldera structure namely the Stipsi caldera, that is intersected by a northeastern-trending fault zone (Fig.3, FF’). The caldera encloses and is bordered by numerous felsic domes, which display various degrees of hydrothermal alteration. The presence of this caldera, its hydrothemal alteration and possible association with epithermal gold mineralization, was first reported by Rokos et al (2000) and Vamvoukakis at al (2001). Here we report details of its geometry and dimensions, associated lava domes and dome intrusion directions. A caldera structure in the area was first reported by Pe-Piper (1998) as a polygon-shaped structure, which passes just west of Mantamados and directly east of Petra and north of Lepetymnos. The caldera structure which was revealed in the Stipsi area after the Principal Component Analysis (Fig.3), is a structure smaller (9.5x9 km) than the one presented by Pe-Piper, obviously more rounded, which is intersected on its eastern part by a tectonic belt, NNE directed (FF´, Fig.3).

Our study delineates the Stipsi Caldera as follows: its rim is defined by the volcanic domes of Mt Lepetymnos to the north (Fig.1), the domes situated north of Stipsi to the west (Fig.3), and the pine-tree covered domes in the south and south-east of Stipsi (Fig.3). To the east, the rim passes east of Napi (Fig.3) and west of Mantamados (Fig.1).

The inner part of Stipsi caldera is pierced by numerous volcanic domes (Rokos et al, 2000, Vamvoukakis at al, 2001). Those situated on its eastern part (Kapi Rhyolites) are aligned parallel to a NNE tectonic zone (Fig.3). The rest do not seem to follow a particular pattern. Argilic alterations inside and outside the caldera were reported by Rokos et al, (2000).

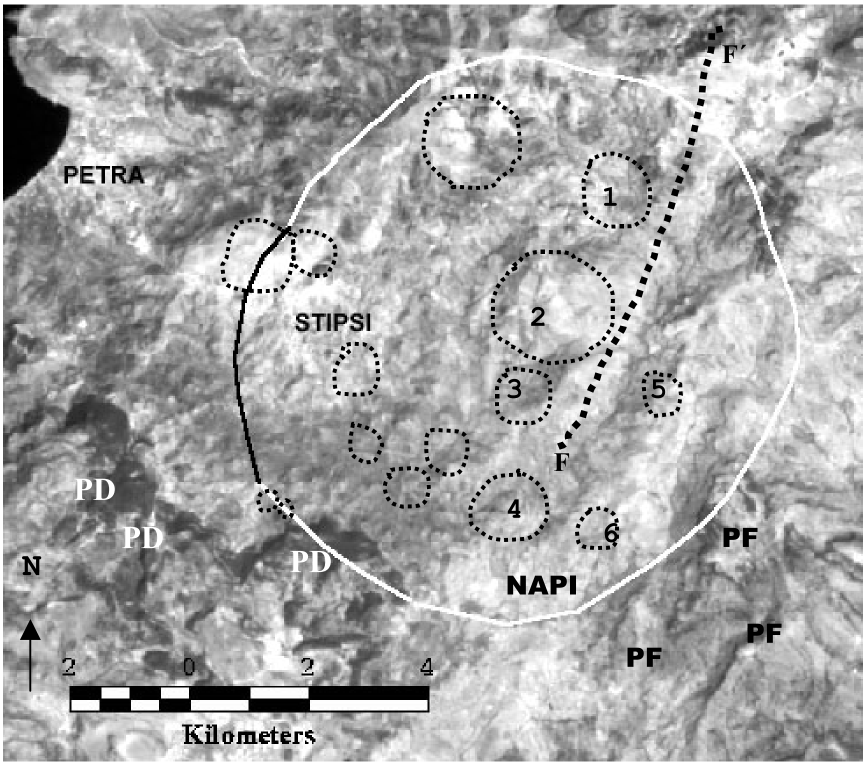


Figure 3. First Principal Component (PC1) image for the Stipsi Caldera. Caldera borders are delineated with a white line. The black line delineates the breached part of the caldera wall. Circular features identified as volcanic domes are marked with a fine dotted line. A NNE trending fault zone is shown in black bold dotted line (FF'). Kapi Rhyolites (1 to 6) are aligned parallel to FF'. Pyroclastic flow deposits are indicated with the letters PF. Dark hues, in the lower left of the PC1 image represent pine-covered domes (PD).

CONCLUSIONS

A combination of remote sensing techniques and geological field investigations, have successfully localized six calderas in the partially eroded Miocene (17 my) volcanic field of Lesvos. In the western part of the island, a major nested caldera, the Sigri Caldera encompasses the Vatoussa Caldera first reported by Pe-Piper (1980b). It is bordered to the south by the satellite Mesotopos and Agra Calderas. The Skalohori Caldera lies northeasterly to the Sigri structure. Extensive coarse breccia formations, radial faults and the remnants of the caldera rim were identified on the western part of the Sigri Caldera by geological ground investigations. We propose the Sigri Caldera as the source of the extensive Sigri Pyroclastic Formation, which covers 30% of the western part of the island of Lesvos and hosts the renown Lesvos Petrified Forest.

The Stipsi Caldera, a circular volcanic structure, much smaller than the one reported by Pe-Piper (1998), lies the eastern part of the island. It is inundated by hydrothermally altered volcanic domes and intersected by a NE trending tectonic zone.

In conclusion, remote sensing techniques coupled with geological field investigations offer an efficient and sophisticated tool, especially in older, partially eroded volcanic terrains, not only for volcanological research but also for the exploration of ore resources.

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