GEOLOGIE EN MIJNBOUW VOLUME 54 (3-4), p. 199-204 1975

THE SHEETED INTRUSIVE COMPLEX OF TROODOS, CYPRUS

H. de BOORDER[1])

ABSTRACT

Geological observations during a mineral exploration programme in the western part of the Troodos Igneous Complex, Cyprus, have led to the formulation of a hypothesis concerning the origin of the Sheeted Intrusive Complex in connection with the development of the Troodos dome. The hypothesis suggests an originally horizontal attitude of the "Diabase" sheets in a large part of the Sheeted Complex. Some related aspects of sulphide mineralisation are discussed.

INTRODUCTION

In 1969 a mineral exploration project was carried out in the western part of the Troodos Igneous Complex by Hunting Geology and Geophysics Limited for the Cyprus Sulphur and Copper Company Limited. Geological maps of a portion of the area were prepared at 1 : 5,000 scale and geophysical surveys were conducted in selected parts. Several geological reconnaissance traverses were made in the area between Kokkina, Vroisha and Pano Panaya. During the field work several working hypotheses were developed. One of them, regarding the origin of the Sheeted Intrusive Complex, is presented here.

GEOLOGICAL SETTING

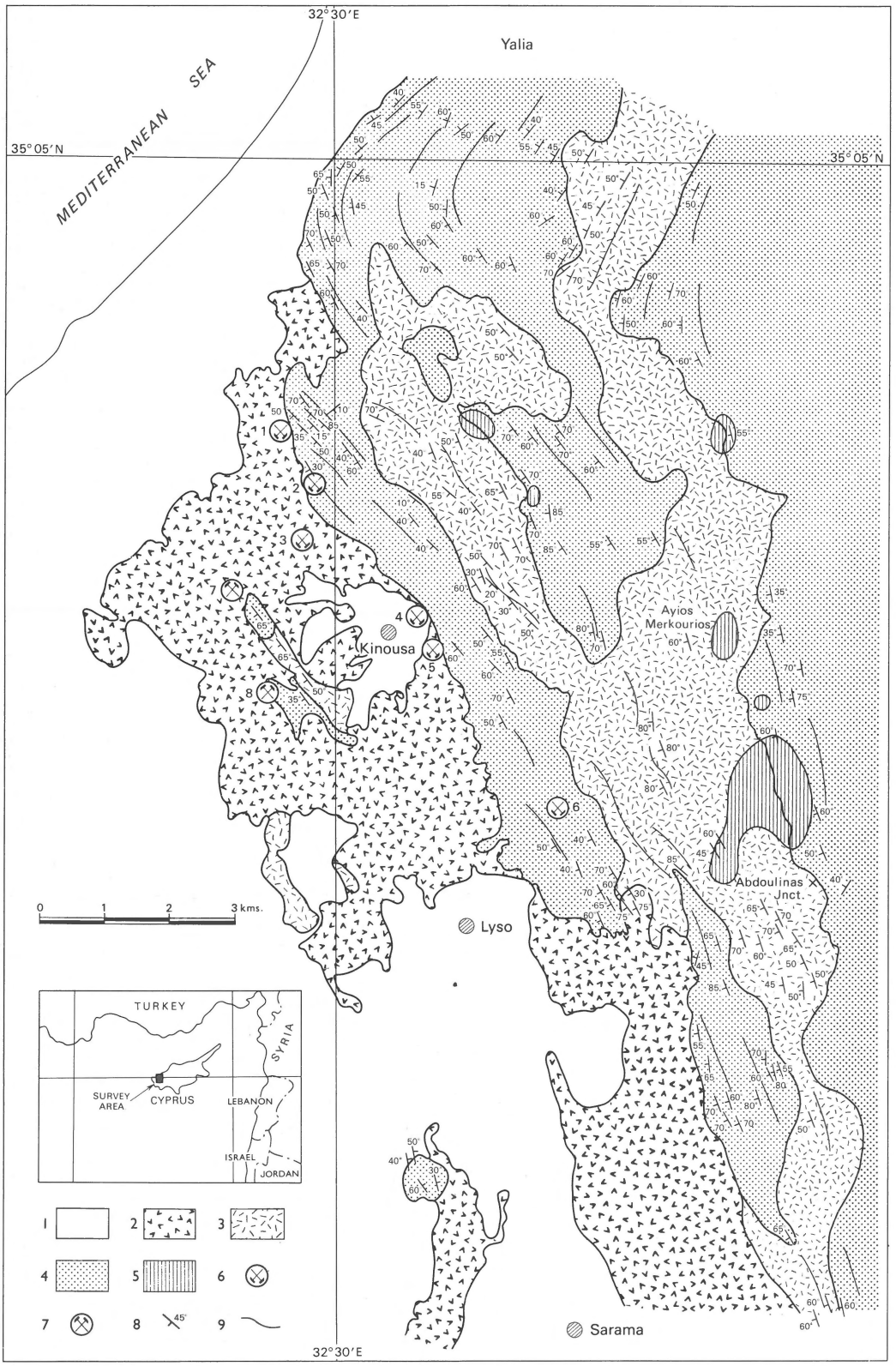
The core of the Troodos massif of Cyprus consists of peridotite, serpentinite, gabbro and associated leucocratic rocks of the Troodos Plutonic Complex. This portion of the massif has a diameter of 16 and 25 km. Similar rocks crop out in the Livadhi area near Pomos and in a triangular area between Yerasa, Mazokambos and Vavla. The principal outcrops are surrounded by a belt of varying width of the rocks of the Sheeted Instrusive Complex. This Complex consists mainly of massive tabular bodies up to three metres in width and mostly of fine- to medium-grained light grey to light green mafic rocks. The rocks are generally referred to as "Diabase". Other constituents of the Complex are screens of pillowed and non-pillowed lavas between sheets of diabase. The Sheeted Complex is surrounded and unconformably overlain by the Troodos Lower and Upper Pillow Lava Formations which are of olivine basaltic and andesitic composition. The rocks of the Troodos Plutonic Complex, the Sheeted Intrusive Complex and the Troodos Pillow Lava Formations, are generally considered to be co-genetic and grouped together as the Troodos Igneous Complex. Similar rocks are also found in the Akamas Peninsula and to the east of the Troodos massif in the Troulli inlier. The Troodos Igneous Complex is unconformably overlain by a series of mainly calcareous sediments ranging in age from Upper Cretaceous to Recent. Detailed accounts of the various rock types have been published in Memoirs and Annual Reports of the Geological Survey Department of Cyprus, e.g. by Ingham (1955), Wilson (1959), Bear (1959, 1966) and Pantazis (1967). Gass and Masson-Smith (1963) reported on a gravimetric survey of the island. Gass (1968) suggested that the Troodos Massif may represent a fragment of a mid-Tethyan rise, comparable with present mid-oceanic rises. This suggestion was followed up by Moores and Vine (1971) who conducted investigations of the remanent magnetism of the rocks of the Troodos Complex. These authors compared the Troodos Complex with ultramafic complexes around the Mediterranean.

THE SHEETED INTRUSIVE COMPLEX

The Sheeted Intrusive Complex of Troodos has been sub-divided into two units, according to the proportions of intrusive diabase to lavas (Bear, 1966). The Diabase unit of the Complex consists almost completely of diabase sheets whilst the Basal Group unit contains in addition much pillowed and non-pillowed lava. The Basal Group lavas were considered by Bear (1966) to represent the original host rock of the diabase sheets. Recently Pantazis (1967)

[1]) Centro Interamericano de Fotointerpretación Apartado Nacional 762, Chapinero, Bogotá, Colombia.

Formerly with
Hunting Geology and Geophysics Ltd., Borehamwood, Herts., England.



Mineral localities and closed mine workings.

1 North Magounda;
2 South Magounda;
3 Double Seven;
4 Kinousa Underground;
5 Uncle Charles;
6 Larmou.

Open cast workings.
7 Limni;
8 Evloimeni.

Fig. 1
Geological map of the Limni area, N.W. Cyprus, scale 1 : 75.000. 1. Postvolcanic sediments; 2. Upper and Lower Pillow Lava Formations; 3. Basal Lava Group Formation; 4. Diabase Formation; 5. Area with gossan and relatively high copper content in stream sediments; 6. Mineral deposits with low copper content or closed mine working; 7. Open cast working; 8. Strike and dip of sheets in Sheeted Intrusive Complex; 9. Strike trend of sheets.

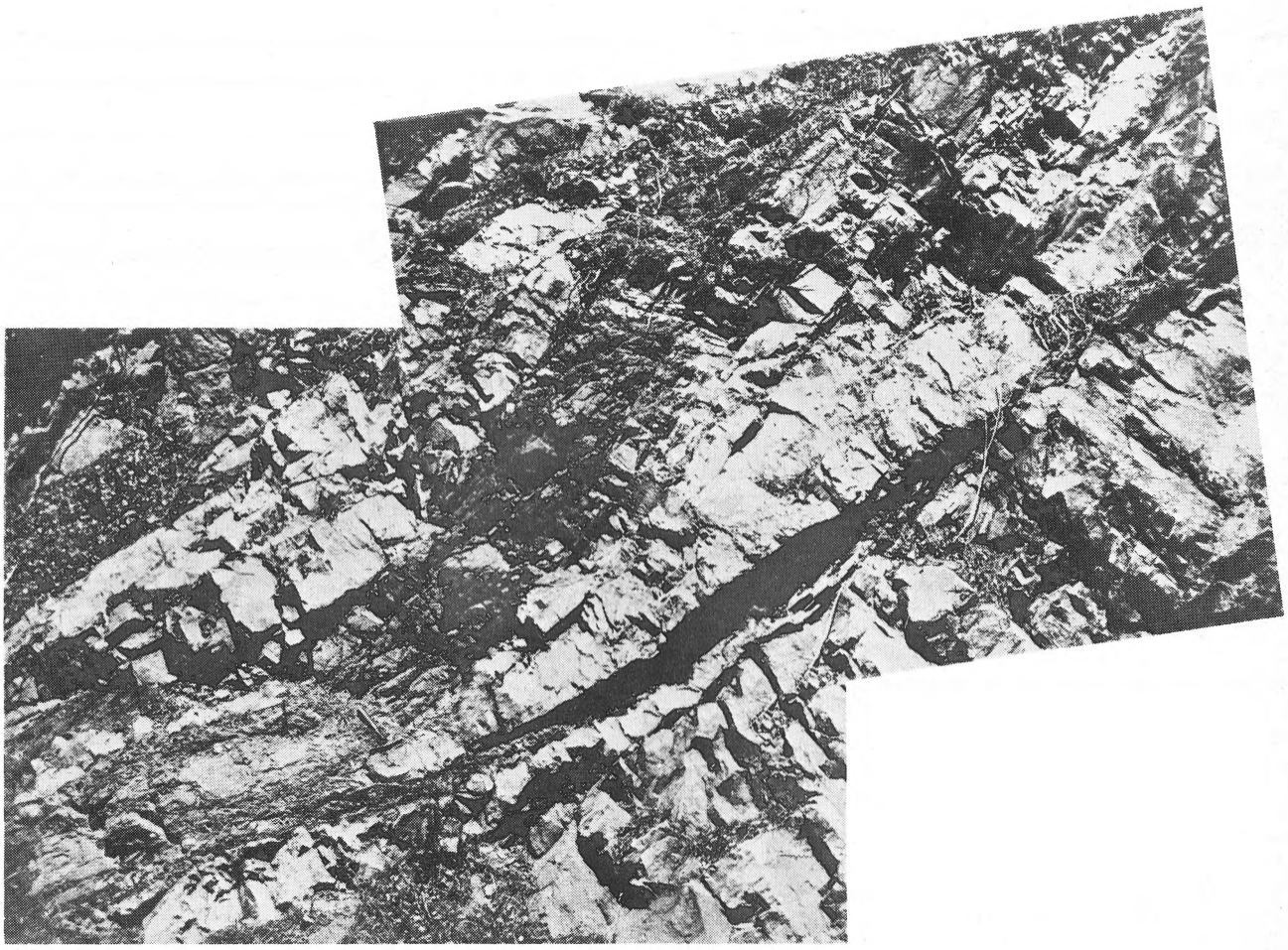


Fig. 2
Wedging sheets in Sheeted Complex. Hard Diabase Sheets with screens of soft, deeply weathered, originally glass-rich lavas. Approximately 3 km along road south of Abdoulinas Junction.

suggested that in the Kalavasos area the Basal Group lavas are closely related to the Lower Pillow Lava Formation. Observations in the western part of the Troodos Complex support this suggestion. In several localities there is a relatively sharp contact between Basal Group and Diabase units. Elsewhere the proportion of sheets and lavas changes only gradually and the contact appears to be transitional.

The sheets of the Sheeted Intrusive Complex are normally referred to as of diabase. However, the texture and mineral composition of these rocks vary considerably from sheet to sheet. Fine-grained to medium-grained microporphyritic varieties alternate with non-porphyritic types, and volcanic breccias also occur. Chilled margins are regularly present. The mineral assemblage consists mainly of varying proportions of actinolite, chlorite, albite, calcite, epidote, clinozoisite, sphene and quartz. Locally pyrite crystals up to one centimetre across are abundant and as an accessory it occurs regularly in crystals up to one millimetre in diameter. This mineral assemblage is largely a product of saussuritisation and uralization of basic extrusive and intrusive rocks during low-grade metamorphism.

B i s h o p p (1952-a, b) thought that most of the Complex represents a folded series of extrusives. Currently the Sheeted Complex is usually considered to be a vast dyke swarm in which the dykes generally strike about N-S. Remnants of the original host rocks are thought to constitute approximately ten percent of the Complex (G a s s, 1968).

THE ATTITUDE OF THE SHEETS

Several maps have been published by the Geological Survey Department for the central and eastern portions of the Troodos Massif, showing the strike and dip in the Sheeted Complex. In a geological sketch map of southern

Cyprus Gass and Masson-Smith (1963) include some more details of the attitudes in the western part of the Complex. Zinovieff (1960) reported on an area between Pomos and Xerovounos, but without strike and dip data on the map. According to Zinovieff the dips in this area are steep in the coastal section but on the Pomos-Stavros road are shallow, as low as 15° being common. The average dip is there about 45° to the northwest, though south of Pakhy Ammos and Pomos the sheets are inclined between 60° and 80°.

In the centre of the massif the sheets strike predominantly N-S. The dip is mainly east between 35° and vertical, but westerly dips occur as well, in particular west of Xeros. In the eastern portion of the massif the strike varies from NE-SW to E-W with dips to the southeast and south between 60° and 80°.

In the western part of the Troodos Complex the strike of the sheets varies from NW-SE in the south to NE-SW in the north with dips to the southwest, west and northwest respectively, generally between 40° and 80°. The strike trend is here roughly conformable with the boundary between the Sheeted Complex and the surrounding Upper and Lower Pillow Lava Formations (Figure 1). The sheets dip away from the strike of the sheets consistently following the contact horizontal, as for instance along the road to the lower adit at Kinousa. The sheets are practically always considerably buckled. Discordant sheets are rare. In several outcrops between the villages of Yalia and Sarama individual sheets were observed to wedge out between others showing both upward and downward wedges (Figure 2).

In the Limni area several inliers of the Sheeted Complex occur surrounded by Upper and Lower Pillow lavas. Field observations indicate that these inliers are largely bounded by faults. In the main inlier between Limni and Evloimeni the strike of the sheets is NW-SE. The dip increases gradually from approximately 35° SW in the southeastern portion of the inlier to approximately 75° SW in the northwestern part.

The consistent outward dip of the sheets and the gradual changes in dip from steep to almost horizontal together with the strike of the sheets Consistently following the contact with the Pillow Lava, are difficult to reconcile with the dyke swarm hypothesis. These features could also have resulted from the differential uplifting of originally horizontal sheets into a broad dome with a WNW-ESE longest axis. This would imply that the sheets must be considered as sills and flows, rather than as dykes. It is envisaged that fracture folding and hinge faulting during differential uplift, with much of the movement taken up by the (chilled) margins, could have been the principal mechanism.

The problem of the origin of the sheets is difficult to solve because their internal structures are not diagnostic either of dykes or of sills. Gravitational differentiation is conspicously absent and the occasionally observed spindle-shaped amygdales indicate merely a flow direction parallel to the margins of the sheets.

The Basal Group lavas, often assumed to be the country rocks of the massive sheets, constitute only approximately ten percent of the Complex (e.g. Gass, 1968). They are generally in a severely weathered condition which makes it extremely difficult to recognize top and bottom. Although it is tempting to take the attitude of pillows to indicate not only the attitude of the flow but also of the containing formation, isolated observations of this type are unreliable. Good examples of the variation in pillow attitude with position within a flow were observed in large exposures in the Limni and Evloimeni pits. On the flanks of the flows the pillows were seen to be steeply inclined and grade downwards into steep columns in medium-grained massive lava. Towards the top of the flows the pillows were much less steeply inclined.

The possibility that the Sheeted Complex was initially a horizontally disposed series of lava flows and sills, was suggested by Bishopp (1952-a, b), who also believed that the volcanic rocks had been isoclinally folded. Gass and Masson – Smith (1963) put forward evidence for a largely intrusive origin of the Complex. These authors also examined several of the outcrops critically for Bishopp's assumption of isoclinal folding and concluded that the reversals in dip can be explained by hinge faulting along the strike of the intrusives. From present observations in the western part of the Troodos massif, it is thought that Bishopp's contention concerning the original attitude of the rocks of the Sheeted Complex still merits as much attention as the dyke-swarm hypothesis. A process like the 'sill-stacking' suggested by Keith (1972) could account for the pile of sheets encountered in Cyprus. An explanation of the present variation of sheet attitude which reconciles the elements of the dyke swarm hypothesis with those of the sill hypothesis could possibly be founded on the diagrams by Piper and Gibson (1972). These concern the variation in the mode of igneous intrusion into a semi-infinite plate with the width across which the plate is stressed and serve to illustrate that intrusion as dykes in the centre could go together with intrusion as sills in the marginal portions of the Complex. Due consideration should be given to modifying tectonic processes related to differential uplift, however.

THE TROODOS DOME

From studies of the morphology of Cyprus de Vaumas (1959, 1961) concluded that the Troodos massif represents a large dome which originated from the end of the Pliocene onwards during several stages of differential uplift. Gass and Masson-Smith (1963) arrived at a similar conclusion in postulating that the regional gravity anomaly

pattern over Cyprus could be explained by crustal thickening. In connection with assumed underthrusting of continental Eurasia by the African shelf they would expect eustatic uplift as a result of isostatic adjustment.

The variation in the strike of the sheets across the Troodos Igneous Complex makes it evident that the structure is irregular. However, the differential uplift commonly agreed could easily have led to a number of subordinate culminations which could account for considerable changes in strike. This suggestion is substantiated to a certain extent by the occurrence of a number of inliers of the Troodos Plutonic Complex, viz. in the Livadhi area southeast of Pomos, south of Palekhori, northwest of Vavla and further to the northeast in the Mosphiloti area. Another minor culmination is thought to be represented by the Troulli inlier which consists mainly of Upper and Lower Pillow Lavas. Rocks of the Troodos Plutonic Complex are not known here.

The Troodos Plutonic Complex is generally considered as an intrusion into the Sheeted Complex. The question of whether emplacement followed doming of the country rock or caused the doming, is not of immediate relevance to the present discussion. P a n t a z i s (1967) recognised two stages in the development of the Troodos Plutonic Complex in the Kalavasos area, and considered that the rocks of the first stage were older than the Sheeted Complex and that the serpentinite constituting the second phase is younger than the latter Complex. He favours a diapiric mode of emplacement for the second phase.

There are several zones along which the differential uplift may have taken place. D e V a u m a s (1959, 1961) concluded that the external and internal boundaries of the rocky piedmont are probably major hinge zones. The external one coincides with the main boundary of the Troodos Complex and the overlying sediments, the actual fault zone being largely hidden. The internal boundary of the piedmont and its hinge would coincide with the contact between the main Diabase unit and the Basal Group unit of the Sheeted Complex. Major boundary faults were postulated by B a g n a l l (1960) along the northern and southern margins of the Troodos Igneous Complex. A number of NNW-SSE faults cross the Troodos massif west of the central outcrop of the Plutonic Complex. The prominent NNW-SSE strike of the sheets in this part of the Sheeted Complex may well be a consequence of differential uplift along this fault system.

G a s s (1968) suggested that the Sheeted Intrusive Complex of Troodos represents Oceanic Layer 2, in between the Pillow Lava Series and the Troodos Plutonic Complex. The latter would be Oceanic Layer 3. In the vertical sections accompanying most published geological maps of Cyprus the formations of the Troodos massif are shown in a layered succession. It would appear that an initial horizontal attitude of the elements of the Sheeted Complex is more compatible with the generally assumed stratiform structure of Troodos than an original vertical attitude as currently invoked.

SULPHIDE MINERALISATION

In the western part of the Sheeted Intrusive Complex indications of sulphide mineralisation are fairly widespread. The economic potential of these occurrences is generally not considered to be significant. Sulphide occurs regularly in accessory amounts as small pyrite crystals and occasionally also as pyrite phenocrysts. Copper, probably in chalcopyrite, occurs in association, but only in minor amounts. Locally copper indications are found in widespread thin crusts of azurite and malachite. More massive pyrite deposits are not uncommonly associated with major faults. The copper content remains low, however. From the abundance of pyrite crystals in certain sheets and the absence of pyrite in adjacent sheets, it is inferred that the primary control of the emplacement of the sulphides in the Sheeted Complex is related to the sheets themselves.

In the western part of the Troodos massif sub-economic copper sulphide deposits occur within the Sheeted Complex, very close to the contact with the Upper and Lower Pillow Lavas, at South Magounda and Larmou. The North Magounda deposit occurs in lavas close to the contact with the massive Diabase unit (Figure 1). Owing to deep weathering these lavas are difficult to classify.

East of Kinousa, between the village of Yalia and the Abdoulinas Junction a number of minor concentrations of sulphide are reflected by weak gossans straddling the boundary between the massive Diabase and pillowed and non-pillowed lavas probably belonging to the Basal Group. Within these lavas massive sheets occur abundantly.

The stratigraphical position of the sulphide deposits and in particular of the strongly cupriferous deposits is still debated. Since the assumption by C u l l i s and E d g e (1927) considering the Perapedhi sediments as an impervious horizon checking later sulphide emplacement, attention has moved towards syn-volcanic exhalative deposition (K i n k e l, 1966) at the end of volcanic periods as represented by the Basal Group Lavas, the Lower Pillow Lavas and the Upper Pillow Lavas, respectively. Initially the higher levels of the Upper Pillow Lavas enjoyed major interest in view of the occurrence of the major deposits supposedly observed at the top of the Upper Pillow Lava Formation. Later the boundary of the Upper Pillow Lavas and the Lower Pillow Lavas was considered to be of similar significance (S e a r l e, 1964). In recent discussions opinion on the stratigraphical position(s) still appeared equivocal (S e a r l e, 1972; C o n s t a n t i n o u and G o v e t t, 1972; G o v e t t and P a n t a z i s, 1971; discussions of these papers in Trans. I.M.M., section B, 1973, vol. 82, Bull. 798).

On the basis of recent, though unspecified, work concerning the relationship between sulphide mineralisation and the stratigraphy of the lavas S e a r l e (1972) suggested that a single phase of mineralisation is probably responsible for the sulphide deposits. Searle (op.cit.) indicates the discontinuity between Basal Group Lavas and Lower Pillow Lavas as the most likely period of sulphide depositon. V i n e (1973) still

considers the upper boundary of the Lower Pillow Lavas as the most important level.

Much of the confusion appears to be due to widespread propylitization of host rocks in association with sulphide emplacement. The alteration often results in the mineral assemblage characteristic of a large proportion of the rocks of the Sheeted Complex: chlorite-epidote-quartz, to a large degree obscuring the original identity of the host rock. The identification is the more diffucult since the structure of the lava flows, even in the Upper Pillow Lavas, may vary from pillows in the outer parts to massive and columnar in the centre. These aspects of the central portions may easily suggest a distinct similarity with the massive sheets in the Sheeted Complex, especially in small outcrops. Alteration of these massive portions of Upper Pillow Lavas into chlorite-epidote-quartz and chlorite-quartz assemblages may well lead to mis-identification as original Basal Group Lavas. It is felt that these problems may apply to all of S e a r l e 's (1973) cross sections of selected mineralized areas, inclusive of section C-D of Limni Mine, presented by T r e n n e r y and P o c o c k (1972) and referred to by S e a r l e (op.cit.). This was originally designed by S e a r l e (1964) as well as the block diagram of the Limni ore body also presented by T r e n n e r y and P o c o c k (op.cit., Figure 4), which still shows the former concept of the ore to reach as far up as the contact of the Upper Pillow Lava Formation and the overlying Perapedhi argillite. Much of the current problem is very well defined by Searle's phrase: "Direct evidence is lacking for either horizon: the intense alteration of the stockwork precludes any identification of its original lava grouping..."

If an originally horizontal disposition of the elements of the Sheeted Complex, or of a considerable proportion in the marginal parts, is accepted, the concentration of its sulphides near its upper contact would indeed suggest increased prominent deposition towards the end of this particular volcanic episode, in agreement with the generally accepted syn-volcanic deposition process. These occurrences do not necessarily represent the remnants of the feeder system of the Upper Pillow Lava deposits. Although it is very reassuring that the level represented by the contact of Lower Pillow Lavas and Sheeted Complex is brought into the limelight of mineral exploration it will be very difficult to disprove the possible significance of the stratigraphically higher levels of volcanic discontinuity.

ACKNOWLEDGEMENTS

The author wishes to thank Esperanza Trade and Transport Limited and Hunting Geology and Geophysics Limited for their permission to publish some of the results of a mineral exploration programme. Thanks are also due to Dr. P.H. Martin-Kaye and Mr. D.L. Dundas for critically reading the manuscript.

REFERENCES

Bagnall, P.S., (1964) – Wrench Faulting in Cyprus. J. Geol., 72: 327-345.

Bear, L.M. (1959) – Useful criteria for distinguishing between the Upper Pillow Lavas, the Lower Pillow Lavas and the Pillow Lavas of the Basal Group. In: Ingham, F.T. 1959. Annual Report of the Geological Survey Department for the Year 1958, Nicosia.

——— (1966) – The evolution and petrogenesis of the Troodos Complex. In: Stavrouni, Y., Hji, 1966. Annual Report of the Geological Survey Department for 1965, Nicosia.

Bishopp, D.W., (1952a) – The Troodos Massif, Cyprus. Nature, 169, No. 4299: 489-490.

———, (1952b) – Some new features of the geology of Cyprus. Intern. Geol. Cong. Algiers, 19th Session, Section XV, Fasc. XVII: 113-118.

Constantinou, G., and G.J.S. Govett, (1972) – Genesis of sulphide deposits, ochre and umber of Cyprus. Trans. I.M.M., section B, 81: B 34-46.

Cullis, C.G. and A.B. Edge, (1927) – Report on the cupriferous deposits of Cyprus. Crown Agents for the Colonies, London, 48 p.

Gass, I.G. (1968) – Is the Troodos Massif of Cyprus a fragment of the Mesozoic ocean floor? Nature, 220: 39-43.

Gass, I.G. and D. Masson-Smith (1963) – The geology and gravity anomalies of the Troodos Massif, Cyprus. Phil. Trans. Roy. Soc. Lond., Ser. A, 225: 417-467.

Govett, G.J.S. and Th.M. Pantazis, (1971) – Distribution of Cu, Zn, Ni and Co in the Troodos Pillow Lava Series, Cyprus. Trans. I.M.M., Section B, 80: B 27-46.

Ingham, F.T. (1956) – Notes on the mineral resources of Cyprus. In: Ingham, F.T. 1956. Annual Report of the Geological Survey Department for the Year 1955, Nicosia.

Keith, M.L. (1972) – Ocean-floor convergence: a contrary view of global tectonics. J. Geol., 80: 249-276.

Kinkel, A.R. (1966) – Massive pyrite deposits related to volcanism and possible methods of emplacement. Econ. Geol., 61: 673-694.

Moores, E.M. and F.J. Vine, (1971) – The Troodos Massif, Cyprus and other ophiolites as oceanic crust; evaluations and implications. Phil. Trans. Roy. Soc. London, Ser. A, 268: 443-466.

Pantazis, T.H.M. (1967) – The geology and mineral resources of the Pharmakas-Kalavasos Area. Memoir No. 8, Geological Survey Department, Nicosia.

Piper, J.D.A. and I.L. Gibson (1972) – Stress control of processes at extensional plate margins. Nature Physical Science, Vol. 238, No. 84, Aug. 7: 83-85.

Searle, D.L. (1964) – Geological Report on the Limni opencast mine. Unpublished U.N.S.F.P. Report, Survey of Groundwater and Mineral Resources.

———, (1972) – Mode of occurrence of the cupriferous pyrite deposits of Cyprus. Trans. I.M.M., Section B, 81: B 189-197.

Trennery, T. and B.G. Pocock, (1972) – Mining and milling operations at Limni mine, Cyprus. Trans. Inst. Min. Metall. Section A, 81: A 1-12.

Vaumas, E. de (1959) – The principal geomorphological regions of Cyprus. In: Ingham, F.T., 1959. Annual Report of the Geological Survey Department for the Year 1958, Nicosia.

———, (1961) – Further contributions to the geomorphology of Cyprus. In: Bear, L.M., 1961. Annual Report for the Year 1960. Geological Survey Department, Nicosia.

Vine, F.J. (1973) – In report of discussion of papers by Govett and Pantazis (1971), Constantinou and Govett (1972) and Searle (1972), Trans. I.M.M., Section B, 82: B 68-75.

Vokes, F.M. (1966) – Remarks on the origin of the Cyprus pyritic ores. Can. Min. Metall. Bull., 59 (647): 388-391.

Wilson, R.A.M. (1959) – The geology of the Xeros-Troodos Area. Memoir No. 1, Geological Survey Department, Nicosia, 135 pp.

Zinovieff, P., (1960) – A description of the Kato Pyrgos and Pomos Area. In: Ingham, F.T., 1960. Annual Report for the Year 1959. Geological Survey Department, Nicosia.